



Lead Papers



4th World Congress on Conservation Agriculture
4-7 February 2009, New Delhi, India

Innovations for Improving Efficiency, Equity and Environment



4th
World Congress on



New Delhi, India



Published by 4th World Congress on Conservation Agriculture and printed at M/s Print Process, 225, DSIDC Complex, Okhla Industrial Area, Phase I, New Delhi 110 020

Contents

Plenary Session

Enhancing Resource Productivity and Efficiency through Conservation Agriculture <i>Thomas A. Lumpkin and Ken Sayre</i>	3
Conservation Agriculture: Why? <i>Paul L.G. Vlek and Lulseged Tamene</i>	10
Indigenous Knowledge in Conservation Agriculture <i>Y.L. Nene</i>	21
Will Improving the Productivity of “Green” Water Lead to Food Security? <i>Colin J. Chartres</i>	24
Global Conventions and Partnerships: Their Relevance to Conservation Agriculture <i>R.S. Paroda</i>	30
Impact Analysis of Conservation Agriculture <i>S.S. Johl</i>	35

Theme 1: Resource Productivity and Efficiency

Session 1.1: Soil and Residue Management

No-Till System Applied to Northern Africa Rain-Fed Agriculture: Case of Morocco <i>Oussama EL GHARRAS, Azeddine EL BRAHLI and Mohamed EL MOURID</i>	41
Critical Research for Dryland Conservation Agriculture in the Yellow River Basin, China: Recent Results <i>Yan Changrong, He Wenqing, Mei Xurong, John Dixon, Liu Qin, Liu Shuang², Liu Enke</i>	51
Innovations through Conservation Agriculture: Progress and Prospects of Participatory Approach in the Indo-Gangetic Plains <i>M.L. Jat, Ravi G. Singh, Y.S. Saharawat, M.K. Gathala, V. Kumar, H.S. Sidhu, and Raj Gupta</i>	60
Strategies to Overcome the Competition for Crop Residues in Southern Africa: Some Light at the End of the Tunnel <i>Patrick C. Wall</i>	65
The Importance of Crop Residue Management in Maintaining Soil Quality in Zero Tillage Systems; A Comparison between Long-term Trials in Rainfed and Irrigated Wheat Systems <i>Nele Verhulst, Bram Govaerts, Els Verachtert, Fabian Kienle, Agustin Limon-Ortega, Jozef Deckers, Dirk Raes, Ken D. Sayre</i>	71
Conservation Agriculture – Constraints, Issues and Opportunities in Rainfed Areas <i>B. Venkateswarlu, K.L. Sharma and J.V.N.S. Prasad</i>	80

Session 1.2: Input Management (Water, Nutrients, Seed and Agro-chemicals)

Perspectives on Nutrient Management in Conservation Agriculture <i>Amir Kassam and Theodor Friedrich</i>	85
Opportunities and Challenges for Water and Nutrient Management in Conservation Agriculture Farming Systems of Asia and Africa <i>Christian H Roth, Merv Probert, Jack McHugh and Greg Hamilton</i>	93
Polymicrobial Formulations for Enhanced Productivity of a Broad Spectrum of Crops <i>C.A. Reddy and J.Lalithakumari</i>	94

Developing Alternate Tillage and Crop Establishment Strategies for Higher Resource Use Efficiencies in the Rice-Wheat System <i>J.K. Ladha</i>	102
Session 1.3: Diversified Farming Systems	
Lessons Learned from the Extension of Direct Seeding, Mulch-Based Cropping Systems (DMC) in the Main Agro Ecological Zones of Madagascar <i>Rakotondramanana, O. Husson and A. Rakotondralambo</i>	103
Direct Drilling is Behind Agronomy of Opportunity in Tunisia <i>Moncef Ben-Hammouda, Khelifa M'Hedhbi, Hatem Cheikh M'hame D and Houcine Ghouili</i>	110
Alternative Land Uses and Farm Diversification Strategies to Strengthen CA <i>Ademir Calegari</i>	117
A Model Suiting Small Farm Diversification : A Case Study from India <i>Gurbachan Singh</i>	122
Session 1.4: Irrigated Systems	
Rational and Application of CA for Irrigated Production in Southern Europe and North Africa <i>Helena Gomez-Macpherson, Hakim Boulal, Rachid Mrabet, Emilio Gonzalez</i>	129
Implementing Conservation Agriculture Concepts for Irrigated Wheat Based Systems in Northwest Mexico: A Dynamic Process Towards Sustainable Production <i>Bram Govaerts, Nele Verhulst, Ken D. Sayre, Fabian Kienle, Dagoberto Flores and Agustin Limon-Ortega</i>	136
Rationale for Conservation Agriculture under Irrigated Production in Central Asia: Lessons Learned <i>J.P.A. Lamers, A. Akramhanov, O. Egamberdiev, A. Mossadegh-Manschadi, M. Tursunov, C. Martius, R. Gupta, K. Sayre R. Eshchanov and S. Kienzler</i>	146
Session 1.5: Mechanization and Energy Management	
Energy Balance in Conservation Agriculture and Conventional Farming: a Comparison <i>S.K. Tandon and Surendra Singh</i>	156
Actual Challenges : Developing a Low Cost No-till Wheat Seeding Technologies for Heavy Residues; The Happy Seeder <i>H.S. Sidhu, Yadvinder Singh, Manpreet Singh, J. Blackwell, Harmanjit Singh, Rajinder Pal Singh and H.S. Dhaliwal and Ajaib Singh</i>	167
Actual Challenges: Developing Low Cost No-Till Seeding Technologies for Heavy Residues; Small-Scale No-Till Seeders for Two Wheel Tractors <i>Israil Hossain; R. Jeff Esdaile, Richard Bell; Chris Holland^d; Enamul Haque, Ken Sayre and M Alam</i>	171
Research and Development of Light No-till Seeders in China <i>Li Hongwen, Wang Qingjie, Wang Xiaoyan, He Jin, Gao Huanwen, Li Wenying</i>	178
Avoiding Soil Compaction in CA: Controlled Traffic Systems for Mechanized CA and their Effect on Green House Gas Balances <i>J.N. Tullberg and CTF Solutions</i>	185
Improving No-Till Seeding Quality with Low Disturbance Furrow Openers and Residue Handling Devices <i>Augusto Guilherme de Araújo</i>	191
Resource Saving Equipment for Conservation Agriculture Leading to Higher Productivity and Profitability <i>Nawab Ali</i>	192

Session 1.6: Genetic Strategies

Constraints to Zero Tillage in Mediterranean Environments <i>E. Acevedo, E. Martínez and P.Silva</i>	195
Breeding for improved adaptation to conservation agriculture improves crop yields <i>Richard Trethowan, Yann Manes² and Tariq Chattha</i>	207
Adapting Wheats to Zero Tillage in Maize-Wheat-Soybean Rotation System <i>Man Mohan Kohli and Jorge Frascina</i>	212
Challenges and Prospects to Realize Diversified Agriculture in the Tropics: The Brazilian Savannah Case <i>Carlos R. Spehar</i>	223
Strategies for Developing Rice-Wheat Genotypes for Conservation Agriculture <i>B. Mishra and Ravish Chatrath</i>	234

Session 1.7: Indigenous Knowledge and Practices

Blending Indigenous and Scientific Knowledge for Innovative CA Development using Participatory Action Research <i>H.J. Smith</i>	242
Adoption of Conservation Agriculture in Kazakhstan <i>M. Karabayev and M. Suleimenov</i>	243
Uncertified Organic Farming – Holistic Paradigm Imperative for Mass-scale Sustainable Agriculture <i>Bharat Mansata</i>	249

Theme 2: Institutional Innovations and Policies

Session 2.2: Integrated Approach for Technology Development and Dissemination

Adoption of Conservation Agriculture Technologies: Constraints and Opportunities <i>Theodor Friedrich and Amir Kassam</i>	257
Institutional Innovations for Participatory Approaches for Conservation Agriculture in Africa <i>Pascal G. Kaumbutho</i>	265
Development, Integration and Dissemination of Resource Conservation Options through Community Watershed Approach <i>Suhas P. Wani, T.K. Sreedevi, P.K. Joshi and B. Venkateswarlu</i>	277
Fast-tracking <i>Low-Disturbance No-Tillage</i> for Emerging Market Agricultures <i>C. John Baker and Volodymyr Khorishko</i>	294

Session 2.3: Capacity Building

Capacity Building: Harnessing Off-farm Employment Avenues in Harmony with On-farm Resources <i>J.C. Katyal</i>	306
Human Resource Development for Converting Input (resource) Intensive Agriculture into Input (resource) Efficient Agriculture <i>Mushtaq Ahmad Gill and Naveed A Awan</i>	307

Session 2.4: Enabling Policies

Policies and Institutions to Promote the Development and Commercial Manufacture of Conservation Agriculture Equipment <i>Brian G Sims, Peter Hobbs and Raj Gupta</i>	308
The Tragedy Is On, The Tragedy Is Over: Pastoral Challenges and Opportunities for Conservation Agriculture <i>Michele Nori and Constance Neely</i>	329

Theme 3: Environment

Session 3.1: Climate Change

Conservation Agriculture Protocols for Greenhouse Gas Offsets in a Working Carbon Market <i>Tom Goddard, Karen Haugen-Kozyra and Andy Ridge</i>	341
Carbon Sequestration Opportunities with Smallholder Communities: Forestry, Agriculture and Agro-Forestry <i>Louis V. Verchot and Viendra P. Singh</i>	351
Mitigating Climate Change and Better Ensuring Agriculture's Adaptation for Impending Climate Change through Conservation Agriculture <i>Des McGarry</i>	362
Greenhouse Gas Mitigation in Rice-Wheat System with Resource Conserving Technologies <i>H. Pathak</i>	373

Session 3.2: Biodiversity

Diversifying Crop Rotations with N ₂ -fixing Legumes <i>Bruno J.R. Alves, Claudia P. Jantalia, Luis Henrique De B. Soares, Segundo Urquiaga and Robert M. Boddey</i>	378
The Importance of Biodiversity in Crop Rotations under Direct Drill in Controlling Weeds, Plant Diseases and Crop Pests <i>Renato Serena Fontaneli, Henrique Pereira Dos Santos, Leandro Vargas, João L. Nunes Maciel, José Roberto Salvadori</i>	389
Enhanced Opportunities for Use of Plant Genetic Resources in Conservation Agriculture Initiatives: A Critical Appraisal <i>P.L. Gautam, S.K. Sharma and I.S. Bisht</i>	396

Session 3.3: Environmental Services

Environmental Service Provided by Conservation Agriculture in Tropical Rural Catchments: Water and Soil Credits?!" <i>J. Miguel Reichert, Jean Paolo Minela, Gustavo Henrique Merten², Nadia Bernardi Bonumá, and Dalvan José Reinert</i>	407
Role of Carbon in Ecosystem Services from Conservation Agriculture <i>D.C. Reicosky</i>	418
Weathering the Storms - Conservation Agriculture in Africa's Potential to Ameliorate 21st Century Environments <i>R.M. Fowler</i>	425

Theme 4: Impact Assessment and Equity Issues

Session 4.1: Impact of Conservation Agriculture

Global Overview of Conservation Agriculture Adoption <i>Rolf Derpsch and Theodor Friedrich</i>	429
Adoption and Impact of Conservation Agriculture-based Resource Conserving Technologies in South Asia <i>Olaf Erenstein</i>	439

Session 4.2: Equity Issues (Employment, Drudgery and Regional Disparities, etc.)

Conservation Agriculture for Drudgery Alleviation in SSA <i>Josef Kienzle, Amélie Berger, Brian Sims and Tom Apina</i>	445
---	-----

Session 4.3: Common Property Resources

Contribution of Commons to Conservation Agriculture in Mountain Areas <i>Narpat S. Jodha</i>	455
Governance and Institutional change in Traditional Commons: Lessons from Chhattisgarh, India <i>Dinesh K. Marothia</i>	463
Community Management of Common Property Resources in the Agrarian Economy <i>V.N. Sharda and Swarn Lata Arya</i>	478
Irrigation Tanks: A New Way Forward? (focus on tanks in South India) <i>K. Palanisami</i>	492
Improving Efficiency and Sustainability of India's Agriculture through Judicious Management of Common Property Resources : A Perspective <i>Katar Singh</i>	508

Plenary Session

Enhancing Resource Productivity and Efficiency through Conservation Agriculture

Thomas A. Lumpkin and Ken Sayre

*Director General and Agronomist, International Maize and Wheat Improvement Center (CIMMYT),
Apartado Postal 6-641. Mexico DF, Mexico CP 06600
(Email: t.lumpkin@cgiar.org and k.sayre@cgiar.org)*

Farmers, agricultural research directors/policymakers, agriculture-based non-government organizations (NGOs), international agricultural research centers (IARCs), and the private agro-business sector, whether in developing or developed countries, are struggling to cope with trade globalization, unstable commodity market prices, unreliable supplies and increasing costs of inputs, concerns about the effects of climate change on future agricultural productivity, and shrinking budgets for many national agricultural research and extension systems (NARES) and IARCs. Yet these sectors are expected to continue to feed and now, in many cases, fuel, a continually growing world population—a population that presents an accelerating demand for agricultural products and entertains the optimistic presumption that farmers will meet this demand using economically viable, ecologically sustainable means. This is a tall order, and for these remarkable outcomes to occur, new crop management technologies that drastically increase the productivity and efficiency of resource use will be required. This does not mean we can forget the population monster: the growth in world population must be slowed even as food production is increased. Rapidly evolving strategies and crop management technologies, such as conservation agriculture (CA), are being developed and used by farmers to confront the issues outlined above, creating innovative and sustainable opportunities for farmers.

Conservation Agriculture: Toward Sustainable, Resource-Conserving Crop Management Systems

In recent years, farmers interested in sustainable crop production systems have begun to adopt and adapt improved crop management practices, a step toward CA, which may be considered the ultimate solution. CA, which focuses on the complete agricultural system, involves major changes in farm cropping operations from the widely used, traditional tillage-based farming practices. Appropriate CA technologies encompass innovative crop production systems that combine the following basic tenets (Sayre 1998; Derpsch 1999):

- Dramatic reductions in tillage
Ultimate Goal – Zero till or controlled till seeding for all crops in a cropping system if feasible.
- Rational retention of adequate levels of crop residues on the soil surface
Ultimate Goal – Surface retention of sufficient crop residues to protect the soil from water run-off and erosion; improve water infiltration and reduce evaporation to improve water productivity; increase soil organic matter and biological activity; and enhance long-term sustainability.
- Use of sensible crop rotations
Ultimate Goal – Employ economically viable, diversified crop rotations to help moderate possible weed, disease, and pest problems; enhance soil biodiversity; take advantage of biological nitrogen fixation and soil enhancing properties of different crops; reduce labor peaks; and provide farmers with new risk management opportunities.
- Farmer conviction of the potential for near-term improved economic benefits and livelihoods from sustainable CA systems
Ultimate goal – Secure farm level economic viability and stability. To achieve this will involve the development of innovation systems focused on the needs of farmers and will include multiple agents who will use their comparative advantages to adapt the principles of CA to the farmers' various biophysical and socioeconomic conditions.

These basic tenets define an approach to crop and soil management that is not location-specific; i.e., the knowledge, the approach, and the fundamental and strategic principles are applicable to a wide range of crop production systems, from low-yielding, dry rainfed conditions to high-yielding irrigated conditions. However, the optimum

application of these techniques will vary across different agro-climatic situations. Specific and compatible management components (weed control tactics, nutrient management strategies, appropriately-scaled implements, etc.) will need to be developed through adaptive research with active farmer involvement to facilitate farmer adoption of CA under contrasting agro-climatic conditions and production systems, much as specific crop cultivar traits (grain color, end-use quality characteristics, genetic disease resistance requirements, etc) vary for specific production situations.

Successful farmer adoption of the first three CA tenets will essentially alter generations of traditional farming practices and implement use (including hand hoes), especially for small- and medium-scale farmers in developing countries who may have had minimal exposure to new farming technologies. In fact, the change in mind-set not only by farmers but also by scientists, extension agents, private sector members, and policy makers in developing as well as developed countries may be the most difficult aspect associated with the development, transfer, and farmer adoption of appropriate CA-based technologies.

In many cases, it may be difficult to explain the importance of CA adoption to farmers beyond its potential to reduce production costs, mainly by tillage reductions. It is therefore necessary to educate farmers on the links between excessive tillage and residue removal with soil sustainability problems, and how these problems can be alleviated through CA. Most smallholder farmers are risk-averse and cannot afford reductions in farm productivity to try a new system. This makes it very important to show immediate benefits in increased productivity of land or labor from CA, apart from the effects of CA on soil and land regeneration. Increased, immediate profits will be relevant to more farmers than the delayed gratification of improving their land gradually through adoption of CA-based technologies. However, if the development, adaptation, and adoption of CA-based technologies are done properly, they can offer farmers and society both possibilities.

Potential CA Contributions to Enhanced Resource Productivity and Efficiency

For CA to succeed, farmers will need to be in the forefront, helping to identify, develop, and deploy new technologies. If we are to insure that adequate food, fiber, and fuel are produced, farmers must employ appropriate crop management technologies not only to stabilize or increase crop production in a cost-effective manner, but also to conserve the integrity and sustainability of their resource base. To achieve this, farmers, researchers, and policy makers alike must insure that the following actions are properly implemented.

1. Increase the efficiency of water use for crop production: Under rainfed conditions this may be done by reducing runoff and evaporative losses, as well as reducing other limitations to crop productivity, to generate “more crop per rainfall drop.” Figure 1 below illustrates how the use of sound CA-based technologies (zero till seeded maize in rotation with wheat with surface retention of all crops residues) provided consistently superior rainfed maize yields over 10 years, as compared to the normal, tillage-based, farmer practice for maize production in the central highlands of Mexico. Maize is the predominate crop in these largely rainfed highlands, which average around 500 mm of rainfall annually⁻¹ with a range of 300 - 800 mm⁻¹ which is erratically distributed—50 mm in an hour during an afternoon may easily be followed by two weeks without rain.

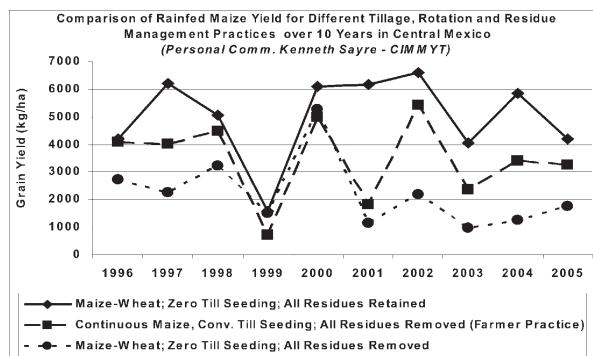


Figure 1

Figure 1 also illustrates how the use of zero till seeding but with removal of all crop residues can lead to serious problems, since the retained residues are crucial to keep rain water in the field. Farmer adoption of reduced/zero till

Table 1. Comparison of estimated irrigation water use for raised bed seeding with furrow irrigation versus flat seeding with flood irrigation for different crops at the Directorate of Wheat Research (DWR), Karnal, Haryana, India.

Crops	Irrigation water use (cm)		% saving of irrigation water by furrow irrigation
	Raised bed seeding with furrow irrigation	Conventional seeding on the flat with flood irrigation	
Wheat	28	33	17
Maize	25	30	16
Pigeon pea	13	15	16
Soybean	17	20	16
Green gram	17	21	16
Vegetable pea	8	10	18
Mustard	9	11	17

Personal Comm. – Dr. S. C. Tripathi, Agronomist at DWR/Karnal.

seeding without retention of adequate crop residues on the soil surface has led to many failures of these seeding systems, especially for rainfed crop production systems.

Improving the productivity of irrigation water is increasingly important: in many developing countries, especially in Asia, irrigated crop production accounts for a major portion of strategic food supplies, insuring food security. The water resources available for irrigation are becoming increasingly scarce and irrigated systems are becoming more fragile, especially with respect to increases in soil salinity from poor irrigation management. Table 1 below illustrates how the use of a CA-based, raised bed, furrow irrigated seeding system in northwest India resulted in both higher yields and significant irrigation water savings for a wide spectrum of crops, when compared to the traditional farmer practice of seeding on the flat with flood irrigation.

The results in Table 1 contribute to the growing evidence that the use of furrow irrigation with raised bed seeding systems can provide striking increases in irrigation water use efficiency, especially permanent raised bed seeding systems where no tillage is used on top of the beds, but beds are “reshaped” as needed in the furrows. As a consequence, in the southern part of the state of Sonora in northwest Mexico, over the past 25 years nearly all farmers have shifted from flood irrigation to furrow irrigation for all crops, and they indicate that they obtain an average irrigation water savings of 20-25% with equal or higher crop yields (Sayre and Moreno Ramos 1997).

2. Halt and reverse the widespread degradation of the soil resource base: Soil degradation from wind and water erosion, as well as a decline in soil physical, biological, and chemical properties, can be linked to excessive levels of tillage and extensive removal/burning of crop residues that are associated with many conventional farming systems.

Figure 2 illustrates the effects of 11 years of tillage and residue management practices on soil wet aggregate stability, one of the more relevant soil physical properties. The conventional tillage treatment with incorporation of all crop residues had a mean weight diameter of aggregates (a measure of aggregate stability) of only 65% of that for the permanent beds with all residues retained. However, the effect of residue retention on aggregate stability is also evident within the permanent bed system: the more residues that are left, the better the aggregate stability. The treatment with permanent beds in which all residues have been burned had a lower aggregate stability than the conventionally tilled practice.

3. Augment crop and soil biodiversity: Augmenting cropping diversity through CA offers farmers alternative, economically viable crop rotation options that help minimize ever-present economic risks and enables farmers to react to rapid fluctuations in markets. In addition, there is considerable evidence that sound crop rotations can result in positive yield increases for the different crops in a rotation. Figure 3 below presents the results for wheat seeded on raised beds with furrow irrigation in northwest Mexico and using different crop rotations. Wheat yields are higher in systems that involve more diverse rotations, as compared to the wheat-fallow system, especially when a legume (in this case chickpeas) is included in the rotation.

4. Confront increasing input prices by boosting input use efficiency to reduce production costs: The increases in the prices of chemical fertilizers, as well as other inputs like herbicides, pesticides, and fuel in the last 18-24 months, have been astounding, especially in many developing countries. In some countries, farmers have access

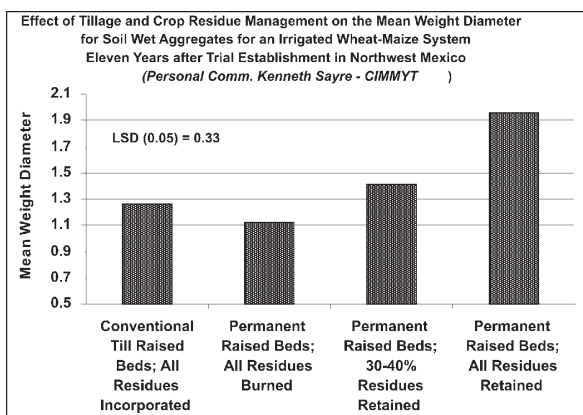


Figure 2

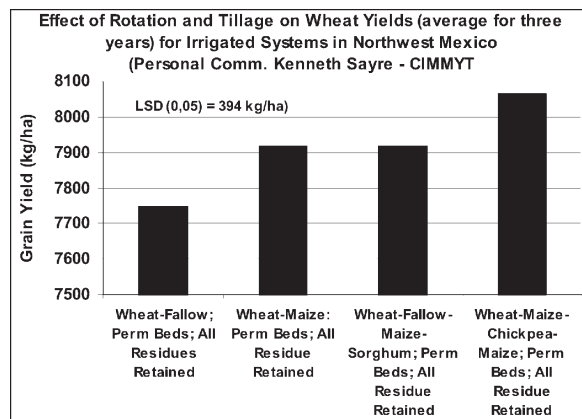


Figure 3

to only restricted amounts of fertilizers through government rationing programs or have not been able to afford/acquire fertilizer. There is some concern that CA-based technologies using markedly reduced/zero till seeding systems combined with soil surface residue retention may lead to decreased fertilizer N-use efficiency, requiring the use of higher fertilizer rates to obtain similar yields as conventional till systems. When this has occurred, it has likely been due to factors associated with differing production situations. Obviously, suitable fertilizer management practices that are compatible with appropriate CA-based technologies may result in enhanced N-use efficiency. Figure 4 below illustrates how N fertilizer use efficiency for wheat was enhanced in a permanent raised bed furrow irrigated wheat-maize system in northwest Mexico when adequate residues were retained, as compared to the traditional conventional till system. The results show how the removal of residues on the permanent beds dramatically restricted N use efficiency.

5. Reduce agricultural-related greenhouse gas (GHG) emissions: Soil erosion and leaching of applied agricultural products (fertilizers and pesticides) has long been recognized as detrimental to the environment. However, greenhouse gas (GHG) emissions from agriculture, almost certainly linked to climate change, are a more recent concern and certainly more controversial.

Emissions of CO₂ by agriculture can be decreased by reducing tillage and maintaining crop residues on the soil surface to increase C sequestration in the soil (Reicosky 2001), especially when combined with the reduced burning of fossil fuels for field operations associated with reduced/zero till seeding systems. In addition, the field burning of crop residues—yet a widespread practice in developing countries—should be stopped.

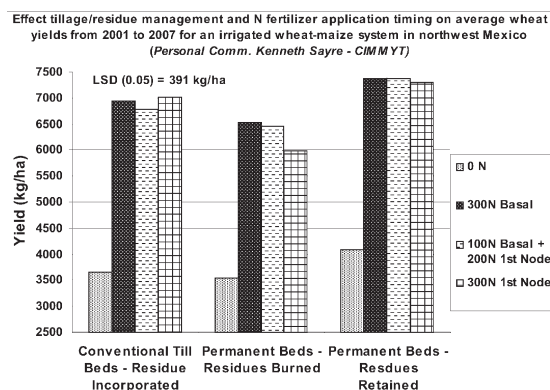


Figure 4

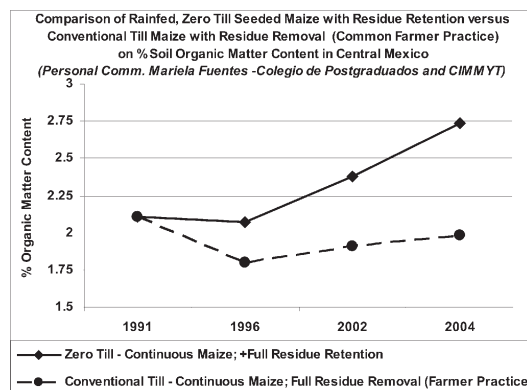


Figure 5

At the same time NO_x emissions, far more damaging to the environment than CO₂, can be reduced by improving N fertilizer management and cutting methane emissions (also more damaging than CO₂) by limiting the extent of flooded rice cultivation where appropriate (Patino-Zuniga et al 2009).

If adequate levels of crop residues are retained on the soil surface and combined with reduced or zero till seeding systems, there is good evidence that C sequestration in the soil will occur with corresponding reductions in CO₂ emissions (Reicosky 2001). Figure 10 above illustrates the changes in the soil organic content under rainfed maize production in the central highlands of Mexico with contrasting management practices. Zero till with full residue retention has resulted in a substantially higher soil organic matter content (SOM) (and therefore C content) as compared to conventional till with full residue removal, in this experiment established in 1991. This figure also illustrates that achieving a new equilibrium in soil properties through the adoption of CA is a long-term process.

6. Confront the growing shortages of agricultural labor: Agricultural labor shortages are growing even in the two most populous Asian countries—China and India—and this is causing many farmers to consider the adoption of CA-based technologies which, under most situations, can reduce labor requirements. One of the major benefits that smallholder farmers perceive with CA is the labor savings (Wall 2007). In Asia, for example, hand transplanting of puddled rice after conventionally tilled, irrigated wheat has a high labor requirement that peaks in June and July (especially in northwest India). This creates serious labor shortages during this critical time, and has provoked farmer interest in technologies available for direct seeding rice without puddling. One of these technologies is direct (zero till) seeding of rice into dry soil after zero till wheat. Farmer interest is particularly keen in the lowland rice growing areas, where a major portion of the water used in rice production is provided by irrigation.

Experience has shown that dramatic labor reductions are possible with dry soil direct seeding and that substantial irrigation water savings are also possible under many situations. Achieving satisfactory weed control, however, is a challenge that is being resolved with different weed management practices. What is earnestly needed to advance dry soil direct seeded and zero tilled rice is serious efforts by rice breeders to breed and select new, appropriate rice cultivars for this system in the pertinent soil types. There are many positive experiences with direct seeding of rice into dry soil using the available cultivars that were developed under and for transplanted conditions. Certainly, even better results will be achieved with cultivars selected and developed under this management system.

Although there are few reliable economic comparisons of dry seeded, zero till rice compared to transplanted, puddled rice, much more is known in relation to wheat. Figure 6 presents a very thorough on-farm, economic comparison of conventionally tilled irrigated wheat and zero till wheat in the rice-wheat system. Variable costs are substantially lower for zero till (partly due to reduced labor costs) and gross benefits are higher, generating correspondingly higher net benefits for the zero till wheat. These results are similar to most other examples where farmers have adapted suitable CA-based technologies.

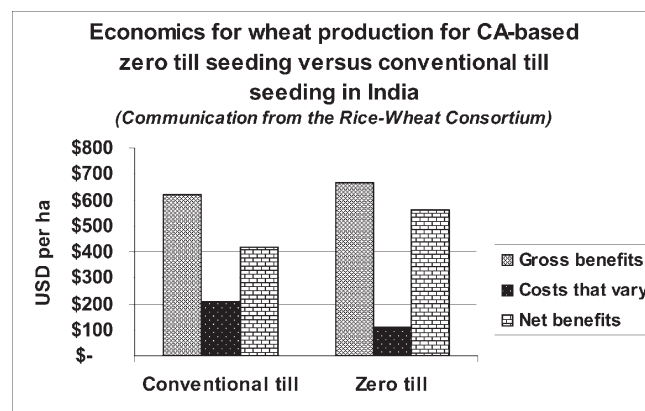


Figure 6

7. Reductions in fuel and machinery use: Along with reductions in labor, in mechanized systems CA results in a marked reduction in the use of tractors and equipment, all of which cuts fuel use, reducing both farmers' costs and GHG emissions. Generally, CA reduces tractor use by approximately 70%, depending on the intensity of tillage in the conventional system (e.g. Wall 2002). The reduction in tractor use means that a single tractor can provide the required traction for a greater area. In the example of Bolivia (Wall 2002), this provided for the expansion of the agricultural area using existing tractors, but in the Indo-Gangetic Plains (especially in northwest India) it has

meant that relatively large-scale farmers could become service providers to the smaller farmers in the community. Anyone who has watched a tractor working dry soil, especially alluvial soil, cannot help but notice the cloud of dust in which the tractor and the operator have to work. In CA systems, where residue covers the soil and is not tilled, dust is almost completely absent, benefitting the operator and the farmer, since tractors and equipment operating in dust-free environments require considerably less maintenance and their useful life is extended, reducing again the costs of production.

Toward the Future

Farmer, researcher, and private sector attempts to develop reduced/zero till seeding practices with crop residue retention on the soil surface combined with expansion of crop rotation opportunities have been going on for more than 40 years. This led to the delineation about 25 years ago of the principles or tenets that now characterize CA. It was estimated in 2005 that CA-based technologies using zero till seeding were being practiced on over 95 million hectares worldwide (Derpsch 2005) and currently this area is likely to be approaching 120 million hectares. It is sobering, however, to realize that over 90% of the current area under CA-based technologies occurs in just 5 countries (Argentina, Australia, Brazil, Canada, and the USA) and that less than 5% involves crop production systems under gravity-based irrigation systems. This poses two questions: why has there been such meager adoption of these technologies under irrigated crop production situations, and what factors are constraining farmer adoption of CA-based technologies in other countries?

The answer to the first question is perhaps less complicated. First, rainfed crop production systems predominate in the five leading CA countries listed above. This has led to the dedication of more time, funds, and effort by farmers and researchers to improve crop management practices for rainfed situations. Second, the negative effects of excess tillage and crop residue removal and/or burning are much more obvious under these rainfed conditions: extensive wind and water erosion, crop failures in drought years, etc. As a correlate, the effects of excessive tillage and residue removal on soil health and quality are not as apparent under irrigated conditions, as their effects may be masked by irrigation and additional fertilizer use.

The answer to the second question (what factors seem to be constraining farmer adoption of CA-based technologies in other countries?) is more difficult to explain. Two things that characterized the rapid and extensive adoption of CA-based technologies in the five countries, especially Brazil and Argentina, were, firstly, that farmers realized they had a problem they needed to overcome, and secondly, farmers organized themselves and together began to develop many of the new CA-based technologies. In fact in both of these countries, most agricultural researchers and policy makers initially (and in some cases for several years after) flatly stated that CA would not work. It is also important that most farmers in CA-adopted countries are large-scale mechanized farmers who are able to experiment and bear more risk than small-scale farmers. Large farmers also normally have better links to information systems and are therefore in a better position to circumvent bottlenecks in knowledge flow.

These three key ingredients appear to be important if the development of CA-based technologies is to occur. In most other countries, for various reasons, this development and adoption has not happened or is only just beginning. For example in the higher latitudes, because of the slower breakdown of organic matter and often less intense rainfall, the impact of tillage on soil quality is not as marked as in tropical and subtropical environments. In the latter regions, smallholder farmers poorly linked to information systems, resource poor, and risk averse predominate. They require considerably more support to be able to understand the problems behind their declining yields and increasing costs.

Meanwhile, CA efforts in most countries are outside the mainstream efforts of the NARES. When only a few individuals are convinced of CA's benefits, it can result in a confrontational situation with the mainstream "regular agronomists, soil scientists, etc." who still believe that a good tillth is a prerequisite to successful crop production. The fact that many research and extension directors, as well as university professors, are in this latter category means that it is exceptionally difficult for a few individuals to bring about change in institutional thinking.

Given the widespread soil degradation occurring in the developing world, it is entirely relevant that the three principles of CA (dramatic tillage reductions/zero till, rational crop residue management, and diversified crop rotation, all acting together to economically benefit farmers) should guide routine agronomic and cropping systems activities. They should provide the foundation upon which the development of new practices is based, rather than as a parallel option to mainstream research activities that continue to focus on improving the current tillage-based production

systems. Further degradation of the resource base dedicated to agriculture due to continued, widespread use of tillage-based production systems is obviously unsustainable and therefore neither a valid nor ethical option for agricultural research and development. Continuing to rely on efforts to fine tune the conventional tillage-based crop production systems where crop rotations are generally absent and crop residues are removed, grazed, and/or burned will, at best, limit us to small production increases, and, in all likelihood, result in further land degradation and the demise of agriculture.

Therefore, CA must be brought into the mainstream of crop management research and be closely linked with crop breeders and other agricultural disciplines to insure the development of tactical management practices (cultivars, weed, pest, disease, water management strategies and practices, etc.) suitable for CA-based crop management technologies. CA must not continue to be sidelined as an alternative development pathway, as it represents our best option for a sustainable future.

References

- Derpsch, R. 1999. Expansión mundial de la SD y avances tecnológicos. In Proceedings of the 7th National Congress of AAPRESID, 18-20 August 1999. Mar del Plata, Argentina.
- Derpsch, R. 2005. The extent of Conservation Agriculture adoption worldwide: Implications and impact. III World Congress on Conservation Agriculture: "Linking Production, Livelihoods and Conservation," 3rd to 7th October 2005, Nairobi, Kenya. 15 p.
- Patino-Zuniga, L., J.A. Ceja-Navarro, B. Govaerts, M. Luna-Guido, K. D. Sayre and L. Dendooven. 2009. The effect of different tillage and residue management practices on soil characteristics, inorganic N dynamics and emissions of N₂O, CO₂ and CH₄ in the central highlands of Mexico: a laboratory study. *Plant Soil*. 314: 231-241.
- Reicosky, D.C. 2001. Effects on soil organic carbon dynamics: Field experiments in the U. S. corn belt. In D. E. Scott, R. H. Mohtur and G. C. Steingerdt (eds). *Sustaining the Global Farm: Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Laboratory*. pp 418-485.
- Sayre, K.D., Moreno Ramos, O. H. 1997. Applications of raised-bed planting systems to wheat. *Wheat Special Report No. 31*. Mexico, D. F.: CIMMYT.
- Sayre, K.D. 1998. Ensuring the use of sustainable crop management strategies by small wheat farmers in the 21st century. *Wheat Special Report No. 48*. Mexico, D.F. CIMMYT.
- Wall, P.C. 2002. Extending the Use of Zero Tillage Agriculture: The Case of Bolivia. Paper presented at the International Workshop on Conservation Agriculture for Sustainable Wheat Production in Rotation with Cotton in Limited Water Resource Areas, Tashkent, Uzbekistan, October 13-18, 2002.
- Wall P.C. 2007. Tailoring Conservation Agriculture to the needs of small farmers in developing countries: An analysis of issues. *Journal of Crop Improvement* 19, 137-155.

Conservation Agriculture: Why?

Paul L.G. Vlek and Lulseged Tamene

Center for Development Research (ZEF), University of Bonn, Walter Flex Str. 3, 53113

This paper first assesses the processes and rates of land degradation (mainly soil erosion, nutrient depletion and soil carbon loss) in the world of conventional agriculture based on studies conducted in different places of the world. The paper goes on to evaluate the benefits of conservation agriculture in retarding land degradation by reviewing some research results worldwide. Evidence collated from different sources show that population pressure and unsustainable uses of land are causing severe land degradation and food insecurity in many places of the developing world. This is likely to increase with growing population pressure unless measures are in place to be able to produce more food from less land through more efficient use of natural resources and with minimal impact on the environment. Conservation agriculture, which is mainly based on three principles – minimum soil disturbance, permanent soil cover, and appropriate crop rotation, has become an interesting intervention since it is economically profitable, environmentally safe, and practically efficient as demonstrated on over 95 million ha of land worldwide where it is adopted. If implemented properly, conservation agriculture is a suitable approach to fulfill the Millennium Development Goal 1 (“... eradicate extreme poverty and hunger ...”) and Goal 7 (“... ensure environmental sustainability ...”). The wide acceptance by many countries also shows that farmers are convinced of the benefits of the technology.

1. Land Degradation: Challenges to Estimation

Land degradation is a serious environmental problem that threatens ecosystem health and food security worldwide. This environmental problem has been a major global issue during the 20th century and will remain high on the international agenda in the 21st century (Eswaran et al., 2001). Though methods to assess land degradation on a large scale are deficient, there is growing concern that degradation of agricultural soil resources is already seriously limiting production and diminishing ecosystem services (Vlek, 2008).

There is ample literature about the magnitude of land degradation. Most focusses on specific geographic regions and generally provides gross estimations which may not be adequate to target conservation practices. Thus, information related to degradation patterns that show spatial differences are important. The absence of studies that indicate the spatial distribution of land degradation at global or continental scales causes problem when attempting to answer questions such as “where should one invest research and/or management efforts in order to target high problem areas?” This is particularly critical in developing regions where such resources are limited. Methods are needed to identify hot-spot areas where land degradation.

A better understanding of the extent and nature of land degradation remains imperative, but spatially distributed quantitative data on land degradation is scarce (Vlek et al., 2008). The Global Assessment of Soil Degradation - GLASOD (Oldeman et al., 1990) is one of the oldest attempts to assess the severity of land degradation worldwide. The GLASOD is based on expert surveys that gave a snapshot impression of the situation in the late 1980ies but failed to capture the dynamics of the process. In addition, the study has become outdated. More recently, some global/regional land degradation assessments using remote sensing technologies have been published (e.g., Prince, 2004; Herrmann et al., 2005; Wessels et al., 2007), mostly focused on the dynamics of degradation processes in arid and semi-arid areas. Three major recent works by Vlek et al. (2008), Bai et al. (2008) and Hellden & Tottrup (2008) outlined elaborated analysis of land degradation at the sub-continental and global scales based on long-term satellite and rainfall data. These studies tried to infer land degradation from the long-term relationship between vegetation productivity and weather dynamics. Table 1 summarizes the spatial distribution of land degradation compiled based on the three studies.

From table 1, it is possible to see differences in the three studies. It is very likely that those who categorized land degradation for GLASOD into different levels would have different perceptions and opinions, which may lead to under or over estimation of processes. In the case of Bai et al. (2008), the proportion of areas experiencing land degradation is calculated by considering all pixels showing a declining trend irrespective of significance level (Bai et al., 2008). The inclusion of pixels that do not experience significant long-term decline may cause over estimation of degradation zones, provided that other assumptions are valid.

Table 1. Land degradation extents by sub-regions

Sub-region	GLASOD (UNEP, 1992)	LADA (Bai et al., 2008)	Vlek et al. (2008)	Vlek et al. (In press)
Sub-Saharan Africa	10	26	10	30
Asia and the Pacific	6	21	-	-
North Africa & Near East	7	3	-	-
Europe	12	11	-	-
North America	0	20.3	-	-
South America	5	23	-	-

Note that Vlek et al. (2008) is based on pixels experiencing significant decline in vegetation productivity but without correcting for atmospheric fertilization effect while Vlek et al. (In press) is based on significant declining pixels but after correcting for atmospheric fertilization effect.

Vlek et al. (2008) analyzed the spatial patterns of land degradation in sub-Saharan Africa (SSA) and indicated that about 10% of SSA experiences land degradation while over 45% shows improvement in land productivity. Many other studies that analyzed the long-term trend of vegetation productivity in the Sahel belt also showed a widespread improvement in vegetation productivity beginning from the early 1980s (Eklundh & Olsson, 2003; Herrmann et al., 2005; Hickler et al., 2005). These studies also highlighted that the observed improvement in long-term trend in vegetation productivity could not totally be explained by improvement in rainfall after the frequent droughts of the 1980s. This means that other processes are in play for the observed “wide-area” biomass greening. The suggestion by Olsson et al. (2005) and Herrmann et al. (2005) that the greening of vegetation has exceeded what can be explained linearly by a recovery in the rains since the early 1980s in certain locations also supports the possible existence of another driver. As the observed greening in general is ‘extensive’ it may also not be possible to ascribe it fully to improved and successful land management, though such practices have played central role in some regions of West Africa (Reij et al., 2005).

One major hypothesis for the observed improvement in land productivity (vegetation greenness) revealed in recent regional and global studies is the potential impact of atmospheric fertilization (Vlek et al., 2008; Hellden and Tottrup, 2008). In fact, there are many studies that highlight the benefits of CO₂ –or NO_x- fertilization to enhance plant growth and development (e.g., Lewis et al., 2004; Ainsworth & Long, 2005; Long et al., 2006; Reay et al., 2008). In an attempt to disentangle the impact of atmospheric fertilization on long-term improvement in biomass and thus its possible masking effect of actual land degradation, Vlek et al. (in press) re-calculated the extent of land degradation after “calibrating” the potential impact of atmospheric fertilization using pristine lands with minimum population density and no cultivation/grazing practices. The basis of the hypothesis is that a positive fertilization effect might result in “greening” of vegetation as viewed from space and thus could mask real degradation due to processes such as land conversion, selective logging, overgrazing and nutrient mining (Fig. 1).

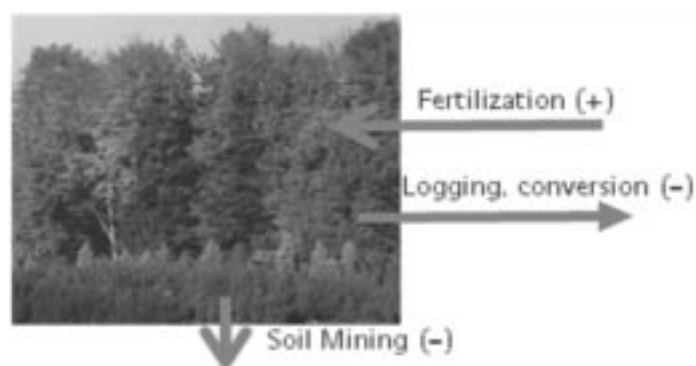


Figure 1. Processes showing the potential effect of atmospheric fertilization in masking land degradation. Note that if rainfall and human management cannot adequately explain the observed greening in biomass, the most plausible factor could be atmospheric fertilization. If atmospheric fertilization enhances photosynthesis and thus biomass greening as observed from space using satellite sensors, it might have concealed possible land degradation caused by selective logging, land conversion, over-grazing (Vlek in press).

Based on the above hypothesis, Vlek et al. (In press), re-calculated land degradation and found the situation to be much more serious, with 30% of SSA experiencing degradation processes instead of the 10% without considering the potential impact of atmospheric fertilization. This means that the real degradation extent has been masked due to atmospheric fertilization which could confuse policy design and conservation planning in the region. However, the results of this analysis need to be tested based on high resolution data and field observation.

The above analysis generally shows that quantifying land degradation and understanding the processes in play at global/regional scale is not an easy task. However, the problem is serious (see below) and could endanger the environment and the sustainability of agriculture for future generations. There is therefore a need for a coordinated effort to try to map land degradation and analyze the key processes or drivers that underlie the problem as a guide to sound decision making.

2. The Threat of Land Degradation: How Costly It Is?

Since thousands of years, increasing human needs often changed the natural system from one that is stable and virtually closed to one that is degrading and more or less open (Vlek, 2008). Several efforts have been made to study the rates and processes of land degradation at different scales in various locations of the world. All studies show that land degradation is a real problem affecting livelihoods and the environment. On a global scale the annual loss of 75 billion tons of soil translates into US\$400 billion per year, about US\$70 per person per year (Pimentel et al., 1995; Lal, 1998; Eswaran et al., 2001). A recent study (Den Biggelaar et al. 2003) shows that the value of annual production losses for some selected crops worldwide could amount to over US \$400 million. Yield reductions in Africa due to past soil erosion may range from 2 to 40%, and if the present trend of erosion continues unabated, yield reductions may average 16% by 2020 (Dregne 1990; Lal, 1995). In South Asia, annual loss in productivity due to water and wind erosion is estimated at 36 million tons of cereal equivalent valued at US\$7200 million (UNEP, 1994). The above figures and many other sources show that the damage inflicted on soils due to land degradation over many years are significant and have resulted in valuable land becoming unproductive and often eventually being abandoned (Pimentel et al., 1995; Pimentel and Kounang, 1998). The increasing demand for food due to population growth requires increasing production which often leads to exploitation of marginal areas and competition with other land uses. Generally, the economic impact of land degradation is severe in densely populated regions of South Asia and sub-Saharan Africa. Unfortunately, many of these regions are facing complex economic problems that prevent them from escaping the trap of land degradation caused poverty because of their limited resources. Then, once land degradation sets in it is likely to result in a vicious feedback loop and a land degradation-productivity decline-land degradation nexus.

3. Major Land Degradation Processes

Due to the escalating human population and the requirement of ever-increasing food supplies, soil erosion, water scarcity, and loss of biodiversity have gained recognition as prime environmental problems throughout the world. The main land degradation processes such as erosion, nutrient mining, carbon loss, etc. are caused or amplified by human activities, mainly agriculture. These processes are likely to become more severe as population grows and the demand for more land and food increases.

Soil Erosion

Soil erosion due to water and wind is one of the most serious forms of land degradation but its true extent is difficult to assess. Yet, soils today are being degraded at a much faster rate than they can be formed by natural processes (Martius et al., 2001). Tillage, often excessive, as practiced in conventional agriculture is one of the most important drivers of erosion (Elliott, 1986; Kay, 1990; Reichert and Norton, 1994; Papendick and Parr, 1997; Salonius, 2008). Although soil erosion takes place very slowly in natural ecosystems and its cumulative impact on soil quality over billions of years has been significant (Pimentel et al., 2005); this is of no consequence on a human time scale.

About 50% of the earth's land surface devoted to agriculture is more susceptible to erosion because of removal of vegetation before planting and frequent cultivation of the soils. As a result, soil erosion on agricultural land is estimated to be 75 times greater than erosion in natural forest areas, and about 75 billion tons of fertile soil is lost from world agricultural systems each year (Myers, 1993). Worldwide, erosion on cropland averages about 30 t/ha-yr, with a range of 0.5 to 400 t/ha-yr (Pimentel et al., 1995). Based on a compilation of worldwide data, Lal (1994) showed that the yield of rainfed agriculture may decrease by ca. 29 percent over the next 25 years because of erosion. El-Swaify (1994)

indicated that water erosion accounted for about 55 percent of the almost two billion ha of degraded soils in the world. Soil erosion losses are highest in the agro-ecosystems of Asia, Africa, and South America, averaging 30–40 t/ha-yr of soil loss (Taddese, 2001). Due to erosion during the last 40 years, about 30% of the world's arable land has become unproductive and much of that has been abandoned for agricultural use (Kendall and Pimentel, 1994).

Soil Nutrient Mining

Soil nutrient mining occurs when extraction of useful nutrients from the soil by agriculture exceeds the rate of replenishment in the system. Nutrient depletion in soils adversely affects soil quality and reduces crop yield and consequently poses a potential threat to global food security and agricultural sustainability. Continued nutrient mining of soils would mean a future of ever increased poverty, food insecurity, environmental damage, and social and political instability (Henao and Baanante, 2006). The degradation of soil in general and nutrient mining in particular is typically a 'creeping environmental problem' which hinders the initiation of counterbalancing measures (Glantz, 1998; Martius et al., 2001).

As the world population keeps growing, balanced ecosystems are on the decrease and nutrient ledgers all over the world have become increasingly negative (Smaling et al., 1997). In almost all countries of the world, food production is currently dependent on depleting large quantities of nutrients from soil reserves and this is likely to continue. Globally, soil nutrient deficits were estimated to accrue at an average rate ($\text{kg ha}^{-1} \text{yr}^{-1}$) of 19 N, 5 P, and 39 K in the year 2000, respectively (Tan et al., 2005). A study by Sheldrick et al. (2002) estimated the world average soil nutrient depletion to be 12 kg N ha^{-1} , 4.5 kg P ha^{-1} , and 20 kg K ha^{-1} for the year 1996.

Nutrient mining and its negative consequences in Africa are the highest in the world (Vlek, 1993; Henao and Baanante, 2006). Based on nutrient balance studies and field observations across Africa, soil-fertility depletion in smallholder farms is the fundamental biophysical root cause of declining per capita food production in the region (Pieri, 1989; Stoorvogel & Smaling, 1990; Van der Pol, 1992; Smaling, 1993; Sanchez et al., 1997). Studies show that an average of 660 kg N ha^{-1} , 75 kg P ha^{-1} , and 450 kg K ha^{-1} has been lost during the last 30 yr from about 200 million ha of cultivated land in 37 African countries (Stoorvogel & Smaling, 1990; Smaling 1993; Sanchez et al., 1997, Smaling et al., 1997). During the 2002–2004 cropping season, about 85% of African farmland (185 million hectares) had annual nutrient mining rates of more than 30 kg/ha, and 40% had annual rates greater than 60 kg/ha (Henao and Baanante, 2006). About 95 million hectares of soil have reached such a state of degradation that only huge investments could make them productive again (Vlek, 1990; Henao and Baanante, 2006). The main causes of fertility decline were depletion due to crop-harvest removals (residues), leaching and soil erosion, lack of supplemental nutrients and mineral fertilizers, unbalanced fertilization, and cultivation of low-potential areas (Smaling, 1993; Sanders et al., 1996; Shepherd & Soule, 1998). These studies depict the urgency of a sustainable nutrient management plan for Africa and many other places in the world to circumvent the potential impact of nutrient deficit on food security and environmental quality.

Soil Carbon Loss

Soil carbon/organic matter is usually referred to as 'black gold' because of its vital role in physical, chemical and biological processes within the soil system (Reicosky and Saxton, 2007). Soil erosion results in the removal of organic matter and essential plant nutrients from the soil and the reduction of the soil depth. These changes not only inhibit vegetative growth, but reduce the presence of valuable biota and the overall biodiversity in the soil (Pimentel et al., 1995).

Conversion of virgin land for cultivation and grazing, repeated cultivation promoting soil respiration without additional carbon inputs and soil erosion are the main causes of loss of organic matter. The estimated total loss of carbon through soil degradation since the advent of agriculture about 10 000 years ago represents 16–20% of the present-day global soil carbon stocks of 1200–1500 Gt (Rozeanov et al., 1990; Haider, 1999). Intensification of agriculture based on conventional techniques has amplified and accelerated the age-old problem of soil degradation causing a C loss of 30 – 50% over the past century during which many soils were brought into cultivation (Schlesinger, 1986; Hillel, 1991).

Since the mechanization of agriculture began a few hundred years ago, scientists estimate that some 78 billion metric tons of carbon once trapped in the soil have been lost to the atmosphere in the form of CO_2 (Lal, 2004). Murty et al. (2002) showed that conversion of forest to agricultural land led to an average loss of about 22% of soil C. The mineralization rate of SOC may range from about 20% in 20 years in temperate climate to about 50% in 10 years in the

tropics (Woomer et al., 1994). Several researchers observed an exponential decline in soil organic matter content with cultivation time in soils of West Africa (Brams, 1971; Jenkins and Ayanaba, 1977; Lal, 1979).

4. The Role of Conservation Agriculture in Sustaining Land Productivity

The above evidence suggests that unsustainable exploitation of land resources is leading to widespread degradation of resources serious implications for food security and ecological integrity. The situation is not likely to improve in light of the increasing world population along with its increased demand for higher quantities and quality of food and water, a challenge being imposed on future generations. The world community is well aware of this challenge since the publication of the Millennium Ecosystem Assessment (2005).

Until the middle of last century, the increase in food production in most countries was achieved by bringing new land into agricultural production. However, reserves of potentially arable prime agricultural land are dwindling (Bockman et al. 1990; Crosson and Anderson 1992) and the remaining land is claimed for numerous purposes, including the provision of essential ecosystem services. There are also indications that the highly effective fertilizer and seed technologies introduced over the past four decades may be reaching a point of diminishing returns (Cassman et al. 1995; Flinn and De Datta 1984). Furthermore, new technologies such as genetically engineered, yield-increasing plants are not expected to be major factors in food production increases in developing countries over the next few decades (Hazell 1995; Peng et al. 1994). Consequently, keeping pace with population growth while dealing with increasing land scarcity and degradation will be more difficult than in the recent past.

The millennium development goals 1 and 7 of reducing poverty while ensuring environmental health would point towards systems that conserve resources and maximize efficiencies of resource use. With soil organic matter a key resource to conserve, the agricultural research community has re-assessed the costs and benefits of conservative soil management systems. Food security, ecological integrity and environmental health may be achieved by reducing tillage, leaving residues on the field augmenting nutrient inputs and reducing pest pressures through crop rotation, in short through conservation agriculture (FAO, 2008).

Conservation agriculture, that involves an application of modern agricultural technologies to improve production, enables maximization of yields but also helps maintain ecosystem health and integrity unlike the traditional systems which mainly intend to maximize yields sometimes at the expensive of the environment (Dumanski et al, 2006). Expansion of conservation agriculture can create a win-win situation through promoting more efficient crop production and reducing soil degradation while maintaining ecosystem integrity. As a result, the impacts of conservation agriculture have been markedly positive both in agricultural, environmental, economic and social terms (Garcia-Torres et al., 2003 and Bishop-Sambrook et al., 2004; FAO, 2002; Dumanski et al., 2006).

Because of its significant contributions, the importance of conservation agriculture is growing worldwide where it currently spans over millions of hectares (Riberio et al., 2007). The FAO (2008) estimates its coverage at about 95-98 million hectares, depending on whether zero-tillage, conservation tillage, direct seeding/planting and/or organic farming are all include in the calculations. This worldwide expansion of the technology is clear evidence of its benefits to farmers. Conservation agriculture has wide range of benefits including improvement in soil fertility, reduction in soil erosion, carbon accumulation, savings in time and energy (fuel), and increase in biodiversity (Knowler, 2003; Reicosky and Saxton, 2007; FAO, 2002, 2008).

Conservation Agriculture and its Role in Reducing Soil Erosion

Some studies have indicated that conservation agriculture is an effective way of controlling erosion (e.g., Packer et al., 1992; Uri et al., 1999). Soil erosion in Brazil fell from 3.4-8.0 t/ha under conventional tillage to 0.4 t/ha under no-till, and water loss fell from approximately 990 to 170 t/ha (Sorenson et al., 1997, 1998). A watershed study in Brazil showed a 22% reduction in sediment load from 1994 to 1998 because of no-till adoption (Derpsch, 2001b). In Paraguay, 23 t/ha/year of soil are lost on average when using conventional agriculture whereas only 0.53 t/ha/year are lost using the no-till system (Venialgo, 1996).

It is important to note that the damage of lost soil in conventional tillage has on- and off-site aspects. It does not only affect farmers situated upslope, but soil is deposited in creeks and rivers also cause sedimentation of rivers, lakes and dams affecting down-slope inhabitants. This deposition of sediments in unwanted places has negative implications on the rural road system, hydraulic energy generation, drinking water production and recreational areas, resulting in significant expenditures for maintenance.

Conservation Agriculture and its Role in Improving Carbon Stock

While conventional cultivation generally results in loss of soil C and nitrogen (Mann, 1986), conservation agriculture has proven potential of converting many soils from sources to sinks of atmospheric C (Kern & Johnson, 1993; Reicosky, 1997), sequestering carbon in soil as organic matter. In general, soil carbon sequestration during the first decade of adoption of best conservation agricultural practices is 1.8 tons CO₂ per hectare per year. On 5 billion hectares of agricultural land, this could represent one-third of the current annual global emission of CO₂ from the burning of fossil fuels (FAO, 2008). Lal et al. (1998) estimated that widespread adoption of conservation tillage on some 400 million ha of cropland by the year 2020 may lead to total C sequestration of 1500 to 4900 Mg.

Leaving crop residue on the field is another practice which could have an important impact on the global carbon cycle (Lal, 1997). The annual production of crop residue is estimated to be about 3.4 billion Mg in the world (Lal, 1997). If 15% of C contained in the residue can be converted to passive soil organic carbon (SOC) fraction, this may lead to C sequestration at the rate of 0.2×10^{15} g/yr (Lal, 1997). Similarly, restoring presently degraded soils, estimated at about 2 billion ha, and increasing SOC content by 0.01%/yr may lead C sequestration at the rate of 3.0 Pg C/yr. Systems, based on high crop residue addition and no-tillage, tend to turn the soil into a net sink of carbon (Greenland and Adams, 1992; Reicosky et al., 1995; Bot et al., 2001). In the USA, the total loss of carbon, from a plot of ploughed-under wheat residues, was up to five times higher than from plots not ploughed, and the loss of carbon was equal to the quantity of carbon in the wheat residues which had remained in the field from the previous crop (CTIC, 1996). Conservation tillage adoption on three-quarter of the land would half this respired CO₂ as compared to 1993, representing an accrual of almost 400 million tons (Bot et al., 2001).

Net soil C stock changes for US agricultural soils between 1982 and 1997 due to shifts towards conservation agriculture are estimated to amount to 21.2 MMT C year⁻¹ (Eve et al., 2002). At an average rate of 0.51 t/ha year, Brazil is sequestering about 12 million t of carbon on 23.6 million ha of no-tillage adoption. In Canada, at a CO₂ sequestration rate of 0.74 t/ha farmers practicing no-till would be sequestering about 9 million tons of CO₂ from the atmosphere each year, while at the same time enriching the soil in carbon (Bot et al., 2001). It is estimated that wide dissemination of conservation agriculture (which leaves at least 30% of plant residue cover on the surface of the soil after planting) could offset as much as 16% of worldwide fossil fuel emissions (CTIC, 1996).

Estimated Monetary Values of Conservation Agriculture

Conservation agriculture in the form of no-tillage has now been adopted on more than 95 million ha world wide and farmers are showing increasing interest in the technology. Approximately 47% of the no-tillage technology is practiced in South America, 39% is practiced in the United States and Canada, 9% in Australia and about 3.9% in the rest of the world, including Europe, Africa and Asia.

Brazil increased its grain production by 67.2 million tons over 15 years by adopting the no-tillage system. Assuming conservative average prices of US\$ 150/t, this means additional revenue of about 10 billion dollars (Derpsch and Benites, 2003; Derpsch, 2005). Similarly, grain production in Argentina increased from 28 million tons in 1988 to 74 million tons in 2001 with adoption of conservation agriculture (Derpsch, 2005). An additional 46 million tons of production at average prices of US\$ 150/t, means additional revenue of almost 7 billion dollars, of which a great portion can be attributed to the adoption of the no-tillage technology (Derpsch, 2005).

In Western Australia, it is believed that adoption of no-tillage practices has increased crop production by at least 3 million tons in the year 2000. Likewise production in 2001 was increased by an extra 5 million tons and in 2002 by another 4 million tons (Derpsch and Benites, 2003; Derpsch, 2005). At an average grain value of US\$ 150/t, this is US\$ 1.8 billion additional revenue. In two regions of Paraguay, Sorrenson (1997) compared the financial profitability of conservation agriculture on 18 medium and large-sized farms with conventional practice over a 10-year period. He found that by the tenth year net farm income had risen on the conservation agriculture farms from under US\$10 000 to over US\$30 000, while on conventional farms net farm income fell and even turned negative. In the USA, Uri et al. (1999) estimated that the realized erosion benefits (avoided losses from sheet, rill and wind erosion) from the existing areas under conservation tillage ranged from US\$90 million to US\$289 million in 1996.

A study that assessed the impact of zero tillage in the rice-wheat system of India (Laxmi and Erenstein, 2006) showed that investment in zero-tillage was highly beneficial with a benefit-cost ration of 39, a net present value of US\$ 94 million and an internal rate of return 57%. A similar study in the Punjab region of Pakistan (Sawrrwa and Goheer,

2007) shows that zero tillage technology is the most economical and attractive option for wheat cultivation. Crop yield using zero tillage (3410 kg/ha) was significantly higher than conventional method (3123 kg/ha) with significantly lower total cost of production (Sarwar and Goheer, 2007).

All these examples and many others available for different regions of the world have demonstrated the significant impact of adopting conservation agriculture including no-tillage technology. The observed gains in crop production and environmental protection are encouraging signs and a compelling argument that conservation agriculture should be practices in other regions as well. Especially developing countries that require improved agricultural production the most could benefit. Awareness creation, policies and incentives could help promote conservation agriculture and its benefits to these regions.

5. Conclusion

Inappropriate agricultural cultivation systems are one of the main reasons for the poverty and food insecurity faced by smallholders in most parts of the rural regions in developing countries. Unsustainable agricultural practices lead to an exhaustion of forest and soil resources, which results in reduced land productivity, land degradation, and a reduction in biodiversity. Conservation agriculture, which is mainly based on the three principles of minimum soil disturbance, permanent soil cover and crop rotation, has shown to improve, conserve and use natural resources in a more efficient way through integrated management of available soil, water and biological resources. It is now widely recognized as a viable concept for sustainable agriculture due to its comprehensive benefits in economic, environmental and social terms. Its ability to increase grain yields to provide better economic performance and reduce production risks and to improve energy use efficiency has been well-documented. What is required is better understanding of its performance and requirements across wider geographic regions and environmental conditions to enable the diffusion of the technology. For its successful implementation in developing regions where it is needed most, the design and dissemination of cost-effective farming tools, access to herbicides and economic incentives will be required in addition to creating awareness.

References

- Ainsworth EA, Long SP (2005) What have we learned from 15 years of free-air CO₂ enrichment (FACE)? A meta-analytic review of responses to rising CO₂ in photosynthesis, canopy properties and plant production. *New Phytologist* **165**, 351-372.
- Bai, Z.G.; Dent, D.L.; Olsson, L.; Schaepman, M.E. 2008. Proxy global assessment of land degradation. *Soil Use and Management* **24**, 223-234.
- Bishop-Sambrook, C., Kienzle, J., Mariki, W., Owenya, M. and Ribeiro, F. 2004. Conservation Agriculture as a labour saving practice for vulnerable households: Suitability of reduced tillage and cover crops for households under labour stress in Babati and Karatu Districts, Northern Tanzania. A joint study by IFAD and FAO. IFAD (International Fund for Agricultural Development) and FAO (Food and Agriculture Organization of the United Nations), Rome, Italy.
- Bockman, O.C., Kaarstad, O., Lie, O.H. and Richards, I. 1990. *Agriculture and Fertilizers: Fertilizers in Perspective*. Norsk Hydro, Oslo.
- Bot, A.J., Amado, T.J.C., Mielniczuk, J., Benites, J. 2001. Conservation agriculture as a tool to reduce emission of greenhouse gasses. I World Congress on Conservation Agriculture Madrid, 1-5 October, 2001
- Brams, E.A., 1971. Continuous cultivation of West African soils: organic matter diminution and effects of applied lime and phosphorus. *Plant and Soil* **53**, 401-414.
- Cassman, K. G., S. K. De Datta, D. C. Olk, J. Alcantara, M. Samson, J. Descalsota, and M. Dizon. 1995. Yield decline and the nitrogen economy of long term experiments on continuous, irrigated rice systems in the tropics. In: R. Lal and B.A. Stewart (eds), *Soil management: Experimental Basis for Sustainability and Environmental Quality*, CRC/Lewis Publishers, Boca Raton, FL (1995), pp. 181-222.
- Crosson, P., Anderson, J. 1992. Resources and Global Food Prospects: Supply and Demand for Cereals to 2030. World Bank Technical Paper Number 184, The World Bank, Washington, D.C.
- CTIC, 1996. Conservation Technology Information Centre, CTIC Partners, April/May 1996, Vol. 14 N° 3.
- den Biggelaar, C., Lal, R., Wiebe, K., Eswaran, H., Breneman, V., Reich, P., 2004. The global impact of soil erosion on productivity II: Effect on crop yields and production over time. *Advances in Agronomy* **81**, 49-95.

- Derpsch, R. and Benites, J.R., 2003. Situation of conservation agriculture in the world. Proceedings, II World Congress on Conservation Agriculture, Iguassu Falls, Brazil, 11 - 15 August, 2003
- Derpsch, R. 2001a. Frontiers in conservation tillage and advances in conservation practice. In: D.E.Stott, R.H.Mohtar and G.C.Steinhardt (eds), 2001. Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24 -29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory, p 248-254
- Derpsch, R., 2001b. Conservation tillage, no-tillage and related technologies. I World Congress on Conservation Agriculture, Madrid, 1-5 October 2001.
- Derpsch, R. 2005 The extent of conservation agriculture adaptation worldwide: Implications and impact. Proceedings of the third world congress on Conservation Agriculture: Linking Production, Livelihoods and Conservation Nairobi, Kenya, October 3-7, 2005.
- DREGNE, H.E. 1990. Erosion and soil productivity in Africa. *Journal of Soil and Water Conservation*, **45**, 431–436.
- Dumanski, J., R. Peiretti, R., Benites, J.R., McGarry, D and Pieri, C. 2006. The paradigm of conservation agriculture, Proc. World Assoc. Soil Water Conserv. P1 (2006), pp. 58–64.
- Eklundh L, Olsson L (2003) Vegetation index trends for the African Sahel 1982–1999. *Geophysical Research Letters*, 30, 1430 doi:10.1029/2002GL016772.
- Elliott, E.T., 1986. Aggregate structure and carbon, nitrogen and phosphorus in native and cultivated soils. *Soil Science Society of America Journal* **50**, 627–633
- El-Swaify, S.A. 1994. State of Art of Assessing Soil and Water Conservation Needs and Technologies, In: Adopting Conservation the Farm: An International Perspective on the Socio-economics of Soil and Water Conservation, Soiland Water Conservation Society, Iowa, USA, pp. 13-27.
- Eswaran, H., Lal, R. and Reich, P.F. 2001. Land degradation: an overview. In: Bridges, E.M., I.D. Hannam, L.R. Oldeman, F.W.T. Pening de Vries, S.J. Scherr, and S. Sompattpanit (eds.). Responses to Land Degradation. Proc. 2nd. International Conference on Land Degradation and Desertification, Khon Kaen, Thailand. Oxford Press, New Delhi, India.
- Eve, M.D., M. Sperow, K. Howerton, K. Paustian and R.F. Follett, Predicted impact of management on soil carbon storage for each cropland region of the conterminous US, *J. Soil Water Cons.* **57** (2002), pp. 196–204
- FAO, 2002. The Conservation Agriculture Working Group Activities 2000 – 2001. Food and Agriculture Organization of the United Nations, Rome, 2002, 25 pp
- FAO 2008. Conservation Agriculture Carbon Offset Consultation – West Lafayette, Indiana, USA, 28-30 October 2008.
- Flinn, J. C., and S. K. De Datta. 1984. Trends in irrigated rice yields under intensive cropping at Philippine research stations. *Field Crops Research* **9**, 1-15.
- García-Torres, L., J. Benites, A. Martínez-Vilela and A. Holgado-Cabrera. 2003. Conservation Agriculture: Environment, Farmers Experiences, Innovations, Socio-economy, Policy, Kluwer Academic Publishers, Boston, USA (2003).
- Glantz, M.H. 1998. "Creeping Environmental Problems in the Aral Sea Basin." In Kobori, I., and M.H. Glantz, eds., Central Eurasian Water Crisis: Caspian, Aral and Dead Seas. New York: United Nations University Press.
- Greenland, D.J. and Adams, 1992. Organic matter in the soils of the Tropics - From myth to complex reality. In: Myths and science of soils in the tropics. SSSA Special publication no. 29.
- Haider K (1999) Von der toten organischen Substanz zum Humus. *Z Pflanzenernähr Bodenk* **162**, 363–371
- Hazell, P. 1995. Technology's contribution to feeding the world in 2020. In Speeches made at an international conference. Washington, DC:International Food Policy Research Institute.
- Hellden U, Tottrup C (2008) Regional desertification: a global synthesis. *Global and Planetary Change*. Doi:10.1016/j.gloplacha.2008.10.006.
- Henao, Julio and Carlos Baanante, (2006). "Agricultural Production and Soil Nutrient Mining in Africa", International Fertilizer Development Center, Muscle Shoals, Alabama, USA.
- Herrmann, S.M., Anyamba, A., Tucker, C.J., 2005 Recent Trends in Vegetation Dynamics in the African Sahel and their Relationship to Climate. *Global Environmental Change* **15**, 394-404.
- Hickler T, Eklundh L, Seaquist JW, Smith B, Ardo J, Olsson L, Sykes M, Sjoström M (2005) Precipitation controls Sahel greening trend. *Geophysical Research Letters*, 32, L21415, doi:10.1029/2005GL024370.

- Hillel D (1991) Out of the earth: civilization and the life of the soil. New York: The Free Press
- Bradford J.m., and C. Huang, C. 1994. Interill soil erosion as affected by tillage and residue cover, *Soil Tillage Res.* **31** (1994), pp. 353–361
- Jenkins, D.S. and A. Ayanaba, 1977. Decomposition of carbon-14 labelled plant material under tropical conditions. *Soil Sci. Soc. Am. J.* **41**, 912–916
- Kay, 1990 B.D. Kay, Rates of change of soil structure under different cropping systems, *Adv. Soil Sci.* **12**, 1–52.
- Kendall, H. W., and David Pimentel. 1994. Constraints on the expansion of the global food supply. *Ambio* **23**,198-205.
- Kern, J.S. and Johnson, M.G., 1993. Conversion to conservation-till will help reduce atmospheric carbon levels. Fluid Journal, Vol. 1, N° 2, 1993
- Knowler, D.J., 2003. Explaining the financial attractiveness of soil and water conservation – a meta-analysis model. Paper presented at the 2003 Soil and Water Conservation Society's Annual Conference, Spokane, Washington, July 26–30.
- Lal, 1979. R. Lal, Physical properties and moisture retention characteristics of some Nigerian soils. *Geoderma* **21** (1979), pp. 209–223.
- Lal, R. (ed). 1994. Soil erosion research methods. Soil and water conservation society, Ankeny, 1A, 340pp.
- Lal R. 1995. Global soil erosion by water and carbon dynamics. In: Lal R, Kimble JM, Levine E, Stewart BA, editors. Soils and global change. Boca Raton: CRC/Lewis Publishers;. p. 131– 41.
- Lal, R. 1997. Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO₂-enrichment, *Soil and Tillage Research* **43**, 81–107.
- Lal R. 1998. Soil erosion impact on agronomic productivity and environment quality. *Crit Rev Plant Sci*; **17**, 319–464.
- Lal, R., J.M. Kimble, R.F. Follett and C.V. Cole. 1998. The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Chelsea, Mich.: Ann Arbor Press.
- Lal, R. Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science* 2004, **34**, 1623–1627.
- Lewis SL, Malhi Y, Phillips OL (2004) Fingerprinting the impacts of global change on tropical forests. *Phil. Trans. R. Soc. Lond. B*, **359**, 437-462.
- Laxmi, V. and Erenstein, O. 2006. Assessing the impact of international natural resource management research: the case of zero tillage in India's rice-wheat system. Paper presented at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12 – 18, 2006.
- Long SP, Ainsworth EA, Leakey ADB, Nösberger J, Ort DR (2006) Food for Thought: Lower-than-expected crop yield stimulation with rising CO₂ concentrations. *Science*, **312**, 1918-1921.
- Mann, L.K. 1986. Changes in soil carbon storage after cultivation, *Soil Sci.* **142** (5) (1986), pp. 279–288.
- Martius, C., Tiessen, H., Paul LG. Vlek. 2001. The management of organic matter in tropical soils: what are the priorities. *Nutrient cycling in agroecosystems*, 61 1-6.
- Murty D, Kirschbaum MUF, McMurtrie RE, McGilvray H (2002). Does forest conversion to agricultural land change soil organic carbon and nitrogen? A review of the literature. *Global Change Biology* **8**, 105-123.
- Myers, N. 1993. Gaia: An atlas of planetary management. Garden City, NY: Anchor and Doubleday.
- Oldeman, L.R., Hakkeling, R.T.A., Sombroek, W.G., 1990. World Map of the Status of Human-Induced Soil Degradation: An Explanatory Note. 34 pp. Wageningen: ISRIC.
- Olsson, L., Eklundh, L., Ardö, J., 2005. A recent greening of the Sahel: trends, patterns and potential causes. *J. Arid Environ.* **63**:556-566.
- Packer, I.J., Hamilton, G.J. and Koen, T.B. 1992. Runoff, soil loss and soil physical properties changes of light textured surface soils from long-term tillage treatments, *Aust. J. Soil Res.* **30** (1992), pp. 789–806
- Papendick and Parr, 1997 R.I. Papendick and J.F. Parr, No-till farming: the way of the future for a sustainable dryland agriculture, *Ann. Arid Zone* **36** (1997), pp. 193–208
- Peng, S., G. S. Khush, and K. G. Cassman. 1994. Evolution of the new plant ideotype for increased yield potential. In *Breaking the yield barrier: Proceedings of a workshop on rice yield potential in favourable environments*, ed. K. G. Cassman. Manila:

International Rice Research Institute.

- Phillips et al. (2004) Pattern and process in Amazon tree turnover, 1976–2001. *Phil. Trans. R. Soc. Lond. B*, 359, 381-407.
- Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., Mcnair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R. and Blair, R. 1995. Environmental and economic costs of soil erosion. *Science*, 267, 1117–1123.
- Pimentel, D., Kounang, N., 1998. Ecology of soil erosion in ecosystems. *Ecosystems* 1, 416– 426.
- Pimenttel, David, Paul Hepperly, James Hanson, David Douds, and Rita Seidel. 2005. Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems. *BioScience* 55(7): 573-582.
- Prince SD (2004) Mapping desertification in Southern Africa. In: *Land Change Science: Observing, Monitoring and Understanding Trajectories of Change on The Earth's Surface* (eds Gutman G. et al.) pp. 163-184. Kluwer, Dordrecht.
- Reay DS, Dentener F, Smith P, Grace J, Feely R (2008) Global nitrogen deposition and carbon sinks. *Nature Geoscience* 1, 430-437.
- Reichert and Norton, 1994 J.M Reichert and L.D. Norton, Aggregate stability and rain-impacted sheet erosion of air-dried and prewetted clayey surface soils under intense rain, *Soil Sci.* **158** (1994), pp. 159–169.
- Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.L. Douglas and P.E. Rasmunssen. 1995. Soil organic matter changes resulting from tillage and biomass production. *Journal of soil and water conservation* 50(3):253-261.
- Reicosky, D.C., Saxton, K.E. 2007. Reduced environmental emissions and carbon sequestration. In: Baker, C.J., Saxton, K.E., editors. *No-tillage Seeding in Conservation Agriculture*. 2nd edition. Rome, Italy: FAO and CAB International. p. 257-267.
- Reij C, Tappan G, Belemvire, A (2005) Changing land management practices and vegetation on the Central Plateau of Burkina Faso (1968-2002). *Arid Environ.* 63, 642-659
- Ribeiro, M.F.S., J.E. Denardin, A. Bianchini, R. Ferreira, C.A. Flores, H.J. Kliemann, R.A. Kochhann, I.C. Mendes, G.M. Miranda, L. Montoya, N. Nazareno, C. Paz, R. Peiretti, C.N. Pillon, E. Scopel and F. Skora Neto. 2007. Comprehensive inventory and assessment of existing knowledge on sustainable agriculture in the Latin American platform of KASSA. In: R. Lahmar, J.L. Arrue, J.E. Denardin, R.K. Gupta, M.F.F. Ribeiro and S. de Tourdonnet, Editors, *Knowledge Assessment and Sharing on Sustainable Agriculture*, CIRAD, Montpellier, 58 pp.
- Rozanov BG, Targulian V and Orlov DS (1990) Soils. In: Turner BL, Clark WC, Kates RW, Richards JF, Mahtews JT and Meyer WB (eds) *The Earth as Transformed by Human Action*. Cambridge, UK: Cambridge University Press
- Salonius, P. 2008. Intensive Crop Culture for High Population is Unsustainable. <http://www.mindfully.org/Farm/2008/Intensive-Crop-Unsustainable10feb08.htm>.
- Sanchez, P.A., Shepherd, K.D., Soule, M.D., Place, F.M., Buresh, R.J., Izac, A.-M.N., Mokwunye, A.U., Kwesiga, F.R., Ndiritu, C.G. and Wooster, P.L., 1997. Soil fertility replenishment in Africa: an investment in natural resource capital. In: Buresh, R.J., Sanchez, P.A. and Calhoun, F., Editors, 1997. *Replenishing Soil Fertility in Africa* Special publication number 51, Soil Science Society of America, pp. 1–46.
- Sanders, J. H., Shapiro, B. I. and Ramaswamy, S. 1996. *The Economics of Agricultural Technology Development in Sub-Saharan Africa*. Baltimore: John Hopkins University Press. 305 pp.
- Sarwar, M.N. and Goheer, M.A. 2007. Adoption and impact of zero tillage technology for wheat in rice-wheat system – water and cost saving technology: a case study of Pakistan (Punjab). Discussion Paper Series No. 13. <http://www.wepa-db.net/pdf/0703forum/paper16.pdf>.
- Schlesinger, W. H. (1986) "Changes in soil carbon storage and associated properties with disturbance and recovery." In: Trabalka, J. R., Reichle, D. E. eds., *The changing carbon cycle-a global analysis.*, Springer-Verlag, New York, pp 194-220
- Sheldrick, W.F., Syers, J.K. and Lingard, J., 2002. A conceptual model for conducting nutrient audits at national, regional and global scales. *Nutrient Cycling in Agroecosystems* **62**, pp. 61–67.
- Shepherd, K.D. and Soule, M.J., 1998. Soil fertility management in west Kenya: dynamic simulation of productivity and sustainability at different resource endowment levels. *Agriculture, Ecosystems and the Environment* **71**, pp. 131–145
- Smaling, E.M.A., 1993. The soil nutrient balance: an indicator of sustainable agriculture in sub-Saharan Africa. *The International Fertilizer Society Proceedings* 340, p. 18.
- Smaling, E.M.A., Nandwa, S.M. and Jansen, B.H., 1997. Soil fertility in Africa is at stake. In: Buresh, R.J., Sanchez, P.A. and Calhoun, F., Editors, 1997. *Replenishing Soil Fertility in Africa* Special publication number 51, Soil Science Society of America, pp. 47–61.

- Sorrenson, W.J. 1997. Financial and economic implications of no-tillage and crop rotations compared to conventional cropping systems. TCI Occasional Paper Series No.9, Rome, FAO.
- Sorrenson, W.J., Lopez-Portillo, J. and Nuñez, M., 1997. The economics of no-tillage and crop rotations in Paraguay. Policy and investment implications. MAG/GTZ/FAO, 215p
- Stoorvogel, J.J., Smaling, E.M.A., 1990. Assessment of soil nutrient depletion, sub-Saharan Africa: 1983–2000. Report 28. The Winand Staring Centre Wageningen, The Netherlands, pp. 137.
- Taddese, T., 2001. Land Degradation: A challenge to Ethiopia, *Environmental Management*, 27(6):815-824
- Tan ZX, Lal R, Wiebe KD. 2005 Global soil nutrient depletion and yield reduction. *J Sust Agric* 26:123–146.
- Tisdall JM, Oades JM. 1982. Organic matter and water stable aggregates in soil. *J Soil Sci* 1982;33:141– 63.
- UNEP 1992. *World Atlas of Desertification*. Edward Arnold, Sevenoaks, UK.
- UNEP. 1994. *Land Degradation in South Asia: Its Severity, Causes and Effects upon the People*. INDP/UNEP/FAO. World Soil Resources Report 78. Rome: FAO.
- Uri, N.D., J.D. Atwood and J. Sanabria, 1999. The environment benefit and cost of conservation tillage, *Environ. Geol.* **38** (1999), pp. 111–125
- van der Pol, F., 1992. Soil mining. An Unseen Contributor to Farm Income in Southern Mali, Bulletin 323. Royal Tropical Institute (KIT), Amsterdam, The Netherlands, pp. 47.
- Venialgo, N., 1996. Efecto de dos sistemas de labranza en el control de la pérdida de suelo por erosión hídrica. Trabajo presentado en el II Encuentro Latinoamericano de Siembra Directa en Pequeñas Propiedades, Edelira, Paraguay, 11 – 14 de marzo 1996.
- Vlek, P.L.G. 1990. The role of fertilizers in sustaining agriculture in sub-Saharan Africa. *Fert. Res.* 26: 327-339.
- Vlek, P.L.G. 1993. *Strategies for Sustaining Agriculture in Sub-Saharan Africa: The Fertilizer Technology Issue. Technologies for Sustainable Agriculture in the Tropics*. ASA Special Publication No. 56. Madison, Wisconsin, USA, pp. 265-276.
- Vlek PLG, Le QB, Tamene L (2008) Land Decline in Land-Rich Africa: A Creeping Disaster in the Making. CGIAR Science Council Secretariat, Rome.
- VlekP. L.G. (2008). The Incipient Threat of Land Degradation. *Journal of the Indian Society of Soil Science*, Volume: 56, Issue: 1.
- Wessels, K.J., Prince, S.D., Malherbe, J., Small, J., Frost, P.E., van Zyl, D., 2007. Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in South Africa. *Journal of Arid Environment* 68, 271-279.
- Woomer, P.L., A. Martin, A. Albrecht, D.V.S. Reseck and H.W. Scharpenseel. 1994. The importance and management of soil organic matter in the tropics. In: Eds. Woomer, P.L. and M.J. Swift. *The biological management of tropical soil fertility*. J. Wiley, Chichester, UK.

Indigenous Knowledge in Conservation Agriculture

Y.L. Nene

Asian Agri-History Foundation, Secunderabad, 500 009, India

Ever since mankind started practicing agriculture, there was a beginning of awareness of resource conservation. We find evidence of conservation practices in all ancient cultures. Since I am familiar more with Indian classic literature on agriculture that has been published by my Foundation (Asian Agri-History Foundation – AAHF) in the last 12 years, my lecture includes most information from literature published by AAHF.

As most of us know, according to Food and Agricultural Organization (FAO) of the United Nations, “Conservation agriculture is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment.” (FAO, 2007). Aspects of conservation that we normally deal are the management of soil, water, crop diversity, animals, storage of produce (seed, fertilizer, etc.), and maintenance of tools, implements, machinery, etc.

The following paragraphs refer to the relevant contents from some ancient texts of India.

1. Rigveda (c. 8000 BC)

This is the oldest text compiled by mankind (Nene and Sadhale, 1997). We can note reference to conservation agriculture in some of the *ruchas* (verses). Rigveda insists that natural forces (earth – solid matter; water – liquid matter; air – subtle matter; fire – energy; and *akasa* – the opposite of matter) must remain in harmony with each other and also the mankind must not disturb the balance between them. Following verses relate to conservation agriculture. The verse numbers are quoted at the end of each verse for ease to locate in Rigveda, which is voluminous.

“O cows! Procreate calves, select fine quality grass, and drink clean, safe water from ponds.” (6:28:7).

“O humans! Do not kill a cow who is mother of Rudras, daughter of Vasus, sister of Aditya, milk bearing, innocent without complex” (8:90:15).

“O Pusha! Do not destroy the trees that support birds but destroy those who hate me”. (6:48:17).

“Let the soil get soaked with water and give us harvests in the years to come”. (4:57:7)

“Let our ploughs open the soil happily, let the ploughman walk happily with the bullocks, and let clouds soak the lands with water. Give us happiness. (4:57:7, 8)

Cow protection, cattle management, discouraging cutting trees, desire for sufficient rain, and contented animals and farmers are the conservation issues covered in these verses.

2. Krishi-Parashara (c. 400 BC)

Parashara stressed soil management, seed health, and overall farm management that included water harvest and conservation, animal management, and maintenance of implements (Sadhale, 1999). No commentary is made since the verses are self-explanatory. Some of the key verses are:

“Farms yield gold if properly managed but lead to poverty if neglected”.

“Even a fourfold yield of crops procured at the cost of health of the bullocks perishes soon by the sighs of their exhaustion.”

“The bullocks of the farmer who keep the cow shed, strong, clean, and free of cow dung grow well even without special nourishment”.

“Crops grown without manure will not give yield.”

“Any implement which is not sufficiently strong or is not manufactured as per the (above – said) measurements will, at the time of farming operations, obstruct the work at every step. There should be no doubt about it.”



Parashara

“Uniform seeds produce excellent results. Hence every effort should be made to procure uniform seeds.”

“One should (therefore) put in maximum effort to procure and preserve these seeds. The origin of plentiful yield is the seed.”

“What hope of harvest can that foolish farmer have who has not made arrangements for preserving water for the crop during *Ashwin* (October) and *Kartika* (November)?

3. Kautilya (321–296 BC)

The *Varta* (crop production, animal husbandry, and trade) was considered one of the sciences of the time. Kautilya mentions intercropping of medicinal plants with any field crop. An example of wasteland utilization was planting cucurbits on river banks, after the excess water receded. The practice continues even today in all parts of India. Some significant statements made by Kautilya are:

“Whoever hurts or causes another to hurt, or steals, or causes another to steal a cow, should be slain.”

“The Superintendent of forest produce shall collect timber and other products of forests by employing those who guard forests.”

“Brahmins shall be provided with forests for soma plantation, for religious learning, and for performance of penance, such forests being granted with safety for animate and inanimate objects, and being named after the tribal name (*gotra*) of the Brahmins resident therein”.



Kautilya

4. Kashyapiykrishisukti (800 AD)



Kashyapa

This treatise is a detailed one and gives advice on management of farm not only to farmers but also to kings. There are details about rice growing practices that are widely followed in India today (Ayachit, 2002)

“Land is intended to receive excellence in every age.”

“A good quality land yields good results to everyone. Confers good health on the entire family, and causes growth of money, cattle and grain.”

“To the west, north, east, or south of the villages and cities at the most convenient places, he (king) should prepare reservoirs of water according to the condition of the land.”

“The reservoir of water to be founded should be deep, equipped with barriers, splendid in the shape of a bow, long in some cases, round in others but essentially unfathomable”.

“They should also be equipped with inlets for water. Hence they should be founded near some hill or a high-level ground joined with a lake”.

“The king should plan its construction at such places as not to cause fear of danger from flooding. Such reservoirs should be regularly examined.”

“Large forests teeming with various trees, on the forest lands, or on the outskirts, or interiors of existing forests, or on mountain slopes should be propagated.”

About canals for irrigation, “Even more than the ponds, lakes, wells, etc. protection of canals should be treated by them (farmers and the king) as their *dharma*” said the sages who know the truth.

“That water (therefore) should be preserved by all (sorts of) efforts, as agriculture is said to depend on water. Hence, kings and (other) eminent persons should obtain water by exerting everywhere in the seasons and conserve it.”

For rice, “The second cultivation in a year is fruitful everywhere and is therefore recommended on various types of farmlands. For taking up this second operation, it is essential to raise the fertility of the soil, which can be achieved by using manure of goat-dung, cow dung, and vegetation (green manure).”

5. Vrikshayurveda (c. 1000 AD)

Vrikshayurveda by Surapala is a 'complete' treatise on arbori-horticulture. It also emphasizes the importance of trees and environment. Some of the verses carry deep meaning (Sadhale, 1996).

Importance of growing trees is versed beautifully below by Surapala.

“Ten wells are equal to one pond.
Ten ponds are equal to one lake.
Ten lakes are equal to one son.
Ten sons are equal to one tree.”

“. . . one should undertake planting of trees, since trees yield the means of attaining *dharma*, *artha*, *karma*, and *moksha* (the four aims of life)”.

“By planting all kinds of trees, useful for fruits and flowers, a person gets reward of thousand cows adorned with jewels.”

“Seeds which are treated and preserved (in prescribed manner) are all good for use. Trees grown from such seeds bear for ever abundant flowers and fruits of an excellent quality.”



Surapala

6. Krishi Gita (c. 1500 AD)



Parshurama

Parshurama recommended deep summer ploughing. This has been in practice in Kerala for several centuries. Green manuring was recommended for rice.

Although forest clearing was recommended as a means to expand cropped areas, farmers were also encouraged to plant trees and other woody perennials.

References

- Ayachit, SM. (Tr.). 2002. Kashyapiyakrishisukti (A Treatise on Agriculture by Kashyapa). Agri-History Bulletin No. 4. Asian Agri-History Foundation, Secunderabad-500009. India. 158 pp.
- Food and Agricultural Organization (FAO). 2007. Agriculture and Consumer protection Department, Rome, Italy. Available from <http://www.fao.org/ag/ca/> (accessed November 2007).
- Nene, YL and Sadhale. Nalini. 1997. Agriculture and Biology in Rigveda. *Asian Agri-History* 3: 177–190.
- Sadhale, Nalini (Tr.). 1996. Surapala's Vrikshayurveda (The Science of Plant Life by Surapala). *Agri-History Bulletin No. 1*. Asian Agri-History Foundation, Secunderabad-500009. India. 94 pp.
- Sadhale, Nalini (Tr.). 1999. Krishi-Parashara (Agriculture by Parashara). Agri-History Bulletin No.2. Asian Agri-History Foundation, Secunderabad-500009. India. 94 pp.
- Shamasastri, R. 1961. Kautilya's Arthashastra. Seventh Edition. Mysore Printing and Publishing House, Mysore, India. 488 pp. (First edition published in 1915).

Will Improving the Productivity of “Green” Water Lead to Food Security?

Colin J. Chartres

Director General, International Water Management Institute, PO Box 2075, Colombo, Sri Lanka

Politically, one of the most pressing questions for many countries over the next 50 years will be that of whether they will be food-secure in the face of potential recurring world food crises. During the 2008 food crisis, although global food stocks reached worrying lows, there was still enough food available to feed everyone. The key problems were those of demand, driving prices above the reach of the poor and food stocks being geographically in the wrong place. Logically, for most countries, food security can be achieved by a combination of domestic production and imports, but as was observed in the 2008 food crisis, logic often flies out of the window in the face of adversity. Some food exporting countries adopted policies that were clearly driven by fear and stopped exports. Other countries froze grain prices which was detrimental to poor farmers, encouraged black marketeering and did little to aid the urban poor. So a critical need for many countries are policy settings that encourage domestic production via increasing productivity, recognize the benefits of importing “virtual water” via trade in food, and enable poor farmers to benefit from price rises so that they in turn can invest in more productive systems.

Currently the world population is 6.7 billion and this large number is forecast to increase to about \$9 billion by 2050. Given a number of drivers and uncertainties that impinge on food production, the fact that close to 1 billion people are undernourished and the fact that we have already come perilously close to a famine-based disaster last year, there has to be concern as to whether we can feed 9 billion people in the future.

Availability of enough fresh water for rainfed and irrigated cropping is probably going to be the single most important factor in our quest to feed so many more mouths. The Comprehensive Assessment of Water Management in Agriculture (Comprehensive Assessment of Water in Agriculture, 2007) has already indicated that if we proceed with a “business as usual” approach, water scarcity will cause us to fail in this quest. “Business as usual” means maintaining water productivity levels at their current low rates. The Comprehensive Assessment was, however, more optimistic about the future if we can substantially lift water productivity levels via a combination of biophysical and engineering inputs and policy levers. Whilst some informed commentators indicate that we will only be able to produce enough food through expanding irrigation, the fact is that approximately 75% of production comes from rainfed areas. This is paralleled by the statistic that 80% of water evapotranspired by crops comes from rainfed farming areas and the remaining 20% from irrigation areas (Comprehensive Assessment of Water in Agriculture, 2007). However, the figures for gross value of production indicate that only 55% comes from rainfed areas indicating the importance of irrigation in terms of its higher productivity per unit area.

This paper examines some of the drivers behind water scarcity and examines ways in which water productivity in rainfed farming systems may be increased to tackle the major challenge of increasing food demand.

Blue and Green Water

Water passing through the hydrological cycle can be viewed as “blue” or “green.” Blue water is that found in rivers, lakes and groundwater (aquifers). Green water can be defined as that very significant proportion of water that is stored in the soil. There is a complicated interaction between green and blue water which depends on the factors (climate, topography, soil type, vegetation cover) and processes that control runoff to rivers and deep drainage to groundwater. It is the remaining green water that is available for evapotranspiration back to the atmosphere that is the critical water supply for rainfed cropping and pasture production.

Water Scarcity

The availability of water and access to water will be major issues for economic development and for the livelihoods of the poor, given that they often suffer most when resources are scarce.

Water scarcity can be described as being physical or economic in nature (Fig. 1).

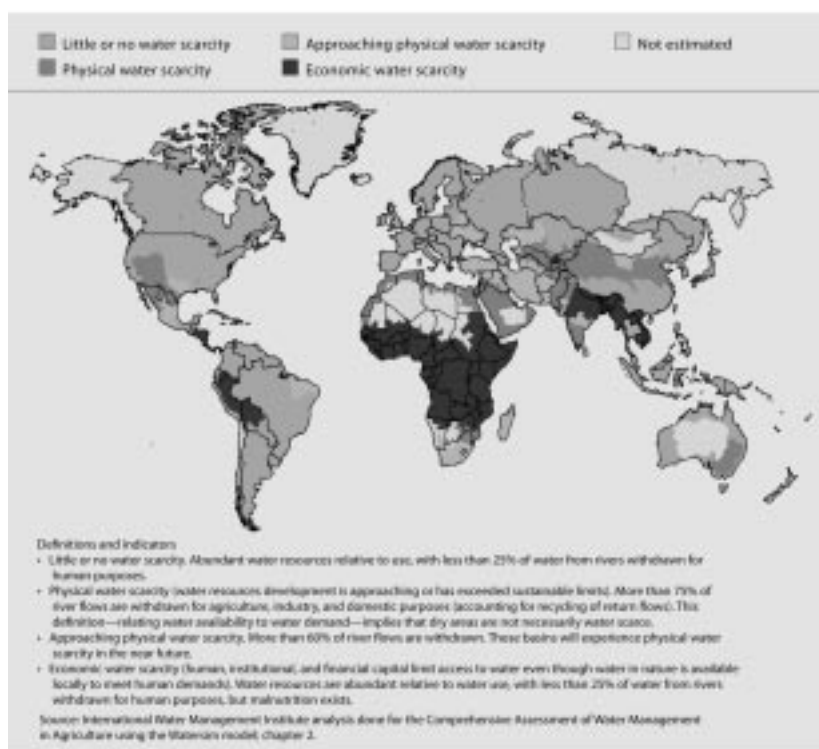


Figure 1. Global Water Scarcity in 2000

Physical water scarcity results from the allocation of virtually all available water supplies leaving nothing for additional use or for the future, or for the environment. It has become a reality for many regions. Much of south and west Asia, China, the Middle East, northern and southern Africa, southern Australia, and south western USA are in this category. Physical water scarcity will put increasing pressure on water planners and managers to develop ways to better manage their existing water resources, to increase the productivity of water, and to develop “new” sources of water, e.g. “reuse” of wastewater. Many countries have already seen water users turn to groundwater often not cognizant of the high degree of connectivity between groundwater and surface water.

There are however, many areas in the developing world, in particular in Sub-Saharan Africa and parts of Southeast Asia, where there are still available water resources, but development and use of these resources has been constrained by lack of capital investment, or appropriate institutions to support the use of that capital. The resulting “economic” water scarcity has major ramifications for the poor and economic development in general, and its solution has the potential to bring global benefits and reduce stresses on other water scarce areas. The issue of insufficient infrastructure development also relates to limited investment in wastewater treatment facilities and the consequent widespread pollution of clean surface water bodies. Whether in areas of physical or economic water scarcity, a critical factor for the future will be the impact of climate change and ongoing and potentially increasing climatic variability on the availability and use of water resources be it for drinking water, hydropower or irrigation. The impact of climate change will vary depending on geography and scale. In some areas, total rainfall and intensity will increase causing flooding, crop damage and erosion. In other areas, total rainfall may decrease, wet seasons become shorter and variability more extreme with greater frequency of droughts. Learning how to store water better and providing supplementary irrigation to make up for erratic rainfall supplies will be the key to overcome these challenges.

Drivers of Water Scarcity

The recent food crisis was driven by a number of factors including increasing demand due to population growth, increasing biofuels production at the expense of food crops, regional impacts of drought on agricultural water availability and changes in economic and trade policy in some countries.

If we look into the future with respect to water availability, not only continuing population growth, but also other factors including dietary change to more water thirsty foods, urbanization, increasing biofuel development and hydropower production will all lead to further pressure on water resources and the environment.

Population Growth Impacts

With respect to blue water Falkenmark (2008) defines a use to availability ratio (so-called criticality ratio) and “chronic water shortage” (level of water crowding). She indicates that already 1.4 billion people are living in areas where water is over-appropriated and that 1.1 billion of these people live in areas which are also suffering under severe water shortage. She further forecasts that by 2050, depending on the rate of fertility decline, the population in countries with chronic water shortages (above 1000 people per million cubic meters per year) will be 3 to 5.5 billion. To date, it has been the environment that has suffered as use to availability ratios rise. Whilst many ecologists would argue that a 40% ratio is a threshold above which ecosystem health is impacted, there are a growing number of major rivers that hardly reach the sea any more leading to the concept of “closed basins.” Included in this number for, example, are the Murray (Australia), Yellow (China), Krishna (India) and Colorado (USA). Population growth therefore represents the biggest single threat to water supplies and food production.

Dietary Change

On average, 1 calorie of food requires 1 litre of evapotranspired water to grow it. However, as large numbers of people in developing countries, particularly India and China, have grown more affluent, their taste in food has moved from diets dominated by grain and vegetables to consumption of more protein rich foods including dairy products and meat respectively. A diet without meat requires about 2000 liters of water per day to produce compared with 5000 liters per day for a diet high in grain-fed beef (Renault and Wallender, 2000). If we very conservatively use an average daily calorie intake of 2500, then to feed the 2050 world population of 9 billion, we will need to find an additional approximately 2,100 km³ of fresh water. This figure is undoubtedly conservative as it is based on a relatively low protein diet and minimal food wastage post farm gate.

Biofuel Production

The global financial crisis has seen oil prices tumble from US\$150 per barrel to US\$37-40 over the last 6 months. Whilst this will undoubtedly have an impact on the attractiveness of ethanol production, growing fossil fuel demand over the forthcoming decades will inevitably see demand for biofuels similarly increasing. So called first generation biofuels production derived from corn, beans and sugar, create competition for not only land, but also water. If ultimately this competition takes over 10-15% of agricultural land, the impacts on food production will be very significant. However there are many uncertainties on the future impact of biofuels on food production given current rates of return, concern that their production is no more greenhouse friendly than fossil fuels and the potential advantages of new technologies that will be able to produce biofuels from crop residues and other wastes.

Urbanization, Globalization and Other Factors

In 2008 the world saw a transition to from one in which more people lived in rural environments to one with more people in the cities and towns. Whilst the turnover point has not yet been reached in the developing world, it is likely to be inevitable in due course. Bigger cities with more industry clearly already compete with agriculture for water resources and this competition will increase. Furthermore, cities generally have political power and the wealth to purchase water from other users. Currently, many agricultural developing countries and developed countries/states such as Australia and California utilize 70% or more of their total available water resources in the agricultural sector. Even if growing urban demand only requires a redistribution of 5% of this water, this will have a significant impact on agricultural production on a global basis.

Globalization will also have a range of impacts on food production. These will include demand for luxury goods such as cut flowers creating competition for land and water in regions close to international airports, product sourcing policies of supermarket chains in developing countries and the recent phenomenon of large food importing countries wanting to buy up large tracts of land in developing countries for food production. Competition for water from the hydropower industry also means that water for agriculture is no longer available at the right place at the right time. All these kind of drivers may significantly impact food production in developing countries and have both beneficial and

adverse impacts on their populations. Lastly, the negative impacts of restrictive world trade policies cannot be overlooked as a factor that may, in countries with abundant water and food production potential, limit the development of their production and marketing capabilities and thus their capacity to contribute to world food production as times get tougher.

Increasing pressure to meet the Millennium Development Goals in terms of water supply and sanitation for the poor also compete for both the water resource and scarce financial resources in the water sector.

Finally, ongoing loss of agricultural land due to urbanization and industrial development and land and water degradation often the result of population pressure will both continue to destroy or reduce the productivity of agricultural land.

Climate Change Impacts

While more detailed regional and local studies are needed to improve understanding of just how climate change will impact food production, there are some ominous signs already appearing that give major cause for concern. Firstly, rainfall and runoff records from countries with Mediterranean climates, such as southern Australia and Spain and Morocco are already indicating that declines in rainfall of up to 30% may be expected with climate change. Studies are also indicating that in some environments for each unit decline in rainfall there is up to a threefold decline in runoff. Data from Central Asia, also suggest that in the long term (30-50 years), runoff from mountain snow melt may also reduce by at least 30%. In the some of the subtropics of Africa, rainy seasons are starting later, have more intense rainfall and are of shorter duration. Even in areas where rainfall is predicted to increase, increases in rainfall intensity may lead to more erosion and flooding. To what extent, such climate change and variability induced impacts on water availability may be compensated for by production being enabled in areas previously too cold for grains is uncertain, but an inescapable fact is that many of the world's poor live in the tropical and subtropical countries likely to be deleteriously impacted by climate change.

Solutions

The analysis of the drivers of water availability demonstrates that it will be foolhardy for any water users to overlook water availability issues in the future. Food crises caused by demand/supply perturbations inevitably impact the poor. Most of the world's poor live in South and East Asia and Africa. Many of the countries in the Asian region, but particularly Pakistan, India and China already have water availability concerns. At the global level, currently, about 7130 km³ of water are evapotranspirated (Figure2) by agriculture annually (Comprehensive Assessment of Water in Agriculture, 2007). Estimates suggest that with current levels of productivity this water requirement will increase by 70-90% by

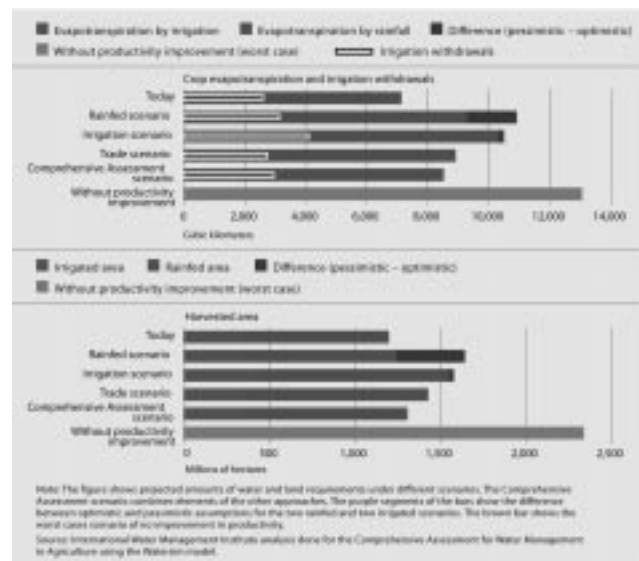


Figure 2. Water and land requirements to meet food demand in 2050 under different agricultural scenarios

2050 under current levels of water productivity. The vast volumes of freshwater (1500-6000 km³) dependent upon fertility decline and water productivity improvement) needed to increase food production are highly unlikely to come from simply increasing irrigation area. If we look at Asia, large areas are already under irrigation. In South Asia 106 m ha out of 200 m ha are under irrigation (Fig.3).

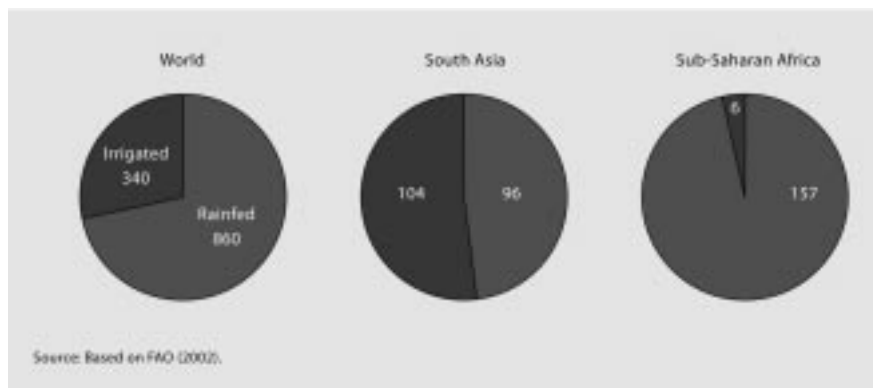


Figure 3. The proportion of harvested area that is irrigated

Furthermore, in South Asia and parts of China, there has been very significant expansion of groundwater irrigation over the last 30 years, with many major groundwater systems consequently under unsustainable extraction regimes. Consequently, with the exception of some smaller areas in South East Asia (e.g. Cambodia), increasing irrigation area will not be the major pathway to food production increases in this region of the world. Increasing water productivity in existing irrigation systems, is, however, a different matter and has to be one of the solutions required. Africa, presents a different picture and has more scope to increase irrigation with only 6 m ha out of 163 m ha currently irrigated. However, international financing for irrigation development has reduced dramatically over the last 20 years based on a perception that the green revolution has dealt with food production issues once and for all and more recently, on a perception that large surface irrigation schemes have not been very successful (hence the significant increase in privately financed groundwater irrigation schemes).

Whilst, food scarcity may see the financial pendulum swinging back to investment in surface irrigation, increasing the productivity of rainfed agriculture must be considered as a sound strategy by governments. The key questions are how can this be achieved in the face of a number of limiting factors including low soil fertility, poor water management practices and often limited human capacity manifest in poor farming communities? These issues notwithstanding, a number of options are available. According to the Comprehensive Assessment of Water Management in Agriculture, these include:

- Improving productivity through enhanced management of soil moisture and supplemental irrigation where water storage is feasible;
- Improving soil fertility management, including the reversal of land degradation; and
- Expanding cropped areas.

If these measures are combined with increasing the productivity of irrigated areas, ensuring that agricultural trade within and between countries is not impeded, reducing food demand by influencing diets and minimizing post-harvest losses including industrial and household waste, they can have a major impact on improving food production.

The Comprehensive Assessment of Water Management in Agriculture modeled a scenario that assumed zero growth in irrigated areas, which showed that rainfed agriculture could meet the increase in food demands projected for 2050. This optimistic scenario had cereal yield increase by 72% and harvested rainfed area increase by only 7%. This scenario would lead to Sub-Saharan Africa, Latin America and most of Asia being largely self sufficient in producing major food crops, with the exception of maize in east Asia. A more pessimistic scenario that included only modest yield improvements saw rainfed area increasing by 53% to meet future food demands. However, this scenario required countries without available land and/or reliable rainfall to significantly increase food imports. Under this scenario world

trade in food would expand from 14% of production today to 22% in 2050. Potentially, there is the land available to increase production even under the pessimistic scenario, but the extent to which it has better than marginal production capability and the extent to which climatic factors including rainfall uncertainty would limit potential production is uncertain.

The next question to ask is whether the modeled changes could realistically be achieved given current climate and other factors? Both optimistic and pessimistic scenarios call for substantial increases in soil water consumption. For the optimistic scenario with little expansion of rainfed area, improved water management, including small amounts of supplementary irrigation, is a prerequisite for yield increases. This will require more evapotranspiration, part of which can be offset by increasing water productivity by improving the harvest index, by reducing losses from soil evaporation, or by increasing transpiration while reducing evaporation.

The optimistic scenario sees rainfed cereal production improve by 72% with a concomitant increase in water productivity of 32% compared with 20% and 10% respectively in the pessimistic scenario. In total, compared with the year 2000, each scenario would use an additional volume of water of 2150 km³ and 3850 km³ respectively. It is highly probable that increase of water consumption of these magnitudes will have major impacts on river flows and groundwater recharge in most areas, so the optimum pathway would be to follow the optimistic scenario.

Obtaining a 35% increase in water productivity in rainfed agriculture is, however a daunting task. It will require major rethinking of the way in which governments and society view agriculture in general. It will require much better knowledge about soil types and soil water and soil structural management to maximize water availability. It will require major investment in capacity building of farmers and other players in the food production chain. It will require governments to pay very significant attention to developing policy settings that promote agricultural productivity increases that build on knowledge and capacity development as opposed to subsidizing particular aspects of agriculture such as fertilizers. It will also be imperative that investment levels for research and development are stepped back up to levels that they were at the time of the green revolution in order to overcome the very significant challenges facing yield and productivity improvements across the agronomic-water interface. Finally, it will require innovative thinking by all concerned to optimize the best production systems for given environments that also pay attention to maintaining the provision of ecosystem services.

Conclusions

This paper set out to examine the role of green water and rainfed agricultural production in facilitating the major production increases required to feed the world's growing population. The data presented suggests that rainfed agriculture, because of its widespread predominance, will have to significantly increase its productivity if this is to be achieved. However, the increases are potentially attainable in terms of available land and water resources. However, in some closed river basins any increases in green water use will have serious impacts on other sectors of the economy and the environment. In reality, we have to strive for greater green water productivity as well as developing new irrigation schemes (particularly in Africa) and ensuring policy settings are conducive to the trade of virtual water. The sheer numbers of people wanting to be fed by 2050 mean that the challenge for the agricultural community will be immense and this needs to be recognized by governments across the world in terms of their preparedness to invest in agriculture and natural resource management at hitherto unforeseen levels.

References

- Comprehensive Assessment of Water Management in Agriculture 2007. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. London: Earthscan and Colombo: International Water Management Institute.
- Falkenmark, M. 2008. Peak Water – Entering an Era of Sharpening Water Shortages. *Stockholm Water Front*. Dec. Issue, 10-11. Published by SIWI (www.siwi.org).
- Renault, D. and Wallender, W.W. 2000. Nutritional Water Productivity and Diets. *Agricultural Water Management* **45**, 275-96.

Global Conventions and Partnerships: Their Relevance to Conservation Agriculture

R.S. Paroda

Chairman, Trust for Advancement of Agricultural Sciences (TAAS), IARI Campus Pusa New Delhi, India, Executive Secretary, Asia Pacific Association for Agricultural Research Institutions (APAARI), FAO Regional Office, Bangkok and Ex-Director General, Indian Council of Agricultural Research (ICAR) & Secretary, Department of Agricultural Research & Education (DARE), Government of India, New Delhi

Since time immemorial, mankind has been relying on farming and natural resources to meet the basic needs of life. Unfortunately, the unprecedented increase in human population during past half century, from 3 billion during 1960 to currently 6 billion, is further expected to grow to 8.5 billion by 2025. Therefore, satisfying the increasing demands for food and other commodities, agriculture sector will have major challenge of improving productivity from same or even less land and other natural resources. Estimates suggest that since 1945, about 23% of the 8.7 billion hectares of global agricultural land, permanent pastures and forests have been degraded. Much of the degradation is mainly taking place on agricultural lands- 74% in Central America, 65% in Africa, 45% in South America and 38% in Asia (Pandya-Lorch, 2000). The study by the UN Food and Agriculture Organization (FAO) led project on Land Degradation Assessment in Drylands (LADA) indicated that an estimated 1.5 billion people depend directly on land that is degrading. Another recent study by FAO, United Nations Environment Programme (UNEP) and World Soil Information, indicates that land degradation is worsening rather than improving, with declining trends revealed across some 24 per cent of global land area. According to this study, the main driver of degradation is poor land management. The study also shows improvements towards sustainable land management, with 19 per cent of crop- and grassland and 10 per cent of forests being managed sustainably or showing improved quality and productivity. The overall picture, however, reveals that land degradation requires renewed attention by individuals, communities and governments through innovation programmes and partnerships. Conservation Agriculture (CA) is also an innovative approach that helps in reducing soil erosion, improves water use efficiency as well as soil health, helps in carbon sequestration, minimizes use of energy and above all improves productivity and income of resource poor farmers (Lal, 1997, 2004). Hence, CA has become a global movement towards sustainable agriculture. This paper summarizes a brief history and future plans of Global Initiatives through Conventions, Congresses and Partnerships for forestalling the degradation of natural resources through adoption of Conservation Agriculture (CA) practices for sustainable development, food security and poverty alleviation.

I. Global Conventions

In view the challenges of resource degradation owing to increasing population pressure, the global community came forward to address this concern through a series of Conventions. The first coordinated effort to revert the process can be traced back to the Stockholm UN Conference on the Human Environment held in 1972, wherein 113 nations adhered to "safeguard and enhance the quality of land and environment". The creation of UNEP in 1973, based in Nairobi, Kenya is one of the major outcomes of the Stockholm Conference. Thereafter, UNEP sponsored a conference on desertification (UNCOD) in 1977 at Nairobi, wherein a world plan of action to combat desertification (PACD) was adopted.

The available information at the time showed that productive land is lost at the rate of 600,000 hectares/year, and that productive land area prone to desertification is about 300 million hectares extending over 100 countries. The cost of productivity lost per year is around US\$ 25 billion, whereas the needed resources to avert this loss is US\$ 2.4 billion per year for the next 20 years. Unfortunately, there was not much progress on the implementation of the recommendations of the PACD, since it was not a binding document and the financial resources allotted to desertification control activities within the international aid schemes were quite limited. At the same time, the national governments in many concerned countries did not include desertification control activities within their development plans. The UNEP assessment for the period 1984 to 1992 showed that desertification was still spreading and that the world effort to combat it was short of being effective. It was estimated that income forgone due to desertification was around US\$ 42.3 billion/year.

In view of the gravity of the problem, the whole issue was discussed in the UN Conference on Environment and Development (UNCED), also known as 'Earth Summit', held in Rio de Janeiro, Brazil in 1992. The Conference produced an action oriented document known as "Agenda 21" - a global blue print for environmental action that revolved around seven themes, one of which is "efficient use of natural resources of land, water, energy, forests and biological resources" and calls on countries to adopt national strategies for sustainable development (NSDS) that should build upon and harmonize the various sectoral (economic, social and environmental) policies and plans that are operating in the country. This is unquestionably the theme for the survival of humanity and for the sustainability of future agriculture. But, it seems that the time is running out and the implementation of this agenda is still a pious hope.

In this endeavor, the National Research Council, National Academy of Sciences, USA in its report on "Our common journey- a transition towards sustainability" concluded that human needs over the next two generations can be met while sustaining the earth's life support systems. But this will require the political will to support the creation of new knowledge through science and technology and a commitment to turn that knowledge into action (National Research Council, 1999). The report sets forth a new research agenda for sustainability science and calls for a linkage of scientific research and private actions to public policies. The report also outlined the greatest threats to sustainability and several priorities for action over the next two generations. Subsequently, the UN General Assembly resolved in the same year to establish an Intergovernmental Negotiating Committee for the Elaboration of an International Convention to Combat Desertification (INCD) and an acceptable convention was reached by consensus in Paris in June 1994 named as United Nations Convention for Combating Desertification (UNCCD). It comprised a framework of general principles and an operative instrument which includes four different Annexes for Africa, Asia, Latin America, and the Northern Mediterranean Countries. The convention placed strong emphasis on a "Bottom-Up" approach and the role of local participation in decision making. For this innovative and complicated process to work, awareness campaigns were organized to inform people at all levels about the new opportunities of the convention, thus resulting in global awareness of "Agenda 21- a comprehensive programme for global action in all areas of sustainable development". In evidence to these commitments, governments signed three legally binding conventions, the United Nations Framework Convention on Climate Change (UNFCCC), UN Convention on Biological Diversity (UNCBD) and Convention to Combat Desertification (UNCCD). The CBD set into motion the actions to place biodiversity at the centre of global, regional and national efforts for sustainable development and poverty eradication.

Subsequently, in 2002 the World Summit for Sustainable Development (WSSD), held in Johannesburg, South Africa urged states not only to take immediate steps to make progress in the formulation and elaboration of national strategies for sustainable development (NSDS) in terms of its five elements i.e. water, energy, health, agriculture and biodiversity (WEHAB) but also to begin their implementation by 2005. In addition, integrating the principles of sustainable development into country policies and programmes is one of the targets contained in the United Nations Millennium Declaration to reach the goal of environmental sustainability. In his regards, the eight Millennium Development Goals (MDGs) were set for sustainable development, wherein agriculture has an important role to play in meeting the three of these eight MDGs- (1): eradicate extreme poverty & hunger, (7): ensure environmental sustainability and (8): develop a global partnership for development. As a result of WSSD, Global community is currently paying renewed attention towards sustainable development for inclusive growth and better livelihood of resource poor people around the globe.

II. Global Congress on Conservation Agriculture

The Food and Agriculture Organization of the United Nations has been supporting the Conservation Agriculture movement globally in partnership with Consultative Group of International Agricultural Research (CGIAR), National Agricultural Research Systems (NARS) of different nations as well as other non-profit organizations. In this endeavor, the First World Congress on Conservation Agriculture (WCCA) was organized at Madrid, Spain during October, 2001 jointly by the FAO and the European Conservation Agriculture Federation (ECAAF) wherein 70 countries shared the experiences on CA especially for resource conservation and improving the livelihoods. The following action plan was developed:

- A discussion forum should be quickly set up within the framework of FAO's Conservation Agriculture Workgroup to facilitate and strengthen international exchanges, while avoiding invasive information,

- Subsequent contributions should be prepared for international conventions and events, such as the Agenda 21 and its conventions {Commission on Sustainable Development (CSD), UNCCD, UNCBD, UNFCCC}, the World Summit on Sustainable Development (WSSD), and
- A special synergy with the Kyoto Protocol should also be examined so that carbon sequestration via Conservation Agriculture could become a substantial incentive for its wider adoption.

Subsequently, the Second WCCA was organized in Brazil during August, 2003 with the theme of *“Producing in Harmony with Nature”*. This Congress endorsed the declaration of the First WCCA and noted the remarkable advances made in the two years and came with the agreement that:

- Integration of CA practices with balanced and efficient application of modern agricultural methods is the principal road to sustainable agriculture leading to food, nutrition, economic and environmental security.
- CA can achieve food security by reversing soil degradation, reducing agrochemical use and contamination, improving food quality, and conserving, preserving and enhancing the quality of natural resources and biodiversity while increasing farmer’s net income and competitiveness, and sequestering carbon from the atmosphere.
- CA is applicable to all sizes and types of farms and to all crops.

In this series, the Third WCCA was organized during October, 2005 by African Conservation Tillage network (ACT), Ministry of Agriculture of the Republic of Kenya and Kenya Conservation Tillage Initiative (KCTI) in association with New Partnership for Africa’s Development (NEPAD) on the theme *“Linking Production, Livelihoods and Conservation”*. The highlights of the congress were:

- It was felt strongly that CA contributed remarkably to poverty alleviation, food security, mitigating impacts of HIV-AIDS, natural resource management, and farmers’ prosperity; and it is environmentally friendly farming system.
- In the development and adoption of CA, farmer participation should be empowered
- The multi-discipline/multi-stakeholder approaches, networking and collaboration (e.g. policies to interest/ facilitate private sector involvement) should be encouraged for innovative developments in CA and their wider scale adoption.
- CA should be linked with other global initiatives on sustainable agriculture and rural development.
- The Congress specially highlighted Africa’s state of affairs with regard to issues and concerns including farmers’ priorities for enhanced adoption of CA practices.

The current WCCA, which is Fourth in the series is being organized at New Delhi jointly by the Indian Council of Agricultural Research, Ministry of Agriculture, Government of India, National Academy of Agricultural Sciences (NAAS) of India, International Center for Agricultural Research in the Dry Areas (ICARDA) and FAO. It is indeed a timely and very important initiative. The theme this time is *“Innovations for improving efficiency, equity and environment”* which covers wide range of the Millennium Development Goals that are directly related to agriculture.

III. Global Partnerships

To address the issues of resource degradation, poverty alleviation and more recently climate change, various partnership programmes have been initiated by the global community. The partnership initiative on CA has emerged as one of the important strategy for meeting the challenges of MDGs and is currently being adopted on nearly 100 million hectares globally (FAO, 2008) with many success stories. In this respect, the Brazil has set a successful example of partnership for averting the events of serious soil erosion and land degradation through CA and took concrete initiative in 1962. In Brazil, CA emerged mainly as a result of partnership among farmers, input supply companies, state and federal research and extension organizations, universities, as well as long-term funding commitments from international donors such as the World Bank and German Technical Cooperation (GTZ). With new innovations through partnerships among CA champions, covering nearly 25 million hectares in Brazil, almost 45-60 % of agricultural land could be managed presently in South American countries (Derpsch, 2001). Similarly, in Sub-Saharan Africa, the Africa Conservation Tillage Network (ACT), established in 1998 to promote CA as a sustainable means to alleviate poverty, make effective use of natural and human resources and reduce environmental degradation has been a major champion for the establishment of a Pan African Network with global links and is currently active

in technology development, networking, information exchange and policy advocacy (ACT, 2003). A few successful examples of partnerships related to conservation agriculture both at the regional and global level are mentioned here:

- In Asia, the intensively cultivated irrigated rice-wheat systems are fundamental to employment, income and livelihoods of hundreds of millions (Paroda et al, 2004), wherein evidences of exhausting the natural resource base under continuous intensive systems during post-Green Revolution period have also emerged (Gupta and Seth, 2007). Rice-Wheat Consortium (RWC) for the Indo-Gangetic plains of South Asia, an eco-regional initiative of the World Bank and subsequently CGIAR involving NARS of India, Pakistan, Bangladesh and Nepal was established with a goal to maintain food security and improve livelihoods of the farmers mainly dependent on rice-wheat production system focused specifically on deployment of resource conserving technologies (RCTs). For co-ordination of this eco-regional program, CGIAR provided annually around US\$ 250000 since 2003. This program had also been supported under the National Agricultural Technology Project (NATP), by the Indian Council of Agricultural Research (ICAR) by allocating around US\$ 1.5 million for a mission mode project on CA. With these investments and strong partnership and an innovative farmer participatory approach, the CA programme facilitated by International Maize and Wheat Improvement Centre (CIMMYT) in its version of RCTs, has now been extended nearly to 3 million hectares in South Asia (RWC, 2006, Gupta and Sayre, 2007). This success story of a regional initiative, involving global partnership, is known globally and had also received 'King Boudouin Award' from the CGIAR.
- A Global Partnership Program (GPP) on Direct Sowing, Mulch based and Conservation Agriculture (GP-DMC), an international initiative by Global Forum on Agricultural Research (GFAR) was launched in January 2000 and a Facilitation Unit was established, with support from CIRAD at Montpellier, France with the aim to strengthen the capacity of key stakeholders to develop suitable conservation agriculture systems and to accelerate their wide adoption in more than 40 countries with the support of stakeholders like CIRAD, CIMMYT, Agronomy Institute of Parana, Brazil (IAPAR), FAO, International Fund for Agricultural Development (IFAD), GTZ etc. Somehow due to resource constraint this initiative could not take off. Considering the importance of CA, GFAR facilitated in July, 2008 a working group discussion on research aspects of CA facilitated by CIMMYT, FAO and CIRAD. It reviewed the achievements of CA globally and actions required to accelerate the adoption of CA-based farming systems. A specific recommendation was made for the creation of a global partnership programme (GPP) as a cluster or network of inter-connected Communities of Practices (CoPs) with the aim to put in place and make operational a global initiative to promote CA for its large scale adoption in remaining potential areas. This way, a global focal point for CA would facilitate the operation of an international network aiming mainly at the application of CA for knowledge, advocacy, education and sustainable agricultural development. This GPP on CA, under the umbrella of GFAR, would aim to have a multi-functional website and a multi-disciplinary register of CA expertise. The major focus would be on knowledge sharing, capacity building and partnership building for faster adoption of CA practices for greater impact.
- Central Asian Countries Initiative for Land Management (CACILM), a multi-country and multi-donor partnership, was initiated in 2003 to support integrated and consistent approaches for investing in sustainable land management (SLM) practices in each of the countries of Central Asia over a period of the next 10 years. The ten-year investment program is divided into three phases (2006-08, 2009-13, and 2014-16, respectively) and its initial structure envisages a total investment of about US\$75 million partly by the Government and donors (including a co-financing by GEF of about US\$14 million) to complement investments made by the Program's target beneficiaries. This programme is expected to increase over time the CA activities in the region, for which great potential exists.
- The Forest Carbon Partnership Facility (FCPF) announced its expansion from 20 to 30 developing countries to support capacity building efforts to reduce greenhouse gas emissions by reducing deforestation and forest degradation (REDD). Developing countries are working with 11 industrialized countries and one non-governmental organization through this innovative partnership and international financing mechanism to combat tropical deforestation and climate change. The FCPF is comprised of two components- a Readiness Fund and a Carbon Fund. The World Bank acts as the secretariat for the FCPF. Its focus is to promote CA practices in protected forest to arrest soil degradation,

The global conventions and partnerships discussed in this paper are mainly focused on the land degradation, poverty alleviation, climate change and over all sustainable development. The conservation agriculture strategy

aimed to revert the land degradation, improve carbon sequestration and reducing GHG emissions has a direct bearing on the MDGs. Therefore, various conventions and partnerships, aimed mainly to promote conservation agriculture practices, have helped greatly in managing our natural resources for sustainable development. Concerted efforts are, however, needed to promote CA globally in order to reap much greater benefits in the future.

References

- ACT. 2003. Newsletter, 21 November, 2003. Harare: University of Zimbabwe and the African Conservation Tillage Network.
- Derpsch, R. 2001. Frontiers in conservation tillage and advances in conservation practice. P. 248-254. In: DE Scott, RH Mohtar and GC Steinhardt (eds). 2001. *Sustaining the global farm*. Selected papers from the 10th International soil conservation organization meeting held may 24 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.
- FAO, 2008. Food and Agriculture Organization of the United Nations, AQUASTAT 2008
- Gupta RK, and Seth A. 2007. A review of resource conserving technologies for sustainable management of the rice-wheat cropping systems of the Indo-Gangetic plains. *Crop Protection*, 26: 436-447.
- Gupta, RK and Sayre, K. 2007. Conservation agriculture in South Asia. *Journal of Agricultural Science*, Cambridge, 145: 207-214.
- Lal, R. 1997. Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO₂-enrichment. *Soil and Tillage Research* 43, 81-107.
- Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304, 1623-1627.
- National Research Council. 1999. Our common Journey a transition towards sustainability. Board on Sustainable Development, National Research Council of USA. National Academy Press, Washington, DC, 363 pp.
- Pandya-Lorch, R. 2000. Assuring food security and sound management of natural resources for the 21st century: the role of agriculture. (in): Proceedings of First International Agronomy Congress on Agronomy, Environment and Food Security for the 21st Century, 2000. Panjab Singh, R. Prasad and IPS Ahlawat (eds). Indian Society of Agronomy, IARI, New Delhi, India.
- Paroda RS, WoodHead T, and Singh RB. 1994. Sustainability of rice-wheat production systems in Asia. RAPA Publ. 1994/11, Bangkok : FAO.
- Rice-Wheat Consortium (RWC). 2006. Research highlights 2005. Rice-Wheat Consortium for the Indo-Gangetic plains, 12th Meeting of the Regional Steering Committee of RWC, Varanasi, Uttar Pradesh, India.

Impact Analysis of Conservation Agriculture

S.S. Johl

Conferences, workshops, seminars, brain storming sessions etc. very often end up in written proceedings only. In most of the cases recommendations made and decisions taken do not get translated into field level actions or only symbolic actions are taken on a limited scale. It seems the Indian agricultural extension system is still suffering from the hangover of colonial past, wherein, “*please the boss*” remained guiding principle of the field level workers. A few well structured demonstrations, which may not have much impact or spread effect on the neighboring areas, are placed as show cases that create an ambience of action and adoption, wherein “*boss-subordinate relations*” do achieve some level of optimality.

Impact analysis or assessment is, unfortunately, the last priority that enters into the calculations of our policy makers and research administrators. There is lack of an explicit and effective built in system even in the country's National Agriculture Research System that would provide a reliable feed back on the effectiveness and impact of the research results when adopted on farmers' fields. Sporadic reports by individual investigations and organizations such as universities and research centers, do emerge that more often than not get consigned to the “*seen and file*” category and are seldom looked at again. These evaluations are not made an integral part of the research system to serve as eyes and ears of the research administrators or programme implementers. Such reports, based on well planned assessment, should serve the crucial purpose of reviewing the impact of research output on a continuous basis and these feed backs should be used to correct the pathways adopted in order to steer the research and extension programmes for optimal results.

Often the amounts spent under given heads out of the allocated funds are treated as achievements. This approach is wide spread in the extension and development activities of the government departments. For instance, the forestation and tree planting programmes end up with number of saplings planted and money spent. It is rare that survivals are checked/counted and financial and economic costs per plant or per hundred *surviving plants* are worked out after one, two or three years. It is sometimes noted that annual tree planting programmes like *Vanmahutsavs* get repeated at the same place. Similarly, demonstration plots are arranged on the same farms year after year with little impact on the neighbouring farms. Many often defective technologies are pushed through with the help of subsidies which in true sense do not find favour even with the farmers on whom these are directed.

The appropriate, useful and profitable technologies in fact need very little effort for their promotion. End users grab these opportunities spontaneously. I recall at one time the farmers stole a wheat variety seeds from the fields of the Punjab Agricultural University at gun point. Such research outputs get popularized within short time. Yet such examples are very few. Most of the appropriate technologies catch up within a couple of years and not-so-good technologies remain confined in their spread and fade out very soon.

In research, results do get evaluated at the level of departments and institutions. Even here, research outputs such as varieties, techniques, implements and other innovations are not evaluated or assessed that rigorously for their impact in respect of the extent of adoption, financial and social costs and returns, environmental impact and sustainability concerns. For instance, breeders generally get satisfied with the release of their varieties. Whether these are adopted by the farmers or not and to what extent, such aspects seldom get into their calculations. If research output does not catch up at the adoption level or fades out sooner than expected, the “*why*” is seldom inquired into. What economic, social and/or environmental impact it leaves, remains of little concern.

Not to speak of research and extension in the field of agriculture, the state level planning also suffers the same debilitations. Governments, both at the center and states, in the plan implementation consider the ‘*money spent*’ out of plan allocations as their achievements. It is not that provisions do not exist for making impact analysis or the assessment of physical output and externalities involved. In fact, quite a number of evaluation reports are written. The problem is that these evaluations do not make any dent on the mindset of the policy makers, planners and administrators. The caravan moves on at its own pace and in the same direction. This system, or lack of it, needs to be drastically revamped, reoriented and redirected at achieving optimality in the expected results and properly weighed against financial and economic costs along with positive and negative environmental externalities involved.

In the back ground of this scenario, the conservation agriculture practices and techniques need to be assessed in terms of enhancing/developing conservation and improvement in the use-efficiency of production resources in quantity and quality in order to provide sustainability to the production process on an upwards shifting production curve driven by the positive effects of improved techniques and technologies. The conservation practices have to be viewed in an all inclusive manner involving soils, water, environment, efficient use of resources, economic viability, equity issues and social implications. Our perception of conservation agriculture most of the time begins and ends up in zero tillage, because the practice has been accepted on a visible scale. As a result, other practices such as leveling, bunding, mulching etc, seem to have been put on the back burner and are operative at the level of demonstration plots mainly, that are maintained by the extension agents mostly at public cost as show pieces. No doubt zero-tillage has its own advantages in terms of savings on labour, costs and time, yet the purview of conservation agriculture goes much beyond soil and zero tillage *per se*. The Conservation Agriculture technologies must be synchronic in nature and more inclusive. Only then such techniques will come up with perceptible impact.

I would like to adduce a few examples of conservation agriculture practices, which deserve serious attention of National Agricultural Research System and Extension agencies. These technologies are amenable to impact assessment on the aspects of conservation and sustainability of resource use as well as their impact on soil health, water conservation, environment as well as economic viability for the farmers. Being size neutral, these are equitable in their impact.

First is aerobic cultivation of rice. Rice crop growing in ponded fields has serious negativities for soil quality, excessive application of scarce water and degradation of environment. On equity ground the system is less favourable for the areas and regions that have lower or limited water availability and also for small and marginal farmers, who either do not have their own means of assured supply of irrigation water or with heavier over head costs per unit of land used, it becomes comparatively more costly for them to grow rice under ponded conditions. There are a few alternative techniques developed by the Agricultural Technocrats in Punjab and by some scientists elsewhere, specially at Bangalore, which I have seen a bit more closely. From dribbling the paddy seeds or transplanting seedlings in *flat fields* in proper moisture to dribbling/pouring the seed or transplanting seedlings on *bed-furrow* or *ridge-furrow* systems have all proved reasonably successful. These systems result in: (1) Water savings between 30 to 60 percent, because of controlled applications of water. A soil scientist at Punjab Agricultural University has estimated 66 percent saving of water in ridge-furrow system. In rainy season these techniques rather harvest the water and crop does not need to be irrigated for long periods. (2) the soil quality improves because no puddling is required to pond the water constantly. These techniques check the formation of hardpan in the soil. (3) Earthworms develop in the soil. (4) Micro-climate remains comparatively dry which lowers the incidence of insect pests and diseases.(5) Emission of green house gasses, specially CO₂ and methane decreases drastically with favourable impact on environment. (6) Being size neutral, the systems are equitable for the small and marginal farmers. (7) There is considerable savings on labour required for transplanted. Since this operation of transplanting rice in standing water involves considerable proportion of female labour, these systems reduce the drudgery of work and is therefore in a sense gender favourable also.

Major problem of these systems of aerobic cultivation has been of weeds. However, pre-emergence and post emergence weedicides have now been developed/identified, which have tackled the problem completely. On yield, the average of twelve trials at the Punjab Agricultural University have indicated 7 percent higher yield compared to the paddy grown in standing water. These techniques are catching up fast with the farmers. Most accepted and updated technique today is that the field is prepared like the one is prepared for sowing of wheat with good moisture. The paddy seeds are broad cast and ridges and furrows are drawn two feet apart. While the field is in good moisture pre-emergence weedicide is applied. The field is left as such for the seeds to germinate. Normally no water is applied up to at least 15 days. As the plants show signs of stress, water is applied in the furrows. The frequency of the water application is at intervals of 7 to 10 days. In case of adequate rain, water is not applied for long periods. Rather the field remains in good shape to harvest the rain water. Post-emergence weedicide is applied only once at a threshold point, normally after thirty days of emergence. Weeds in that case serve the purpose of mulch, which further reduces the need for irrigation. Within a very short span of a few years the technology is expected to catch up with the farmers with perceptible positive impact on soil health, water use efficiency, environmental improvement, and economy of rice cultivation on an equitable basis. However, there is a need to develop reliable system of impact assessment within the National Agricultural Research System that works at the field level in respect of spread of such conservation techniques and positive and/or negative externalities that impact the farm economy, sustainability of production resources and agro-ecological environ of the country side. Some pictures of the system described above are attached as appendices.

The second, I would like to mention about is organic farming and traceability systems. There are many organizations, companies and individuals that are propagating organic farming of various shades. Yet there is no system in place that can reliably assess their results and impact on productivity, production, the farm economy, environment and sustainability of resource use. I have tried to look into the details of one such attempt being made by a company named International Sustainability Systems in collaboration with National Horticulture Mission, Indian Institute of Technology, New Delhi and INDOCERT. They have brought some fifteen thousand hectare of land in Utter Pradesh and three thousand hectare in Punjab under their system of organic farming. They prepare two cultures of micro-organisms isolated from the soils they take under their system. The cultures of micro organisms from soil isolates are prepared in collaboration with IIT New Delhi. The two cultures, *inter alia* contain the following organisms. Some other area specific organisms are also incorporated in these two cultures. Culture-I is primarily for fertilization and control of diseases like root rot, stem rot, leaf rot and soil borne as well as seed borne pathogens of the crops. Culture- II contains bio-pesticides against insect pests and bacterial diseases.

Culture-I Contains

- i) *Azotobacter spp*
- ii) *Rhizobium*
- iii) *Azospirillum spp*
- iv) *Bacillus megaterium var. phosphaticum*
- v) *Frateuria aurentia*
- vi) *Paecilomyces lilacinus*
- vii) *Trichoderma harzianum*
- viii) *Trichoderma viride*
- ix) *Pseudomonas fluorescens*

Culture – II contains

- i) *Metarrhizium anisopliae*
- ii) Nuclear polyhedrosis virus (NPV) of *Spodoptera litura*
- iii) Nuclear polyhedrosis(NPV) of *Helicoverpa armigera*
- iv) *Verticillium lecanii*
- v) *Baillus thuringiensis var. kustaki*, Steriotype H-3a, 3b, strain z-52
- vi) *Beaveria spp*

For application of First Culture, a one kg packet of the culture is mixed in water with one kg of jaggry (Gur) and one kg gram (chickpea) flour. This mixture is then mixed with one quintal (100 kg) of cow dung and covered for seven to eight days. The culture prepared this way is sufficient for one acre of crop. This culture replaces the chemical fertilizers and controls the soil and seed born diseases as well as nematodes and root, stem rots. With this culture six to eight tons of farm yard manure is required per hectare of land for one year crop rotation. Thus, organic production can be extended to the extent the farm yard manure is available for application in the fields at this rate. The second culture is prepared the same way and put in drums of water. Some leaves of Neem (*Azadiracta indica*) trees, Ak () and/or Dhatura () plant. (if available) are added to this culture. Water is decanted and then cleaned of suspensions and applied as spray on crops. This culture is claimed to be controlling all the insect pests of crops, except weeds. The culture-1 is claimed to have controlled even Phyto-pathora of citrus plants and revives the plants if applied in early stage of the disease.

Their approach involves small farmers and small areas under the crops. Clusters of some 50 farmers with around 50 hectare of crop land are formed and a cluster- in-charge is made responsible to train, guide and monitor the activity. A printed note-book is provided to the registered farmers, who are required to note down whatever they do to the field and the crop registered. Every farmer is assigned a code number in record with the National Horticulture Mission. Some samples of clusters in Utter Pradesh and Punjab are given in appendices. The area/crop under organic farming is marked as C1 in the first year (Under Conversion year one), C2 in the second year and C3 in the 3rd year. Internal control is exercised by the ITS and external control and verification is done by the INDOCERT. Organic production is certified only after three years. In the first year and second year the farmer can, on his own. make a statement that, “*No chemical fertilizers or pesticides are used in this product*”. This statement is not, however, certified by the ITS/Indo-cert. The economic analysis of some the crops of the farmers in Punjab, who adopted organic farming is produced in the appendices.

It is observed that the system adds to the organic carbon content of the soils that are put under the system year after year. One year analysis is given below:

I.D Number	Farmer's Name	Village	Crops	Organic Carbon before crop	Organic carbon After crop	Difference*
INPBHO08ORG01	Lakhwinder Singh	Bhikhwal	Kinnow- Inter crop: Tinda, Maize, Potato	0.65	0.72	0.07
INPBHO08ORG05	Jagir Singh	Bhunga	Kinnow-Inter Crop: potato maize	0.30	0.75	0.45
INPBHO08ORG52	Mohinder Singh	Hariana	Potato, Maize, Peas	0.45	0.69	0.24
INPBHO08ORG79	Mandeep Singh	Bohn	Potato, Chillies, Carrot	0.39	0.66	0.27
INPBHO08ORG141	Gurdeep Singh	Kantian	Kinnow	0.51	0.69	0.18
INPBHO08ORG300	Santokh Singh	Chak Gujran	Potato, Maize, Peas	0.60	0.75	0.15

Source: Analysis was got done from the Punjab Government Laboratories.

*Difference in organic matter was worked out on the basis of soil analysis done before the start of the Organic farming programme in Nov.-Dec. 2007 and after the crop rotation was over in Nov. 2008

The analysis is indicative of the improvement in organic content of the soils through adoption of organic farming. The strong point of this system is that micro-organism are the isolates from the regional soils and are mostly area/location specific and multiply quickly in the environ they belong to. Second important aspect is that micro-organism multiply quite speedily in the highly conducive medium created by the mixture of cowdung, jagary and gram flour, which makes it possible to apply the useful micro-organisms culture in the field in substantial quantity.

The ITS and their collaborators have a programme of introducing traceability through preparing and issuing of bar codes that can be pasted on fruits and vegetable packets and even on individual fruit like Kinnow, mango or apple, which can go a long way in fetching higher price in the high end national and international markets.

Yet, this system of organic farming and other ones propagated and promoted by various organizations and NGOs need to be evaluated on a continuous manner through a recognized and accredited system created within the National Agricultural Research System at the central and state levels through the ICAR and the State Agricultural Universities. Unfortunately the Organic Farming approach, which has a potential to revive the soil health, improve agro-ecological environment, save on input costs, realize higher prices of the organic products and improve nutritional security are often out rightly rejected by the scientists of the National Agricultural Research System of the country. There is, therefore, also a dire need for change in the mind set of agricultural scientists of the country in this respect.

Theme 1: Resource Productivity and Efficiency

Session 1.1: Soil and Residue Management

No-Till System Applied to Northern Africa Rain-Fed Agriculture: Case of Morocco

Oussama EL GHARRAS¹, Azeddine EL BRAHLI² and Mohamed EL MOURID³

¹Ag. Eng. Laboratory, INRA-Settat, P.O. Box: 589, Settat, 26000, Morocco (Email: o_elgharras@yahoo.fr)

²Weed Scientist, Consultant, Rue 11 Janvier, Al Kahir, Settat, 26000, Morocco (Email: aelbrahli@hotmail.com)

³Regional coordinator North Africa-ICARDA, 1 Rue des Oliviers ElMenzah V, 2037 Tunis (Email: melmourid@yahoo.fr)

Rain fed agriculture in North Africa is facing the challenge of balancing between natural resources preservation and intensive farming systems. In Morocco, analysis of thirty years of weather data showed a drastic climatic change threatening crop production. The total rainfall amount received is low to support enough grain production in order to cover increasing needs for food and feed growing population and high number of animals. The water scarcity is exacerbated by alarming land degradation from conventional tillage operations and heavy animals grazing of biomass grown or left as crop residues on soil surface.

Research in Morocco investigated over 25 years, conservation tillage systems at experimental research stations. Different tillage combinations were compared to no till with different rates of cereals crop residue, crop rotations and weed management. Results showed that the no-tillage system offers most sustainable way to enhance resources productivity, water productivity and water use efficiency, soil quality and better cost effectiveness.

At farmers' fields complex and well established relationships are integrating crops and livestock as a way to face high variability of climate. This production system makes grain production and crop residue of equal value. Conservation Agriculture principles based on residue and cover crops well demonstrated at research stations, become very difficult to apply especially during drought seasons when animals survival turn to become farmers major priority.

During the last decade, and building on encouraging research results, direct seeding was scaled out to farmers' fields and has led to a better understanding and adaptation of this promising system to Moroccan and North African rain fed agriculture production systems. Applying on-station research results in the farmers' fields resulted in a hybrid no- till system with no threshold of surface residue cover; but with whatever was left and accumulated over years after hand removing and grazing.

This paper reports results over ten years of on-farm research under rain fed conditions in semi-arid Central Morocco (Lat. 34 N.). Results obtained in farmers fields showed in all cases higher yields under drought conditions and higher or equal under normal conditions. These achievements might be attributed to (i) a well adapted cheap and locally developed no- till drill. (ii) Water conservation techniques that allowed more crop production stability. (iii) Simplification of wheat crop establishment with no additional costs of tillage or pre-planting weed control and (iv) Cost effectiveness.

The success of this research is credited to full participation of farmers' communities and to a strong scientific multidisciplinary team along with real involvement of extension agents and local authorities.

Key words: Water conservation, Soil degradation, No-Till, Cereals production, Crop residue, Morocco.

Morocco and North Africa in general have a Mediterranean climate with hot and dry summers, cold and rainy winters and scarce autumn and spring rainfall events. Studies on climatic changes over 30 years period in Morocco showed a trend of drought periods that can occur at any time during the growing season demonstrating the highly erratic annual rainfall distribution (El Mourid et al, 1993 and BenAouda, 2001) (fig. 1). The total amount of rain is decreasing significantly reducing the growing season from 180 days in the sixties to 150 days in the nineties (BenAouda, 2001) (fig. 2). Variability in crop production, mainly cereals, follows the rainfall pattern. Moroccan cereals production varied from 10 millions tonnes in 1996 to 2 millions tonnes in 2006 that was mainly produced in irrigated fields. Average rainfalls recorded in Settat, one of the main cereals production regions, were 450 mm and 150 mm respectively for these years. Frequency of drought that was one over five years becomes one in every two to three years (Yacoubi et al, 1998). In addition to limited water availability increase in temperatures are observed and lead to high evapo-transpiration rate increasing water deficit. Every year drought is affecting at some scale crops and animal production but severely when it occurs successively several years. Any produced biomass; straw, crops residue or hay, reaches maximum market value. Morocco government has the challenge to raise funds to import wheat and forages to feed the growing population and livestock. Number of estimated animals is 15 millions sheep, 5 millions goats and 3 millions cattle that use 49% part of their food requirement from grazing and crop residues (Nefzaoui et al., 1999). Straw has also other important uses such as chicken and cattle bedding.

Straw price in dry years can reach as much as 0.15 dollars/kg. In all conditions and all over the Moroccan territory, cereal crop residues left after harvesting and baling are the main source available to overcome the animal needs through summer time. On the other hand, in high rainfall regions, after successive good cropping years, excessive crop residues left over on soil surface may become a problem for tillage operations and are burnt.

Introducing no till in this production system seems to lack one of its fundamentals requirements that are residue cover. In the present paper we will discuss the limits of modern conventional agriculture based on intensive tillage, continuous cropping system and total export of plant biomass. Review key research finding obtained under no till system as the proposed alternative and the efforts made to reach the farmers and the constraints to succeed the establishment of No-Till system in Morocco.

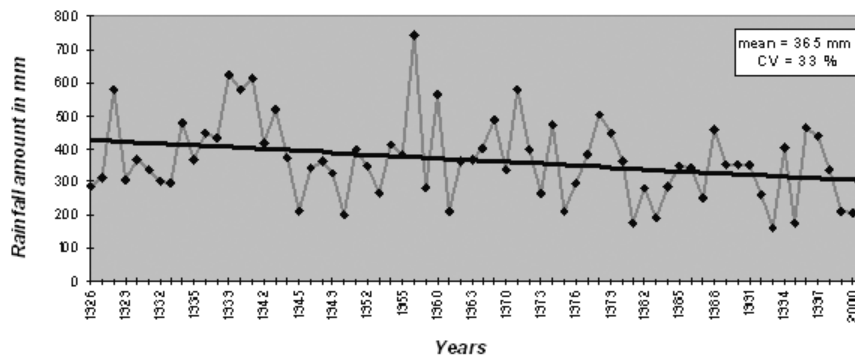


Figure 1. Rainfall evolution in Settat (BenAouda, 2001)

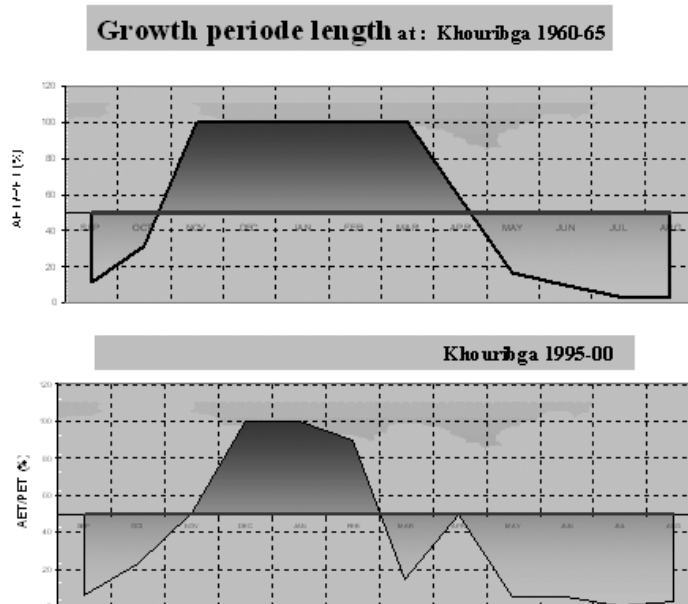


Figure 2. Growth period length for cereal production in dry land central plains (32° 51 N, 6° 54 W), BenAouda, (2001)

Conventional Management

Autumn Sown Field Crops

Cultivation starts with summer intensive tillage that has been synonymous to farming performance. The main used tools are stubble plow, disc harrows and chisel. After harvesting, baling straw and grazing the remaining

residues for four to five weeks, fields are subject to tillage operations. It is believed to improve soil moisture conservation by retuning the soil up side down and eliminating soil cracks. In autumn, just before planting, fields are again disked once or twice to reduce clods size, control weeds, mix the fertilizer with the soil and prepare seed bed.

Rainfall events, optimum planting date and tillage operations for seed bed preparation are the most difficult crop management to deal with in order to succeed crop establishment. First significant rainfall has a random occurrence and late rainfall hold farmer from planting in dry condition. Soil needs several disking or particular equipments such as rotavator or compactors not available in Moroccan farms to obtain a good seedbed. Waiting for rain to prepare seed bed can delay planting and expose crop to end season grain filling water and temperature stresses then risk of low yields. In wet years with early season rainfall, tillage operations are conducted in wet conditions resulting in soil compaction, run off, and soil erosion.

In general, the offset disk is the dominant tool for seed bed preparation. Sowing is accomplished either by drill or broadcast seeds by hand and cover with the offset disk. This seed soil mixing and covering results in uneven seed repartition and non uniform seeding depth. Part of moisture is lost by evaporation and run off caused by formation of hard pan that reduces water infiltration. In order to obtain adequate plant stand farmers increase seed up to double or triple the recommended rates.

Spring Sown Field Crops

In high rain fall areas, field reserved to spring crops such as sunflower and chick pea, are subject to deep tillage in summer time and several shallow tillage operations in the rainy season. Farmers use the mouldboard plow in order to control adequately weeds and have fields ready for seedbed disc harrow in spring time. Repeated tillage operations at a time where chance of rain is narrowed result in drying the top soil layer and increase risk of seed emergence failure. Temperature increase leads to high evaporation rates and crops are often subject to water stress that causes incomplete grain filling. Surface area of these crops is significantly decreasing placing the country on complete dependence on the importation.

The energy used in tillage is estimated to quarter of millions tonnes of fuel that its outcome could be null as in years 1981-83, 1995 and 2006 where almost nothing was harvested (Morocco Ministry of agriculture reports, 1981-83, 1995, 2006).

Common Cropping System and Residue Management

Crops and livestock are integrated in complex production system mainly to manage drought risk and uncertainty of grain production. This integration is stretched with rainfall scarcity and shallow soils. Beyond social and economic consideration, the cropping system is dictated by the average annual rainfall and the nature of soil and its water storage capacity (Table 1).

Table 1. Common crop rotations for different agro climatic conditions

Soil depth	Rain fall in mm		
	less than 300	300 to 400	more than 400
Deep soil	wheat /fallow	- wheat/wheat/fallow or - wheat/wheat/ faba bean or spring chick pea	- wheat/wheat/Sunflower - wheat/wheat/winter or spring food legume
Shallow soil	continuous barely	- wheat/forage - wheat/lentils	- wheat/forage crop - continuous wheat

In dry areas (less than 300 mm) with deep soils farmers have adopted clean fallow with intensive tillage through the season to save moisture. However, (Bouzza, 1990) and (Kacemi, 1992) found that water conservation in this system does not exceed 15%. When rainfall exceeds grain production threshold (around 300 mm), continuous cropping is more common. Crop rotation based on cereals is either continuous cereals break down by fallow or in rotation with food legume, forage or spring crops such as chick pea and sunflower.

Harvesting is done to get out both grain and straw yields. In high production years, straw is baled and fields are subject to animal grazing. Despite the amount of residue removed, more than one tone per hectare is burnt or tilled.

In years of low rainfall or in more arid areas, crops have dual purpose, they can be harvested for grain as well as grazed by animals when farmers are dispirit in getting grains. Fields are completely swiped and only wheat plant crown and roots are left. Rent fields for crop residue grazing is common attitude for farmers that do not have livestock or when fields are far a way from the farm's buildings. Food legume crops are rarely combine harvested instead plants are pulled with their roots exporting 100 % of the crop biomass.

Cost effectiveness of this farming system in terms of energy, inputs, risk of drought and decreased yield due to land degradation discourage investment in dry land agriculture.

No Till System as Alternative to Conventional Farming

Research all over the world has shown that conventional tillage causes considerable damage to the soils. Repeated tillage operations can induce greater soil erosion and moisture losses. The soil clods once broken into small particles become susceptible to be easily transported by wind or water, especially when soil surface is not protected by residues cover. To alleviate these problems and also to save on labour and energy inputs, conservation tillage practices based on direct seeding have become an alternative to conventional tillage. After the three years of severe drought in the early eighties, Moroccan research has addressed the issue of water conservation as one of the main rain fed research program. Highlights of related results are outlined in the following.

Water Conservation

The main objective of water conservation is to reduce evaporation and increase soil moisture conservation by eliminating tillage and keeping part of the crop residues on soil surface. Indeed, different tillage equipments and timing periods were compared to no till in continuous wheat and wheat/fallow rotations (Bouzza, 1990 and kacemi, 1992). Table 2 shows that chemical fallow and no till wheat rotation gave higher production than continuous cropping. The most important feature is the stability of wheat production instead of the sawtooth trend in conventional tillage.

Table 2. Effect of cereal rotation and tillage on wheat yield in t. ha⁻¹ in experimental stations; Sidi El Aïdi and Jemaa Shim. (Bouzza, 1990 and Mrabet, 2000)

Type of tillage	Sidi El Aydi ^a		Jemaa Shaim ^b	
	Wheat-wheat	Wheat-fallow	Wheat-wheat	Wheat-fallow
No-till	1.9	3.5	1.7	3.0
Minimum till	1.6	3.4	1.5	3.0
Conventiional tillage	1.4	2.4	1.6	2.4

^aAverage grain yield 1983-1992 in clay soil Vertisol, average rainfall 370mm.

^bAverage grain yield 1983-1998 in caly soil, Vertisol, average rainfall 270 mm.

Keeping residue on soil surface is known to reduce soil evaporation. Soil can keep its moisture in seed zone up to 5 weeks above the wilting point where it remains only 15 days in tilled plots compare to no till ones with residue cover (Mrabet, 2001). Table 3 shows that water storage efficiency is 1.5 times higher under chemical fallow than under clean fallow (Bouzza, 1990). An average of 84 mm stored in soil profile, instead of 30 mm in weedy fallow, has been saving the cropping season from a mid season water deficit and ensure production stability with all advantages in budget, food security planning and price constancy..

Table 3. Storage efficiency and amount of stored water for different types of fallow in semiarid of Morocco. (Bouzza, 1990)

Type of fallow	Storage efficiency* (%)	Amount of stored water in 1.2 m profile in mm
Chemical	28	84
Clean	18	54
Stubble mulch	21	63
Weedy	10	30

* Calculated as the ratio of stored water and the rainfall received during fallow period.

Carbon Sequestration and Soil Aggregate Stability

In experimental field, at Sidi El Aïdi research station, where crop residues were left on soil surface, at 0-25 mm, soil organic carbon (SOC) increased from 5.62 to 7.21 t/ha under NT, after 4 and 11 years. At the same horizon, SOC level did not change under conventional tillage after the same periods (Bessam and Mrabet, 2003). These authors reported that NT soil has sequestered 3.5 and 3.4 t/ha of SOC more than conventional tillage in the 0-200 mm horizon, after 4 and 11 years, respectively. These findings are illustrated in Fig. 3. Over the 11 years, the 0-200 mm horizon gained 13.6 and 3.3% of its original SOC under no-till and conventional tillage, respectively. The NT improvement of SOC is also proportional to residue level. Increase in residue level helped sequester the greatest amount of C in the top 50 mm of soil, a lesser amount in the 50-100 mm depth and no significant amount in the 100-200 mm (Mrabet et al., 1999).

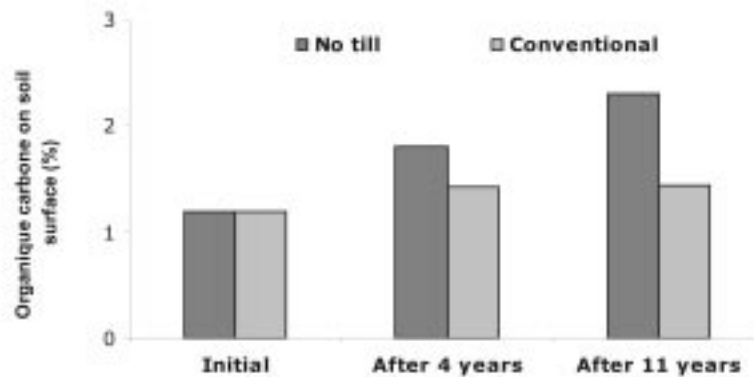


Figure 3. Soil organic carbon in 0-200 mm horizon as affected by tillage system and time (Bessam and Mrabet, 2003)

The Moroccan soils are vulnerable to erosion by water and wind due to their low organic matter content and poor aggregation. Independently of the season, results showed that the proportion of more stable aggregates in the soil surface (seed-zone) is greater in NT than conventional tillage. It was also found that aggregate stability increases with depth as residue cover increases in NT. The development of a good structure at the surface improves water infiltration, movement and distribution and has positive effects on evaporation and erosion control. The aggregation also reflects that SOC is conserved and protected and allows soil organic matter to function as a reservoir of plant nutrients and energy. (Mrabet et al., 1999)

Weed Management

Weed management remains world wide main no till system challenge. In Moroccan dry land, weed emergence depends on the first significant rain. Elbrahli and Mrabet, (2000) reported that, when optimum seeding date overlaps with the first rain, pre-planting herbicide application may not be required since weeds are not yet emerging. However, early post-emergence before tillering is recommended to control the flush of weeds emerging simultaneously with the crop. In years with early rain pre-planting treatment with non selective herbicides is a prerequisite to crop establishment success. A complete crop loss can be observed in fields that herbicide treatment failed to give a good weed control. Long term experiment shows that in one over five years pre-planting treatment is performed. In wheat-fallow rotation, clean chemical fallow is obtained with two applications using non selective herbicide. First one is at planting time and the second is done in late spring season. Chemical weed control in food legume, faba bean, lentils and chick pea are not available. The same above authors recommend that in no till system, delay planting of these crops and use of non selective pre-planting herbicide reduce the weed infestation to a threshold of insignificant yield losses. In these conditions, hand weeding in mid season to obtain complete clean food legume fields requires far less labour than conventional cropping estimated to about one over five.

It appears that in Moroccan dry land farming, no till system does not rely much on the intensive use of herbicides like elsewhere. Weed infestation decrease in the long term shifting to some perennial weeds such as *Arizarum vulgare*, *cynodon dactylon*, *Ecbalium elaterium*, and *Ornithogalum narbonens*. Frequent hand removing of these sporadic

species as they appear in the field can keep their population under control without economical crop losses (Elbrahli and Mrabet, 2000).

In low rain fall areas, weeds are considered as forage for animal. Weedy fallow reserved for animal grazing can get up to 25% of land use. Farmers would like to keep a biodiversity of plant species on their fields. In these environment, the use of non selective pre-planting and post-emergence residual herbicides recommended for the intensive cropping, is replaced by a gentle hormone selective herbicides that give poor control of some legume species such as *Astragalus boeticus*, *Vicia sativa* and *Medicago* spp. The planting of forage crops such as oats on emerged weed seedlings is allowed to increase plant biomass and also keep the biodiversity of this frail ecosystem.

Locally Manufactured No-till Drill

Grain drills for no-till have several soil engaging components and have to operate in untilled, compacted and residue covered soils, thus they must be heavily constructed to provide penetration in these conditions. The success of no-till seeding depends largely on the performance of the coulter, the opener and the press-wheel. The Moroccan soil conditions at seeding time are generally dry, compacted due to animals grazing and contains only small pieces of the left straw and roots. Bahri (1992) tested three combinations of furrow openers in different soils and conditions. He concluded that the hoe opener created a deeper and larger furrow creating more soil disturbance compared to single disc and double disc openers. He also, reported that the hoe opener gave better results in newly converted soils to no-till under the hard and dry conditions of soils during planting season. The grain drill developed in Morocco is a three point hitch machine of 2 to 3 m effective working with. The furrows spacing is 20 cm. The coulter is used to cut through residues and prepare the furrow for proper seed placement by the opener in order to avoid the jam of residues in front of the opener and poor germination that may occur if the seed is placed in a trashy zone with too little soil-seed contact. The coulter is a 45 cm diameter notched disc and each coulter is individually spring loaded and mounted on the main frame. The side to side movement of the coulter is adjusted by a swivel lock and allows the coulter to swing and overcome the obstacles (rock and stones) with no damage and clear the way to the opener. The hoe opener operates in line with the coulter to aid in opening the furrow in which fertilizer and seeds are placed. The fertilizer lands at the bottom of the furrow in a depth superior to seeds through an independent rectangular tube. The seeds are placed 1 to 2 cm above the fertilizer. The hoe opener requires less vertical force in order to improve penetration and creates the necessary needed soil disturbance for good seed-soil contact. The press wheel is used to cover and compact the soil around seeds. In dry soils with low organic matter and poor aggregation, the use of a rod behind the press wheels improve seed cover and flatten the soil surface.

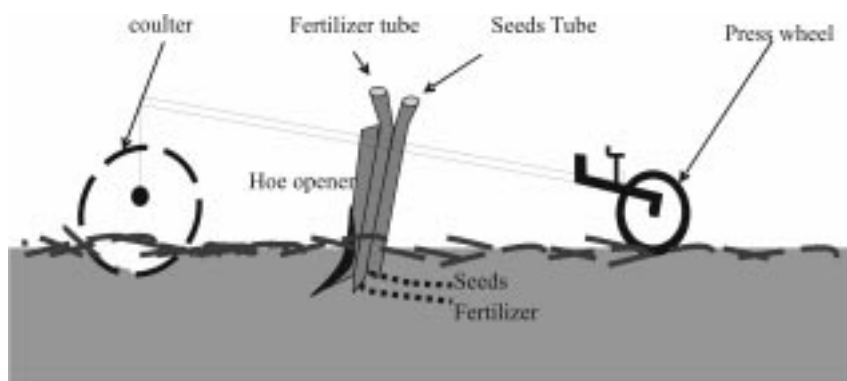


Figure 4. Scheme of the engaging components of the Moroccan seed drill

Introduction of No-Till Technology to Farmer's Fields

Introduction of no till system to farmer fields started in 1997 in Chaouia area where 15% of Moroccan cereal is produced. This region is characterized as an intermediate to low rainfall zone. Deep clay vertisols as well as shallow calcixeroll and silt clay fertalitique are common soil types where the INRA prototype drill was tested. Cropping system was established in common agreement with the farmers depending on the agro ecological and the prevailing cropping system. In all sites crops and livestock were of equal importance. Baling and removing crop residue were systematically done. Farmers' animals as their neighbours' were grazing along summer season up to the first rain where residue



Figure 5. Photo of the Moroccan seed drill operating at farmer's field in the first year introduction of the no till system. The drill is operating on dry soil with high percent of stones and no residue on the soil surface. (El gharras et al., 2004)

becomes not appropriate for grazing. The resulted amount of residue left never exceeds a tone per hectare. In fact the remaining amount of residues is increasing and decreasing as the wheat production. The drill gave a good stand establishment for all cereal crops as well as lentils, vetch and chick pea except broad bean that its seed size need no till planter for a good seed distribution. Even with the small amount of residue change of soil aggregation by the accumulated organic matter was observed (Fig. 6).

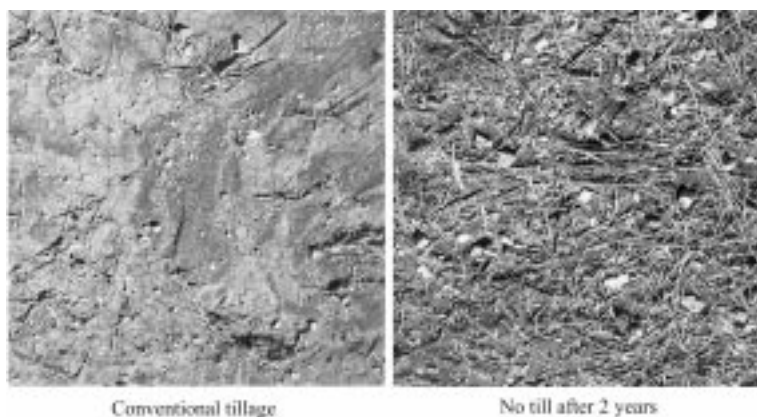


Figure 6. Soil surface at farmer's field after 25 mm rainfall

Performance of no till even with low amount of residue is mainly due to water and nutrient use efficiency during the cropping season. Water stored in fallow was beyond the 30 cm depth (Bouzaa, 1990). Soil types with cracking characteristics left without tillage is suspected to improve water storage by increasing infiltration even with small residue amount. Also, slight decrease in the high pH of calcareous soil coupled with concentration of fertilizer placement one to two centimetres below the seeds, possible with Moroccan no-till drill, enhance nutrient availability (Saber and Mrabet 2002).

Increase in insects, arachnids and other fauna up to become a problem, is a change noticed in long term no till fields, hence contributing to increase cavities in the soils and thus the rate of water infiltration.

In ten years period, pre-planting non selective herbicide was applied only three times. Planting over weeds at seedling stage was followed by early post-emergence herbicide at three leaves wheat stage to prevent weed competition. Crop rotation and animal grazing on fallows prevent the establishment of grass species in cereals and made the use of

cheap broadleaves herbicides of non additional cost to the farmers. Grain yields reported in (fig. 7) from no till pioneer farmer field show the increase yield obtained in dry as well as in wet years. In very dry year where less than 200 mm were received farmers were able to produce 1.1 and 1.5 tonnes of wheat in two different locations where the no till fields were the only ones harvested in the entire region. Straw production has been also improved. Farmer was able to produce in years where straw is a precious commodity. That was the case in 1999 and 2000 where farmer manage to harvest 1 and 1.5 tone per hectare respectively (El Brahli and Mrabet, 2000). In wet years, change on farmer perception toward residue left in the field as an investment in his soil rather than wasted biomass, were noticed by setting up the cutter bar of the combine to leave more residue in the field. Nefzaoui *et al.* (1999) reported that the amount of crop residues is greatly affected by amount of rainfall and nitrogen fertilizer than cereal species or varieties within species. However, barely straw is highly appreciated and consequently, less crop residue is left from barely fields compare to bread or durum wheat ones.

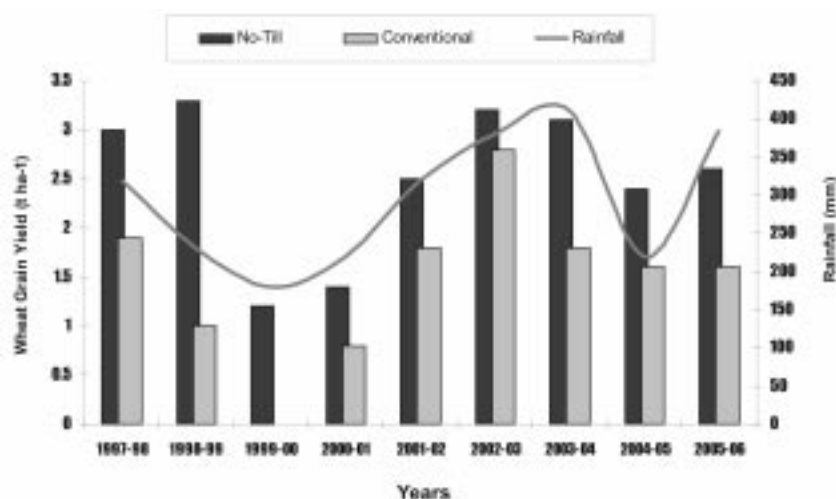


Figure 7. Grain yield at farmer's field under conventional and no-till (EL brahli and Benazouz. 2004)

No till water conservation on wheat and chemical fallow rotation were shown, as in experimental stations, to be able to reach grain production stability and offer some straw and plant residue on years where nothing was available for starving animals.

No Till Program of AAAID and INRA in Morocco

Recently a new no till system development program is initiated between the AAAID (Arab Authority for Agricultural Investment and Development) and INRA - Settat. New drills from Brazil (SEMEATO) were imported to support this

Table 4. Energy and time requirement for different tillage practices (El Gharras *et al.* 2004)

	Power (hp/m)	Time (h/ha)	Fuel consumption (l/ha)	Number of passes
Conventional tillage	100 to 140	6.5 to 8.5	31 to 45	4
• Deep tillage	50 - 70	3.0 - 4.0	10 - 15	
• Secondary tillage	20 - 30	2.0 - 2.5	10 - 12	
• Seed bed preparation	15 - 25	1.0 - 1.5	6 - 8	
• Seeding	15	0.5	5	
Reduced tillage	50 to 70	3.5 to 5.0	21 to 25	3
• Stubble plowing	20 - 30	2.0 - 3.0	10 - 12	
• Seed bed preparation	15 - 25	1.0 - 1.5	6 - 8	
• Seeding	15	0.5	5	
Minimum tillage	30 to 40	2.0 to 2.5	11 to 13	2
• Disc harrowing	15 - 25	1.0 - 1.5	5 - 8	
• Seeding	15	0.5	5	
No-till	25 to 35	0.6 to 1.0	5 to 7	1

program and test their performance under Moroccan soil conditions. Approximately 1200 ha were planted using these machines and the locally manufactured drills during the cropping season 2007-08. About 80 farmers subscribed to this program most of them are at least in their second year. Project provides recommendations and guidance for farmers. Performance of both drills is excellent in clay vertisol and calcixeroll soil types. However, the SEMEATO was not able to offer the necessary penetration in fields presenting high percent of surface stones, discs are rolling over the rocks and seeds remain not covered. We also notice that farmers are manipulating these machines that need more care in term of driving speed and maintenance as they do with conventional drills. Similar remarks could be made in crop management especially concerning weed control that should be timely scheduled and adequately accomplished.

In the first years farmers are much more pleased with the saving of energy and time spend in crop establishments. Indeed, farmers can save as much as 40 litres of fuel per hectare and cut on labour and seeds expenses. Saving in equipments, seeds and labours are all short term motivations for farmers that experience for the first time this cropping system. However, natural resources conservation and improvement are the main objective to achieve.

Conclusions

Farming in rain fed areas of North Africa is a high economic risk activity. Intensive natural resources mining and continuous degradation of soil fertility under conventional agriculture practices will not ensure farm productivity and food security for the coming years. In order to keep cereal production systems sustainable, conservation agriculture based on no till system seems to be the alternative to conciliate agriculture with its environment and overcome the imposed constraints of the climate change and continuous increase of inputs cost. The slight increase in water conservation and water use efficiency obtained by no till system has tremendous effect on yield improvement and production stability in Moroccan agriculture environment. Even though, crop residues have high value and small amount is left after harvesting, a build up over years and change in farmers' behaviour toward residue management as a long term investment on soil quality has been noticed on established farmer's fields. More over, improvement of grain and straw production encourage farmers to leave more residues on their fields and ensure the long term benefit of no till system.

Participatory management approach and on farm demonstrations that succeeds in simple technologies development and their scale out seems to have slow impact on the adoption of no-till farming system. Innovative development approach need to be implemented by activities such as: a) intensive guidance of farmers in order to change the heritage accumulated over years of conventional farming. b) On-job training and development of agriculture enterprises for planting and weed control renting their service to farmers is a practical issue for the adoption of this production system. c) Subsidies allocated to different farm machinery should be withdrawn toward no till technology.

Capital investment is required to boost the cereals production chain toward natural resource conservation. Needed also are the involvement and collaboration of international agencies and institutions such as AAAID development program's in the Arab countries that is willing to invest in conservation agriculture in order to improve farming efficiency and environment quality. Local manufacturing of No-till drills can also be a pillar to enhance private capital investments to play a major role in adoption of no-till system. Recent national developed strategies for Moroccan agriculture encourage the aggregation of small farmers around an aggregator in a production chain where no till system can play a major role in gathering farmers around a common interest.

Acknowledgements

The authors would like to express their recognition to INRA who supports the long years of research, and AAAID that provided, during the last two years, assistance to scale out research results.

References

- Bahri, A. 1992. Evaluation of opener and press wheel combinations on a no-till grain drill when seeding wheat. M.S. thesis, University of Nebraska, Lincoln, NE, USA.
- Benaouda, H. 2001. Evolution de la durée de la période végétative des céréales dans la région de Khouribga. Rapport annuel du Centre Aridoculture de l'INRA Settât, Settât Maroc.

- Bessam, F. and R. Mrabet. 2003. Long-term changes in soil organic matter under conventional and no-tillage systems in semiarid Morocco. *Soil Use & Management*. 19(2):139-143.
- Bouzza, A. 1990. Water conservation in wheat rotations under several management and tillage systems in semi-arid areas. PH.D. Dissertation, University of Nebraska, Lincoln, NE, USA.
- Kacemi, M. 1992. Water conservation, crop rotations and tillage systems in semi-arid Morocco. PH.D. Dissertation, Colorado State University, Fort Collins Colorado, USA.
- El-Brahli, A., et R. Mrabet. 2000. La jachère Chimique: Pour relancer la céréaliculture non-irriguée en milieu semi-aride Marocain. In: *Proceedings of Journée Nationale sur le Désherbage des Céréales*. Centre Aridoculture Settât, Morocco.
- El Brahli, A. et S. Benazzouz. 2004. Rapport d'activité annuel. Centre régional de la recherche Agronomique de Settât - BP 589-Settât 26000, Morocco.
- El Gharras, O., A. Ait Lhaj, et M. Idrissi, (2004). Développement d'un semoir non labour industriel. Actes des Deuxièmes Rencontre Méditerranéennes sur le Semis Direct Tunis. 19-22 janvier, 2004. pp 74-80.
- El Mourid, M. and D.G. Watts. 1993. Rainfall Patterns and Probabilities in the semi-arid cereal Production region of Morocco. pp 59-80. In Jones, Mathys and Rijks (eds) : *The Agrometeorology of Rainfed Barley-Based Farming Systems*. Proceeding of International Symposium Tunis. 6-10 March, 1989. ICARDA, Aleppo Syria.
- El Mourid, M., M. Karrou et M. El Gharous. 1996. La recherche en aridoculture respectueuse de l'environnement. *ALAWAMIA* 92: 69-81.
- Mrabet, R., K. Ibno-Namr, F. Bessam and N. Saber. 2001. Soil Chemical Quality Changes and implications For Fertilizer Management after 11 Years of No-Tillage Wheat Production Systems in Semiarid Morocco. *Land Degradation & Development* 12:505-517.
- Mrabet, R. 2000. Differential response of wheat to tillage management systems under continuous cropping in a semiarid area of Morocco. *Field Crops Research* 66(2):165-174.
- Mrabet, R., A. Bouzza, A. El-Brahli and H. Bouksirat, 1999. Long-term effects of tillage and crop rotation on wheat performances and soil quality in semiarid Morocco. In proceedings of the GCTE Focus 3 Conference 1999, Food and Forestry: Global Change and Global Challenges. September 20 - 23, 1999, University of Reading, UK.
- Nefzaoui, A., A. Chryiaa and M.Y. El-Masari, (1999). A Review of the Research in the North Africa on Cereal Straw Use in Animal Feeding. International Center for Agricultural Research in the Dry Areas (ICARDA). Réalisation et Impression, IMPRIAL. 8, Place des Alaouites-Rabat. Morocco.
- Saber, N. et Mrabet, R. (2002). Impact of no tillage and crop sequence on selected soil quality attributes of a vertic calcixeroll soil in Morocco. *Agronomie*, 22 : 451-459.
- Yacoubi M., M. El Mourid, N. Chbouki. et C.O. Stockle. 1998. Typologie de la sécheresse et recherche d'indicateurs d'alerte en climat semi-aride marocain. *Sécheresse*: 9 : 269-76.

Critical Research for Dryland Conservation Agriculture in the Yellow River Basin, China: Recent Results

Yan Changrong^{1,2}, He Wenqing^{1,2}, Mei Xurong^{1,2}, John Dixon³, Liu Qin^{1,2}, Liu Shuang^{1,2}, Liu Enke^{1,2}

¹*Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences (CAAS) , Postal 100081, Beijing, China*

²*Key Laboratory of Dryland Farming and Water-Saving Agriculture, MOA, Postal 100081, Beijing , China*

³*International Maize and Wheat Improvement Centre (CIMMYT), Apdo. Postal 6-641, 06600 Mexico, D.F., Mexico*

(Corresponding author: meixr@caas.org.cn)

Yellow River Basin (YRB) is the cradle of Chinese civilization. Agriculture production plays a very important role in regional food security. Currently, soil erosion, poverty and water shortages are three major problems that affect the development of agriculture in YRB. Severe soil erosion is leading to loss of fertile topsoil and decreasing soil productivity. These processes are particularly evident in dry and sloping lands associated with rainfed agriculture. How to face and resolve these problems in agriculture? And what are the key techniques to improve rainwater use efficiency? According to the results in the drylands conservation agriculture research and practice, CA is the most promising approach for sustainable development in agriculture, such as harvesting of rainwater using residue mulches, which can increase crop production, and the reduction of soil tillage and construction of water harvesting and supplementary irrigation system. Not only does it generate immediate benefits in terms of increased farm productivity, it also offers social benefits of great relevance to YRB.

Key words: Yellow River Basin; Rainfed field; Farming systems; Conservation agriculture

Yellow River Basin (YRB) is the birthplace of Chinese civilization and situated in Central China, between latitudes 32°-42°N and longitudes 96°-119°E. It originates in the connection between Qinghai and Sichuan Provinces and flows through Gansu, Ningxia, and Inner Mongolia and along the boundaries of Shanxi and Shaanxi and finally through Henan and Shandong before it empties itself into the Baohai Sea.

The Basin has a fairly rugged topography with the elevation decreasing from west to east (Fig. 1). Approximately 75% of the basin is covered with mountains and hills, while plain areas account for 17% only. Now, soil erosion, poverty and water shortage are major problems that affect the development of agriculture in YRB. These processes are particularly prevalent in sloping drylands which are the principal location of rainfed agriculture. According to the severe poverty and poverty lines (Wong Shiyong and Wang Biqiang, 2008), it is estimated that poverty incidence is over 20% in YRB. Agriculture is generally the main source of income for households in this region, therefore, increasing agricultural system productivity and improving the farmer livelihoods, are needed urgently.

The paper reviews the research and application of conservation agriculture in YRB and discusses the problem associated with conservation agriculture and their promising of adaptation in the future.

2. The Resource Base

2.1 Climate

In general, most of YRB is warm temperate zone monsoon climate. It has a high spatial pattern on temperature. In the upstream, the annual average temperature is 10~12°, and in middle stream, the value is 12.0~15.0°, and in downstream, the value is over 14.0° (Fig. 2. Left). The annual averaged precipitation is 452 mm. and it is spatially distributed 372 mm in the upper reaches, 523 mm in the middle reaches, and 671 mm in the lower reaches (Hong et al., 2002). From northwest to southeast, the rainfall increased gradually (Fig.2, Right) (Shao Xiaomei and Yan Changrong, 2006a).

Totally, annual average temperature is reducing gradually from the south to the north and from the east to the west in YRB. The average monthly temperature ranges from -8~29° with January being the coldest month and July the hottest month. Figure 2 shows that it has a trend for cumulated temperature of $\geq 0^\circ\text{C}$ and $\geq 10^\circ\text{C}$ downing from south to north or east to west (Liuqin and Yan Changrong, 2008).



Figure 1. The geographical map of YRB and its location in China

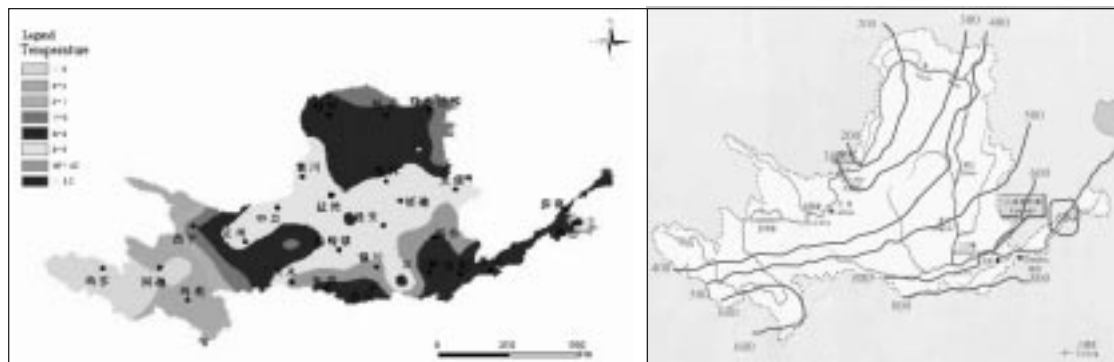


Figure 2. The map of annual temperature (Left) and isohyets (Right) in YRB

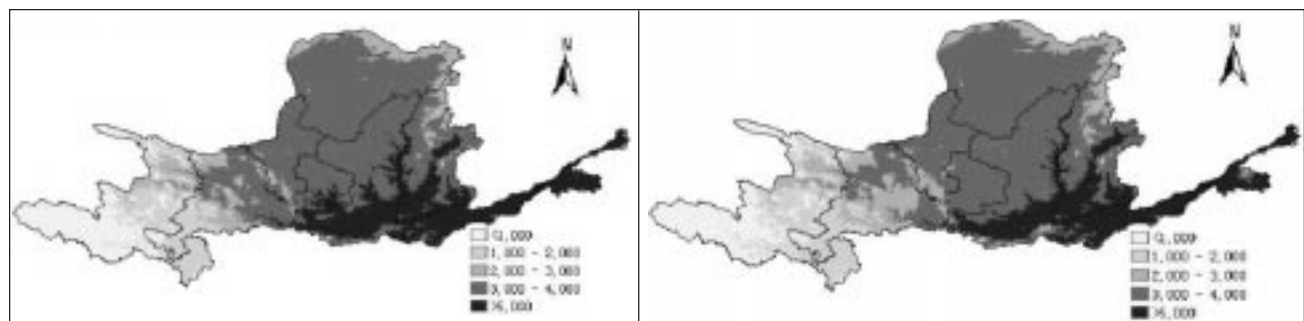


Figure 3. The map of cumulative temperature $\geq 0^\circ$ (Left) and $\geq 10^\circ$ (Right) in YRB

The dryness index and annual water deficit can reflect the states of climate, Using the formula $K = ET_0 / P$, K value was calculated for in the 100 weather stations. The average annual K value is 1.78, and in most of the basin, the value range 1~3.5 (Fig. 4, Left). The annual water deficit has similar spatial distribution, and value range is -110.8~871.5mm (Shi Jianguo and Yan Changrong, 2008) (Fig. 4, Right).

2.2 Soil and Water Resource

Soil is a product of integrated affected by natural factors, such as topography, landform, climate, and human activities, such as tillage. Due to the spatiality of natural factors in YRB, from southeast to northwest, the soil types are

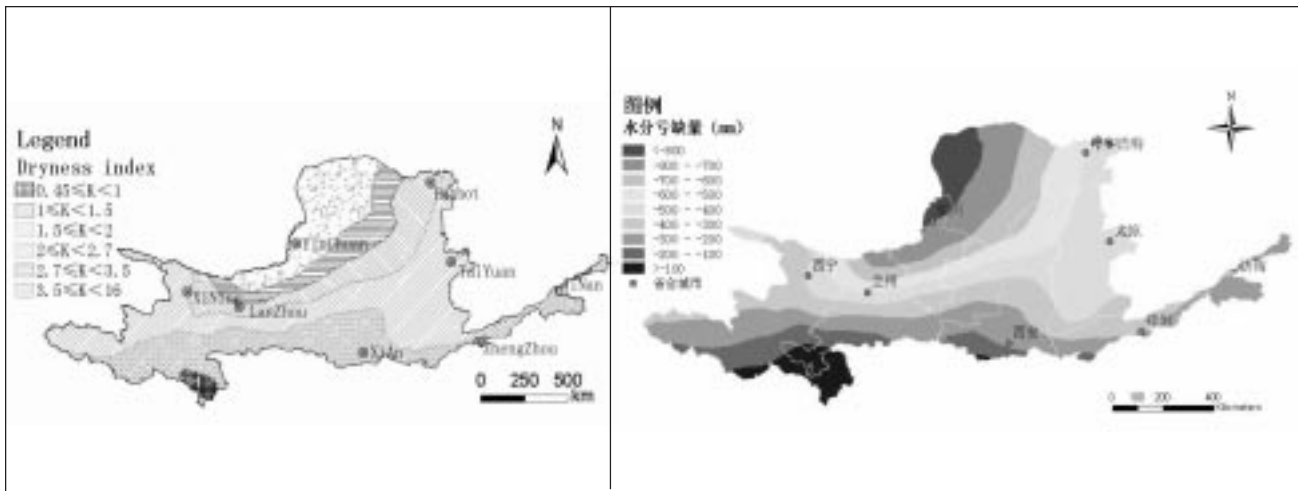


Figure 4. Spatial pattern of annual dryness index and water deficit of 45 years in YRB

drab soil, brown soil, castanozem, gray cinnamon soil, dark loessial soil, cumulic cinnamon soil, loessal soil and desert caliche soil. Drab soil, castanozem, dark loessial soil, cumulic cinnamon soil, and loessal soil are mainly for agricultural production.

According to the data of Ministry of Land and Resource, arable land of 9 provinces in YRB are showed in following table, which indicates that the irrigable land and rainfed land are the main type of arable land, 33.54% and 62.31% respectively, and the other 3 types of field amount to a limited area.

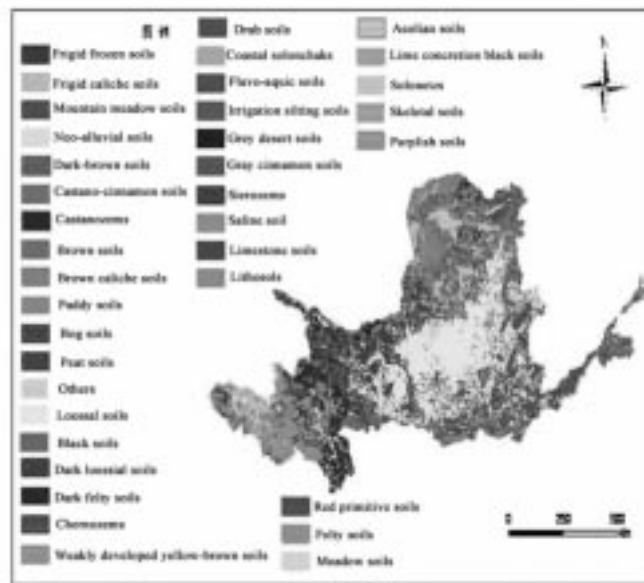


Figure 5. Map of soil type in YRB

YRB is located in arid and semiarid region with shortage of water resource, annual average runoff is 58 billion m^3 about 2% of total annual runoff in China. Water resource of per capita and per arable land hectare are 593 and 4860 m^3 respectively, which are 25% and 17% of average value of China. It has very different spatial pattern of water resource, for example, in upper reaches, about 30% of the basin area, the runoff is over 58% of total amount. According to the rainfall, it can be divided 3 type of rainfall years, wet year, normal year and dry year, and the runoff of wet year is 3 times of dry year. So, water shortage and uneven is main characteristics.

Table 1. The arable land area of provinces in YRB (ha)

Province	Counties	Counties in YRB	Irrigated paddy	Rainfed paddy	Irrigable field	Rainfed field	Vegetable field
Shanxi	119	82	10532	78	868036	3182794	20122
Inner Mongolia	118	30	81108	350	1714240	5257295	47761
Shandong	139	30	129936	813	4340853	2872376	174943
Henan	158	46	645782	50699	3092552	4055085	81186
Shaanxi	107	74	172924	22913	870038	3005516	17786
Gansu	86	54	11261	2435	1003595	3642442	7996
Qinghai	43	33	0	0	176537	357328	8380
Ningxia	23	19	44845	0	353049	698820	3168
Total	793	368	1096388	77288	12418900	23071656	361342

Note: 2005 data from Ministry of Land and Resource, P. R. China. 6 counties in Sichuan are not included in the table, because very little arable land in these counties.

2.4 Farming Systems

In YRB, the main crops are wheat, maize, millet, potato, rape and cotton. The main farming systems are one crop per year, three crops two years and two crops per year, and the cropping systems largely depend on climate. According to features of farming systems, there are 6 first-level crop plantation types and 15 second-level crop plantation systems in YRB (Fig. 5). In the upper region of YRB, where involves transitional ecotone of agriculture and pasture, including the regions between Xining and Lanzhou, Ningxia and Inner Mongolia, the cropping system is one crop per year, such as maize, wheat or oat etc.. In middle region, such as north part of Wei River basin and valley area of Wei-Fen River basin, due to plenty water resource and solar radiation, main crop system is three crops two years, such as spring maize-winter wheat-summer soybean, spring maize-winter wheat-summer potato, winter wheat-summer soybean-winter wheat-summer fallow, winter wheat-winter wheat-summer maize. In the irrigated region of lower region of YRB, such as southeastern plain of Shandong and Henan, the main cropping pattern comprises two crops per year, such as summer maize-winter wheat, summer maize-vegetable (garlic), summer cotton-winter wheat (Fig.5) (Liu Xunhao, 2005). Correspondingly, the cropping index in the south plain of Shandong, Henan and part of Shaanxi, which has fertile soil and abundant water resource, can be as high as 140~170%. Conversely, in the cold dry north of Inner Mongolia, part of Shaanxi and Shanxi Province, the multiple cropping index tends to be below 80%.

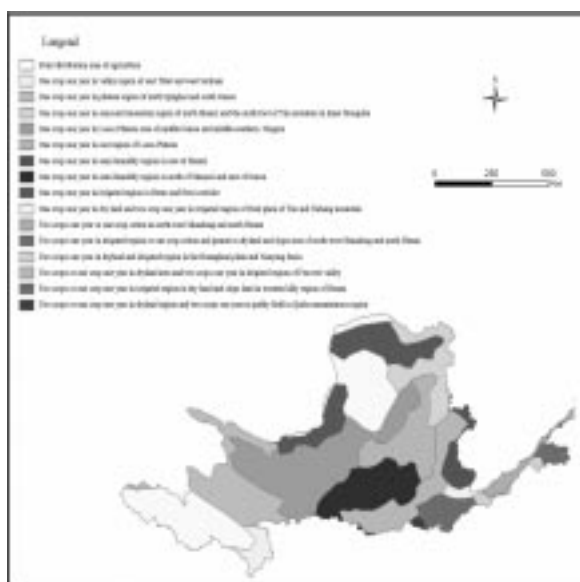


Figure 5. The divisions map of farming system in YRB

3. Problems Encountered with Conventional Tillage System

Soil erosion is a severe problem in this basin, and most of the sediment originates in the thick loess deposits of Shaanxi and Shanxi Provinces. However, soil erosion, both by wind and water, in the basin as a whole removes the most fertile topsoil and aggravates the critical Basin-wide water shortages for agricultural, industrial and domestic purposes and air pollution problems. Only a decade ago demand for fresh water exceeded supply to the extent that the river low dropped to catastrophically low levels. These processes are particularly marked in the drier and more sloping lands associated with dryland agriculture. As conventional tillage, the intensification of crop production results in the environmental problem more serious, especially during the fallow period, and it is easy to wind or water erosion for unprotected and plough soil, leads to land salinity and infertility, and construct tillage pan (Tang, 2002; Wang, 2007). Conventional tillage and crop production practices have also led to a decline of soil quality in many parts of the Basin (He Wenqing and Yan Changrong et al 2008).

How to manage and utilize the crop residues is one of the greatest challenges for conventional tillage as well as, in a different way, conservation agriculture (Sayre and Dixon 2006).. The amount of crop residue is over 600 million tons per year, most of which is discarded or burned in the field. During recent year, residue burning has resulted in a lot of environmental problems, such as air pollution, breaking smoothly traveling of high way and normal activities in airport. Every year, in harvesting time of wheat and corn, the government had to invest much effort to prevent residue burning.

It is widely recognized that CA, is the most promising crop production approach from the perspective of sustainability (Sayre K, 2006). Through the principles of minimum soil movement, retention of residues, effective rotations and immediate economic benefits to farmers, CA addresses the problems of the YRB described above; and shows signs of becoming the next global agricultural revolution.

4. CA Technology Development

4.1 Evolution of CA Technology

In YRB, because water shortage and drought occurs frequently, local farmers have developed some methods to alleviate the effects of drought on agricultural production. The traditional methods include mulching, reduced tillage and no tillage, which are known well as 'sandy covering cultivation', 'furrow-seeding or square-pit methods'. The area is well known for intensive tillage dating from the traditional agriculture two thousand years ago in China. As the cradle of Chinese civilization, the basic characteristics of agriculture production are aligned with high input, especially labor intensive, practices. In the dry land area of YRB, the traditional agricultural production system includes plowing, harrowing, smoothing, rolling and hoeing. With the development and progress of agricultural science input use efficiency has been improved gradually, especially after the 1980s. The environmental problems, such as soil and water erosion, soil compaction, ground water table decrease and erosion of river banks are closely related to agricultural activities, leading to the study and improvement of the traditional tillage techniques and the possibilities offered by modern practices such as CA. Because of different climate, soil, landform, farming system, level of economic development, the experience with the development and impact of CA varies widely across the YRB.

As noted above, in the southern part of Loess Plateau in part of Henan, Shaanxi and Shanxi Province, double cropping of winter wheat-summer maize is common. In Gansu, Ningxia, Inner Mongolia and Qinghai, Shanxi and Shaanxi Province, single cropping of winter wheat or summer maize is common.

For water and soil conservation, a new dryland CA practice is being tested, comprising reduced or zero-tillage with retention of stubble and mulching with straw. Over 10cm of wheat stubble is left in the field after harvest and 8-10 t/ha of wheat straw provides soil cover during the fallow period (Fig. 6). Sometimes, the stubble and straw are pushed down with a stone roller. When sowing date is approaching, the wheat straw mulch is raked into heaps in the furrow and 3~4 t organic fertilizer per hectare is applied. In combination with sowing, 300kg/ha ammonium and 300kg/ha urea are applied. After sowing, the wheat straw is spread in the field again. After 3~4 years, sub-soiling or a single deep tilling is conducted for improving soil compaction and breaking the tillage pan (Wang Zhaohua and Li Like, 2001) .

In the upper region of YRB, especially the ecotone of agriculture and pasture such as Inner Mongolia, northwest of Gansu and south part of Ningxia, main cropping system is one crop per year, such as wheat, maize, potato and oat. For large scale, the key CA technology is reduced tillage and strip intercropping system (Fig. 7), which key function of



Figure 6. Reduced tillage with stubble mulched in Shaanxi



Figure 7. Belt intercropping system in Inner Mongolia

this planting system is to reduce soil erosion, including wind and water erosion. This strip intercropping system involves: in late fall, after harvesting oat and potato, no-till and retaining oat stubble in the field (3.6~8.4m); next spring, and oats is directly sown in the former potato strip, and potato is planted in the former oat belt and the reverse the following year (Wang Shimin, 2004; Jia Yanmin, 2004).

In Ningxia and Gansu Provinces, an absolutely different CA technique-stone mulching, is used. In general, the field is mulched with stone (about 3~5cm diameter, about 10cm depth) which lasts for 10 years. Farmers plant cash crops such as melon and vegetables in these fields (Fig. 8).

The food bowl of the lower reaches in YRB is the Huanghuaihai plain in Henan and Shandong Provinces, the main cropping system is two crops per year, winter wheat-summer maize, with the development of CA machinery and CA subsidy from government, no-till and direct seed techniques for maize is utilized broadly, which processing is after harvesting wheat with machine, about 15cm standing stubble in the field and 1/3 wheat straw chopped broadcasting in the field at same time, and then direct seeding and fertilizing with no till seeder.

In east part of Shanxi Province and west part of Henan of YRB, for dryland, one crop per year is common, and crops include spring maize, oat, millet and potato. One CA practice is chopping straw and returning to field during maize harvesting, followed in the spring by concurrent seeding and fertilizing. Just now, in Shanxi, one third of maize planted area is adopted straw returning to field (Fig. 9).



Figure 8. Scenarios of melon field with stone mulched in Gansu



Figure 9. Maize harvesting and straw chopping and returning in Shanxi

Although the basic elements of conservation agricultural techniques were developed and practiced many years ago, in fact research on CA in YRB began during at the late 1970s. Some agronomists began to evaluate reduced tillage and no tillage in YRB and designed water and soil conservation till system for Loess Plateau region, including mulching with whole corn straw retained on dry land. The first no till seeder was made during this period (GAO

Huanwen, 2004). Around the end of the 1980s, the techniques of residue mulching and reduced till, leaving of high stubble after harvest and reduced till for wheat planting were assessed and applied (Li Shaokun, 2004 ¼–X¼–Zhang Fei, 2004). During the 1990s for drought resistance and reducing soil erosion, an integrated conservation agricultural system with improved machinery was tested and promoted. During these decades much was learnt about CA practices with potential in the YRB but the adoption by farmers was very limited, and CA trials conducted only in 4 agricultural stations belonged to national or provincial agricultural academy.

In the first decade of this new Century, in the east part of YRB, zero tillage with residue incorporated for maize has been adopted significantly on irrigated areas of Henan, Shandong and Shanxi province, and the area utilized reduced till arrived several million Chinese mu. Most research results have shown zero or reduced tillage with residue kept in the field can decrease soil erosion in dryland fields and increase the soil water availability. In the northwest part of YRB, some CA technique, such as strip cropping, intercropping contour planting and strip tillage have also been applied to control soil erosion (Yan Changrong, 2006, Xin Naiquan, 2002).

4.2 Critical Research Results

The CPWF Project for the development of CA in the YRB has been operating research and demonstration trials in five representative locations across the YRB since 2005. The research is focused on critical questions on soil quality, moisture management, agronomy and crop productivity related the problems described above. The following tables compare average soil moisture of conventional tilled research plots and CA plots in five locations across the YRB. And the data indicate CA techniques can increase soil moisture and lessen water stress on crop growth, although the effects of CA on soil moisture depend on many factors, including the tillage, mulching and so on.

The increase in average soil moisture through the growing period is evident, ranging from 1% to 20% (Table 2). As in many other farming systems in the world, CA did not significantly increase crop yields. However, as reported in table 3, the improved soil moisture management contributes to an improvement of soil moisture and increase crop yield (Table 3). However, because of reduced production costs there is a fundamental increase in profitability of CA. For example, as shown in table 4, the results of Shouyang pilot site in Shanxi Province, CA is associated with the reduction of crop production inputs, such as labor, machine. With CA tillage the total inputs may decrease 15~20%. This is consistent with farmer perceptions of the advantages of CA component technologies which are primarily centered on saving labor, and the net income of CA can increase 5.8%~8.3%.

5. Government Support to CA

In recently years, Chinese government adopted a series of policy, economic measures to push CA techniques extension in YRB. MOA has set up 59 CA demonstration counties to extent CA techniques in the basin since 2002 (Table 5). With significant subsidy for CA machinery and effective CA training, it is estimated about 50,000 Chinese mu (approx 3,300 ha) of CA was adopted on arable land per CA demonstration county per year. In general, with development of new CA machinery, more clean understanding advantage of CA, the application of CA will extent quickly, especially for main crops, such as summer maize and winter wheat. With the government support, the capacity of CA application

Table 2. Soil moisture CA/Conventional, five sites

Pilot	Soil depth (cm)	Soil moisture increased (%)	Note
Shandong	00~20	2.0~9.3	From 2008 annual report of Shandong site (the data is measured in March to May, crop is winter wheat, Wang Fahong, 2008)
	20~40	1.2~2.0	
Henan	0-200	3.0~8.0	From 2008 annual report of Henan site (the data is measured during the growth period of winter wheat, Zheng Fei, 2008)
Shanxi	0-40	5.2~15.0	From 2007 annual report of Shanxi site (the data is measured during the growth period of summer maize, Yan Changrong, 2008)
	40-200	1.0~5.0	
Inner Mongolia		3.0~15.0	From 2008 annual report of Inner Mongolia site (the data is measured during the growth period of summer maize, Liu Jinghui, 2008)
Ningxia	0~20	Over 20	From 2008 annual report of Ningxia site (the data is measured during the growth period of winter wheat, Yuan Hanming, 2008)

Table 3. Crop yield of maize and winter wheat for CA vs. Conventional tillage in five sites (kg/ha)

Pilot	Annual Rainfall (mm)	Winter wheat		Maize		Note
		CA	CK	CA	CK	
Shandong	611	3995	3339	6060	6075	From 2008 annual report of Shandong site (Wang Fahong, 2008)
Henan	650	2600	2476	5838	5652	From 2008 annual report of Henan site (Zheng Fei, 2008)
Shanxi	470	-	-	7030	6900	From 2007 annual report of Shanxi site, (Yan Changrong, 2008)
Inner Mongolia	410	-	-	4838	3890	From 2008 annual report of Inner Mongolia site (Liu Jinghui, 2008)
Ningxia	400	-	-	5823	4723	From 2008 annual report of Ningxia site (Yuan Hanming, 2008.) (CA +mulching with plastic film)

Note: in Shandong and Henan pilots, cropping system is two crops per year, and in another 3 pilots cropping system is one crop per year.

Table 4. The input and outcome of different tillage for maize in Shouyang County (2008) (Yuan/ha)

Treatment	Input						Income		(%)	
	Fertilizer	Machine	Seed	Pesticide	Labor	Total	Gross	Net		
CK	1500	1125	412.5	150	1650	4838	11730	6892		
CA	ASRT	1500	1125	412.5	150	1500	4688	12149	7461	8.3
	NTSM	1500	300	412.5	150	1500	3863	11305	7442	8.0
	RRT	1500	525	412.5	150	1500	4088	11380	7492	5.8
	Average	1500	650	412.5	150	1500	4213	11611	7398	7.3

Note: CK-All stalk is moved away, and plowing in autumn, and harrowing and seeding in spring;
 ASRT-Whole stalk ploughed into 0~20cm soil layer in autumn, seeding and fertilizing in spring at one time;
 NTSM-whole stalk were covered on field surface, and no till and directly seeding in next spring;
 RRT-About 1/3 straw is chapping and rotary ploughed into 0~15cm layer in autumn, and in next spring, harrowing and seeding.

Table 5. CA pilot counties in YRB during 2002-2007

Province	County Name	Pilot counties	Total counties
Shanxi	Zuoyun, Pianguan, Shouyang, Changzi, Xiaoyi, Tunliu, Xiyang, Xiangfen	8	82
Inner Mongolia	Liangcheng, Wuchuan, Yijinhuoluqi, Dongsheng, Guyang, Chayouzhongqi, Qingshuhe	7	29
Shaanxi	Shenmu, Dingbian, Tongchuan, Pucheng, Heyang, Binxian, Fuping, Henshan, Longxian, Jingbian, Huangling, Hancheng, Qianxian, Qianyang, Chengcheng	15	74
Gansu	Xifeng, Gangu, Yuzhong, Jingchuan, Ningxian, Lingtai	6	51
Ningxia	Pingluo, Lingwu, Yanchi, Zhongwei Pengyang*	5	19
Qinghai	Huangzhong, Xinghai, Huzhu, Datong, Pingan, Huangyuan	6	32
Henan	Yanshi, Puyang, Huaxian, Boai, Junxian, Wushe, Luolong, Xiuwu	8	47
Shandong	Huiming, Zhangqiu, Gaoqing, Yanggu	4	30
	Total	59	364

has improved greatly, which include farmer's understanding of CA and agricultural implements. The percentage of agricultural production activities with machine increased sharply. For example, in Shanxi, Shandong and Henan, over 80% area of planting maize mainly depend on no till seeder. In Inner Mongolia and Ningxia, small CA seeders suitable for mountain or hilly region, are developed and applied broadly in recent year.

6. Conclusion

More suitable and better CA techniques for dry land in YRB are being developing by introducing new soil and water management techniques, new machinery and improving the traditional drought resistance practices (Reicosky, 2007; Xu Jiguang, 2005). The CA techniques have showed very good results in the research and demonstration sites.

Compared to conventional tillage system, CA tillage system can improve rainwater harvesting and water efficiency, increase water storage, reduce soil erosion, save energy and labor input (Table 4). The crop yields utilizing CA techniques are not much different compared to conventional tillage. In wet years, CA techniques maybe induce low soil temperature and seed emergence in part of YRB and decrease crop yield, and in normal and dry year, crop yield may be increased lightly. But farmer's net income from crop planting can increase obviously with utilization of CA techniques. In a word, CA is the most promising sustainable agriculture option for us. Not only does it generate benefits in terms of improved water use efficiency, increased farm productivity, but also offers social benefits of relevance to YRB.

Acknowledgement

This study was funded by a grant from the CGIAR Challenge Program on Water and Food (CPWF) "PN12: Conservation Agriculture in Yellow River Basin dry lands", and the 11th five-year plan of National Key Technologies R&D Program: "Water Balance and Crop Potential Productivity in Field Scale (No. 2006BAD29B01)", the 11th five-year plan of National High-tech R&D Program: "The Pilot Base Construction of Modern Water Saving Technology of Agriculture in Shanxi Province (No.2006AA100220)".

References

- Black, C.A., 1965. Methods of Soil Analysis, Part I and II. Amer Soc. Inc. Pub., Madison, U.S.A., pp. 770~779.
- Liu Qin, Yan Changrong, He Wenqing, 2008. Dynamic variation of accumulated temperature data in recent 40 years in the Yellow River Basin. *Journal of Natural Resources*, (in press).
- Liu Xunhao, Chen Fu, 2005. Farming system in China, Beijing, Published by *China Agricultural Press*, pp 46~172.
- Shi Jianguo, Yan Changrong, He Wenqing, Liu Keli, 2008. Study on spatial and temporal variation of water surplus and deficiency in Yellow River Basin. *Journal of Natural Resources*, 23(1):113~119.
- Wang Zhaohua, Li Like, Zhao Relong and; Hong Xiaoqiang, 2001. An effective new technique of dryland farming in Western China low or non-tillage with stubble and whole course straw covering. *Chinese Journal of Ecology*, 20 (3): 71~73.
- Wong Shiyong, Wang Biqiang, 2008. The poverty lines will be re-demarcated in China: annual income 1300 Yuan will include about 40 million persons. http://news.xinhuanet.com/fortune/2008-04/12/content_7963187.html.
- X.B. Wang, D.X. Cai, W.B. Hoogmoed, O. Oenema U.D. Perdok, 2007. Developments in conservation tillage in rainfed regions of North China. *Soil and Till. Research*. 93, 239~250.
- Yan Changrong, Mei Xurong, He Wenqing, Yang Jie, 2006. Status and characteristics of conservation tillage in Yellow River Basin. *Journal of Agro-Environment Science*, 25(S):844~847.
- Li Shaokun Zhao Ming, et. al., 2004. The progress of conservation tillage techniques research. Forum of food security strategy. *The collection of thesis in the 90th youth scientists' forum of Chinese Scientific Association*, PP 21~25.
- Zhang Fei, Zhao Ming, et. al., 2004. The problems of conservation tillage development in Northern China, *Journal of Agricultural Science and Technology*, (3):36-37.
- Tang, C.S., C.F. Drury, J.D. Gayor, T.W. Welacy, and W.D. Reynolds, 2002. Effect of tillage and water table control on evapotranspiration, surface runoff, tile drainage and soil water content under maize on a clay loam soil. *Agriculture Water Management*. 56:173-188.
- Wang Xiaobin, Cai Dianxiong, W. B. Hoogmoed, O. Oenema and U. D. Perdoc, 2005. Scenario analysis of tillage, residue and fertilization management effects on soil organic carbon dynamics, *Pedosphere*, 15(4):478~483.
- Gao Huanwen. 2004. The techniques and machinery of conservation agriculture. Beijing: Published by *Chemical industry Press*, pp19~29.
- Jia Yanming, Shang Changchun. 2002. Study on suitability of conservation tillage. *Transactions of the Chinese Society of Agricultural Engineering*, 18(1):78~80.
- Wang Shixue, Gao Huanwen. 2003. The trial results of conservation tillage in sand cold region. *Transactions of the Chinese Society of Agricultural Engineering*, 19(3):120~122.
- Shao Xiaomei, Yan Changrong, Wei Hongbing. Spatial and temporal structure of precipitation in Yellow River Basin based on Kriging method. *Chinese Journal of Agrometeorology*, 2006, 27(2):65-69.
- Xin Naiquan, 2002. The study on dryland agriculture in north China. Beijing: Published by *China Agriculture Press*, pp300~320.
- Xu Jiguang, 2005. Conservation tillage is a greatly progress of dry land farming in history. <http://www.sxnj.org.cn/njlt/2005092701.htm>.
- Sayre K, Dixon J. 2006. The Crop Residue Utilization Dilemma: Sustain Existing Livelihoods, Generate Bioethanol, or Improve the Soil and Crop Production? Distributed paper, GFAR APAARI CIMMYT IFPRI Workshop, Bioethanol, Maize and Wheat: Opportunities and Risks (4 November), New Delhi.
- He Wenqing, Yan Changrong, Liu Qin, Liu Shuang, 2008. Protection and construction of farm land and grass land ecosystem in Western China, *Journal of Agricultural Science and Technology*, 10(S1):52-55.

Innovations through Conservation Agriculture: Progress and Prospects of Participatory Approach in the Indo-Gangetic Plains

M.L. Jat¹, Ravi G. Singh², Y.S. Saharawat^{3,4}, M.K. Gathala⁴, V. Kumar⁴, H.S. Sidhu⁵, and Raj Gupta²

¹Directorate of Maize Research, Indian Council of Agricultural Research, Pusa Campus, New Delhi, 110 012, India

²International Maize and Wheat Improvement Centre (CIMMYT), India Office, NASC Complex, Pusa, New Delhi, 110 012, India

³International Centre for Soil Fertility and Agricultural Development (IFDC), Muscle Shoals, Alabama, USA

⁴International Rice Research Institute (IRRI) India Office, Pusa New Delhi, 110 012, India

⁵Punjab Agricultural University, Ludhiana, Punjab, India

The scientific and technological innovations have been the basis for promoting agricultural development. The historical focus of research on improved agricultural technologies has undeniably been successful. But, these strategies have had limited impacts on the intended beneficiaries, as the complexity of their livelihood and farming systems has not been taken into consideration. The conservation agriculture (CA) in its initial version of zero-tillage in South Asia during 1970's and 80's is a good example of it wherein during technology development, little or no attention was paid to the farmers' knowledge for their local settings and innovations. However, linking dynamic knowledge systems of the farmers with scientific basis of technology through "Participatory Innovation Development" on CA in its version of Resource Conserving Technologies (RCTs) played a great role in promoting the adoption of RCTs (3.0 million hectares) for resource conservation, poverty alleviation and sustainable development in irrigated intensive production systems of the Indo-Gangetic Plains of South Asia.

The Indo-Gangetic Plains (IGP) of South Asia encompassing most of northern and eastern India, the most populous parts of Pakistan, *terai* of Nepal and virtually all of Bangladesh is a fertile and most productive region that supports 1/7th (900 million) population of the world. In the IGP, rice and wheat are the major crops grown in rotation on 13.5 m ha area. In addition, the other major crops grown in system are maize, sugarcane, and cotton. The rice-wheat (RW) production system has played a vital role in food security and remained the cornerstone for food security, rural development and natural resource conservation in the region (Paroda et al, 1994; Timsina and Connor, 2001; Gupta et al, 2003; Ladha et al, 2003). But, now evidences of second generation problems such as declining factor productivity, plateauing crop productivity, declining soil organic matter (SOM) receding ground water table, diminishing farm profitability, environmental pollution etc. started appearing mainly attributed to monoculture of intensive conventional production systems (Sharma and De Datta, 1985; Hobbs and Gupta, 2000; Sharma et al, 2003; Gupta and Sayre, 2007). At present, the challenge is to produce more quality food from the same land and water resources, besides sustaining soil and environmental quality. Thus, the major challenge for the researchers is to develop an alternative system that produce more at less cost and improve farm profitability and sustainability (Gupta and Seth, 2007). This suggests that agriculture systems needs a mixture of new technologies that are able to knock new sources of productivity growth and are more sustainable. This necessitates more attention on issues of sustainability and conservation agriculture (CA) in intensive production systems. The CA in its initial version of zero tillage before 1990's could not make much impact at farm level despite of the proven advantages of higher crop productivity, resource conservation and improving farm profitability because of higher investment costs of the imported ZT drills and design problems associated to suit the location-specific adjustments of the local ZT drills. The research efforts made since mid 1990's on developing, refining and accelerating the adoption of CA technologies in the IGP has brought a "Tillage Revolution" in which the 'Farmers Participatory Research Approach' played significant role. In this paper, progress and prospects of technologies involving one or more of the key elements of CA in the predominant cropping systems (rice-wheat, maize-wheat, rice-maize and sugarcane based systems) developed, evaluated and accelerated in various agro-ecologies of the IGP using innovative modifications in the planters and/or other production techniques through farmer's participatory research approach are being discussed.

Development, Evaluation and Acceleration of Innovative CA Techniques

Research on CA in irrigated production systems of South Asia in its version of zero tillage can be traced back in 1970's wherein efforts were made to develop the zero tillage technology at Punjab Agricultural University, Ludhiana, India. However, the technology did not reach at farm level due to the obvious reasons of lack of innovations for

location/situation-specific suitability. In early 1980s, the CIMMYT made efforts on zero-till technology in the region with the import of Aitcheson zero till drills from New Zealand to Pakistan. After Pakistan, four drills were shipped from New Zealand to India by CIMMYT during 1988, however, due to expensiveness of the imported ZT drills and poor crop establishments due to design problems in the locally manufactured ZT drills, the technology could not made impact at farm level. Thereafter, the innovations started with use of “Inverted T” openers of Aitcheson ZT drills in locally manufactured ZT drills in 1992. Thereafter, with the farmers’ innovative suggestions for ZT technology, a series of improvements were made to make the technology user-friendly and acceptable at farm level. Later the commissioning of Rice-Wheat Consortium, an eco-regional initiative of CGIAR involving NARS of India, Pakistan, Bangladesh and Nepal in 1994, took initiatives in close collaboration of NARS of participating countries, manufacturers and local artisans for development and refinement of RCTs using “Participatory Innovation Development (PID)” approach. This PID approach made significant impact on resource conservation and sustainable farming through development, refinement and adoption of CA in its version of RCTs (3.2 million hectares) in the irrigated intensive production systems of IGP of South Asia (Table 1).

Table 1. Adoption of RCTs in Indo-Gangetic plains of south Asia

Country/Region	Acreage under RCTs (000' hectares)				
	2001-02	2002-03	2003-04	2004-05	2005-06
India	133.6	375.8	870.2	1870.5	2388.7
Pakistan	79.9	192.1	338.9	438.0	421.2
Bangladesh	10.4	10.4	10.6	388.8	419.9
Nepal	0.4	0.6	2.7	12.4	14.3
IGP	224.2	579.0	1222.0	2709.0	3244.0

Source: Gupta and Sayre (2007)

Farmer Participatory Field Trials

Results of large number of farmer’s participatory on-farm and on-station trials across the IGP showed that no-till wheat in the RW system has shown similar system productivity as of conventional till wheat in rotation with puddled transplanted rice but with less water use and more farm profitability (US \$ 50 to 100 ha⁻¹) in western through eastern IGP (RWC, 2006). However, there was no much advantage on soil quality due to intensive tillage during rice season and no retention of residues. Further, the innovations of second generation planters (Happy seeder, turbo seeder, rotary disc drill etc) enabled to retain rational amount of residues in no-till systems that led to 6 to 20 % increase in system productivity, 50-100 mm saving of irrigation water, higher farm profitability (US \$ 95 to 190 ha⁻¹), enabled regulating terminal temperature up to 2 °C in wheat (Figure 1), reduced global warming potential (GWP) and improved soil quality. The benefits in respect to water saving, profitability and soil health in the RW system further improved with development of double no-till technology wherein rice was directly sown using innovative precise (cupping type, inclined plate) seed metering systems. Double no-till practice (no-till direct-seeded rice-No-till wheat) having rational soil cover with residues led to higher (US \$ 200 to 240 ha⁻¹) profitability of RW system compared to puddle transplanted rice-no-till wheat across the IGP (Table 2). In maize-wheat (MW) rotation, permanent beds (PB) and double no-till using disc openers and inclined plate multi-crop precision seed metering systems resulted in higher systems’ grain and water productivity than the conventional practice. The profitability of MW system (average of 3 yrs) under PB and no-till (US\$ 863-865 ha⁻¹) was similar but higher than conventional till (US\$ 543 ha⁻¹) and had positive effect on soil health (Jat et al 2008a). In rice-maize (RM) rotation in the eastern IGP, double no-till resulted in 17% increase in RM system productivity compared to conventional tillage. The PB system improved the RM system productivity by 5% when residues were not retained and to 18% when residues were retained over conventional till practice (Figure 2). Similar to cereal production systems, innovative new generation planters also increased the sugarcane productivity by 21-58% (Table 3) and farm income by US\$ 250 to 300 ha⁻¹ compared to conventional planting techniques in sugarcane based system through advancing cane planting in furrows and wheat or other winter crops on top of the raised beds. In this production system, the disc planters enabled planting of winter crops as intercrops with cane ratoon having thick cane trash that could increase the farm profitability by 15-20%. Also the development of innovative bullock drawn and modular power tiller operated ZT planters have made significant impact on small and marginal farmers, and Hill agriculture where mechanization is very difficult.

The laser assisted precision land leveling, a precursor technology for RCTs was introduced for the first time in India at farm level in western Uttar Pradesh during 2001 that has been demonstrated and accelerated in larger domain in the region. Farmer participatory field trials were carried out on direct seeded (DSR) and puddle transplanted

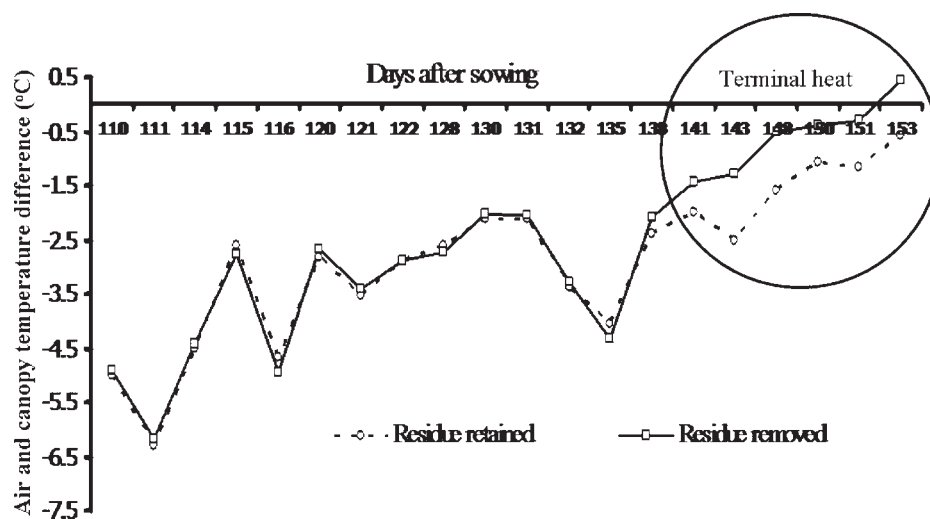
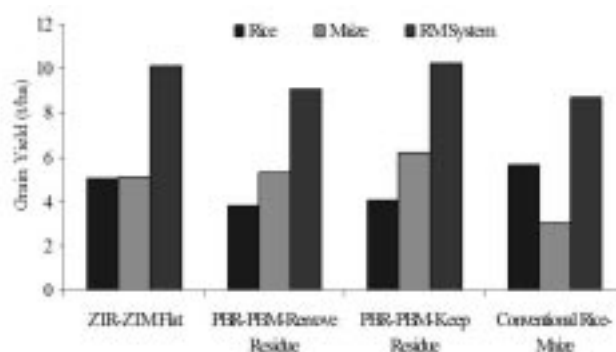


Figure 1. No-till with and without surface retained residues effects on canopy temperature in wheat (ML Jat et al, 2008, Unpublished)

Table 2. Double no-till effects on yield, water productivity and profitability of RW system

Tillage Systems	RW System Yield (t/ha)	RW System Input Water Use (cm)	RW System Net Returns (US\$/ha)
TRR-ZTW	11.9 a	316.7	887 d
ZTDSR-ZTW+Residues	11.5 a	306.8	1128 a
ZTDSR-ZTW	11.1 b	304.9	1073 b
RTDSR-ZTW+Residues	11.9 a	308.6	1086 ab
RTDSR-ZTW	11.4 a	306.3	1013 c
Average	11.6 a	308.7	1037 bc

TPR- Puddled transplanted rice, ZTDSR-Zero till direct seeded rice, RTDSR- Reduced till direct seeded rice, ZTW- Zero till wheat
 Source: ML Jat et al (2008), Unpublished



ZTR-Zero till rice, ZTM-Zero till maize, PBR-Rice on permanent beds, PBM-Maize on permanent beds
Figure 2. Conventional v/s conservation tillage in rice-maize, an emerging cropping system (Singh Ravi Gopal et al, 2008, Unpublished)

rice (TPR) during 2005 and 2006 revealed that the yields of both DSR and TPR increased with laser land leveling compared to traditional land leveling during both the years. The average yield of rice with laser land leveling was 6 and 12% higher compared to traditional land leveling practices during yr 1 and yr 2, respectively (Table 4). The average water saving in rice under laser leveling compared to traditional leveling was recorded at 9.5 and 6.6 % respectively during 2005 and 2006. Further, it was recorded that the water saving due to laser leveling compared to

Table 3. Yield of wheat and cane under innovative (FIRB) and conventional planting systems, western IGP, India

Crop establishment techniques	Western Uttar Pradesh				Haryana [‡]	
	Year-1 ^a		Year-2 ^b		Wheat yield (t ha ⁻¹)	Cane yield (t ha ⁻¹)
	Wheat yield (t ha ⁻¹)	Cane yield (t ha ⁻¹)	Wheat yield (t ha ⁻¹)	Cane yield (t ha ⁻¹)		
FIRB planted wheat- summer planted sugarcane (Sole cropping)	-	-	-	-	6.00 (± 0.22)	60.0 (± 7.10)
FIRB planted wheat-sugarcane intercropped in furrows (simultaneous cropping)	3.44 (± 0.34)	81.8 (± 6.9)	4.21 (± 0.22)	78.9 (± 7.2)	5.84 (± 0.25)	94.5 (± 8.11)
Conventional flat planted wheat-summer planted cane (sole cropping)	3.50 (± 0.21)	59.5 (± 7.2)	4.35 (± 0.31)	64.6 (± 8.1)	5.57 (± 0.31)	60.0 (± 7.78)

^a11 farmer participatory field trials, ^b9 farmer participatory field trials, [‡]7 participatory field trials

Source: Jat et al (2005)

traditional leveling was more in TPR being 1338 and 1271 m³ ha⁻¹ respectively during yr1 and yr 2 compared to DSR with 1271 and 333 m³ ha⁻¹. A marked improvement in water productivity of rice was recorded due to laser land leveling compared to traditional leveling irrespective of crop establishment techniques, however, in yr 1, the improvement was much more under DSR compared to TPR but in yr 2 it was similar under both the establishment techniques (Table 4).

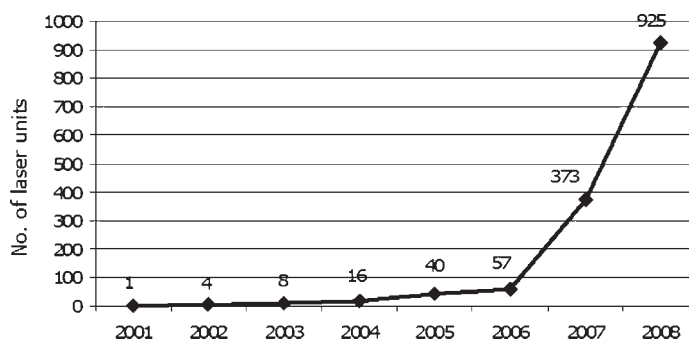
Efforts are being made to accelerate the adoption of this technology as an entry point for the CA based RCTs for realizing the potential benefits of RCTs at farm level. Being an initial cost intensive technology, initial progress was very slow, but large scale demonstrations and promoting custom services has resulted in very fast progress during last three years and currently nearly 925 farmers are rendering custom services on laser technology in the Indo-Gangetic Plains of India (Jat et al 2008c) mainly concentrated in the western IGP (Figure 3). The adoption of laser leveling technology is accelerating at multiple rates and currently nearly 0.2 M ha area has been brought under this technology in the IGP and saved significant energy, irrigation water, fuel, and electricity in addition to the yield advantages in several crops and cropping system (Jat et al 2008c).

Table 4. Land leveling and crop establishment effects on rice grain yield, irrigation water use and productivity under farmer participatory field trials, Western Uttar Pradesh, India

Land leveling	Crop establishment	Grain yield (t ha ⁻¹)		Irrigation water use (m ³ ha ⁻¹)		Water productivity (kg grain m ⁻³ water)	
		2005 [§]	2006 [#]	2005 [§]	2006 [#]	2005 [§]	2006 [#]
Laser	DSR	5.25 ab	4.90 a	11200 d	9067 d	0.50 a	0.54 a
	TPR	5.41 a	4.94 a	13718 c	10150 ab	0.39 b	0.49 b
Traditional	DSR	5.10 b	4.18 bc	12471 b	9400 c	0.41 b	0.45 b
	TPR	4.98 bc	4.49 b	15056 a	11171 a	0.33 c	0.40 c
Mean		5.19	4.63	13111	9947	0.41	0.47

TPR- Puddled transplanted rice, DSR- Direct seeded rice, [§]17 participatory trials, [#]15 participatory trials

Source: Jat et al (2008c)

**Figure 3.** Growth of laser leveler custom service providers in the Indo-Gangetic plains of India

Conclusions and Future Prospects

Development and fine tuning of CA techniques for different production systems in the region in a farmer participatory innovation development mode has made significant impact at farm level and accelerated the adoption of these CA based RCTs. Participatory research findings indicated that CA techniques has resulted in equal or higher productivity, savings in irrigation water use, improved farm profitability, reduced GWP, able to adapt with climate change effects, and improved soil health for long-term sustainable farming under intensive agro-ecosystems compared to conventional intensive tillage practices. However, for realizing potential benefits, the full CA involving all the key elements in systems' perspective are to be developed and adopted at farm level. Tailoring efficient genotypes for CA and tillage x genotype interaction studies in cropping systems perspective needs special attention in future. Long-term effects of CA on crop, soil, biodiversity and climate in various production systems and agro-ecologies should be the future agenda of research under natural resource management program. Animal component is the basis for farming and in CA, retention of crop residues is must, therefore, studies on conservation agriculture based farming systems should be initiated for long-term sustainability of the technology.

References

- Gupta RK and Sayre K. 2007. Conservation Agriculture in South Asia. *Journal of Agricultural Sciences*, Cambridge, 145: 207-214.
- Gupta RK and Seth A. 2007. A review of resource conserving technologies for sustainable management of the rice-wheat cropping systems of the Indo-Gangetic plains. *Crop Protection*, 26: 436-447
- Gupta RK, Hobbs, PR, Jiaguo J, and Ladha, JK. 2003. Sustainability of post-Green revolution agriculture. (in): Ladha JK et al, Improving the productivity and sustainability of rice-wheat systems: Issues and impacts. ASA Spec. Publ. 65. ASA, CSSA, and SSSA, Madison, WI, p.1–25.
- Gupta RK, Hobbs, PR, Jiaguo J and Ladha, JK. 2003. Sustainability of post-Green revolution agriculture. (in): Ladha JK et al, Improving the productivity and sustainability of rice-wheat systems: Issues and impacts. ASA Spec. Publ. 65. ASA, CSSA, and SSSA, Madison, WI, p.1–25.
- Hobbs PR and Gupta RK. 2000. Sustainable resource management in intensively cultivated irrigated Rice-wheat cropping systems of the Indo-Gangetic Plains of south Asia: Strategies and options. (in): Proceedings of the International Conference on Managing Natural Resources for Sustainable Production in 21st Century, 14-18 February 2000 New Delhi (India). p. 584-592.
- Jat ML, Chandana P, Sharma SK, Gill MA, and Gupta RK. 2006. Laser land leveling-A precursor technology for resource conservation, Rice-Wheat Consortium Technical Bulletin Series 7, New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains, pp 48.
- Jat ML, Gupta RK, Sharma SK, Gill MS, Dass Sain and Singh RP. 2008a. Evaluating conservation tillage systems under maize-wheat rotation in Indo-Gangetic plains of India. (in): Proceedings of the 10th Asian Regional Maize Workshop, 20 - 23 October 2008, Makassar, Indonesia, p. 7.
- Jat ML, Gathala M K, Singh KK, Ladha JK, Singh Samar, Gupta RK, Sharma SK, Saharawat, YS and Tatarwal JP. 2008b. Experiences with permanent beds in the rice-wheat system of the Western Indo-Gangetic plain. (in): Humphreys E, Roth CH editors. Permanent beds and rice-residue management for rice- wheat system of the Indo-Gangetic plain. ACIAR Proceedings, 127: 98-107
- Jat ML, Gupta Raj, Ramasundaram P, Gathala MK, Sidhu HS, Singh Samar, Singh RG, Saharawat YS, Kumar V, Chandna P and Ladha JK. 2008c. Laser assisted precision land leveling: a potential technology for resource conservation in irrigated intensive production systems of Indo-Ganges. (in): Proceedings of ADB project, International Rice Research Institute, Las Banos, Philippines (*Under Publication*).
- Jat ML, Singh S, Rai, HK, Chhokar RS, Sharma SK, and Gupta RK. 2005. Furrow Irrigated Raised Bed Planting Technique for Diversification of Rice-Wheat System of Indo-Gangetic Plains. *Journal of Japan Association for International Cooperation Agriculture Forestry*, 28: 25-42.
- Ladha JK, Pathak H, Padre AT, Dawe D, and Gupta RK. 2003. Productivity trends in intensive rice-wheat cropping systems in Asia. (in): Ladha JK et al. editors. Improving the productivity and sustainability of rice-wheat systems: Issues and impacts. ASA Spec. Publ. 65. ASA, CSSA, and SSSA, Madison, WI. p. 45–76.
- Paroda RS, WoodHead T, and Singh RB. 1994. Sustainability of rice-wheat production systems in Asia. RAPA Publ. 1994/11, Bangkok : FAO.
- Rice-Wheat Consortium (RWC). 2006. Research highlights 2005. Rice-Wheat Consortium for the Indo-Gangetic plains, 12th Meeting of the Regional Steering Committee of RWC, Varanasi, Uttar Pradesh, India.
- Sharma PK, and De Datta S.K.1985. Effect of puddling on soil physical properties and processes. In: Soil physics and rice, Manila (Philippines), International Rice Research Institute. P. 217-234.
- Sharma PK, Ladha JK, and Bhushan L. 2003. Soil physical effects of puddling in rice-wheat cropping system. (in): Ladha JK et al, Improving the productivity and sustainability of rice-wheat systems: Issues and impacts. ASA Spec. Publ. 65. ASA, CSSA, and SSSA, Madison, WI, p. 97-113.
- Timsina J and Connor DJ. 2001. Productivity and management of rice-wheat cropping systems: issues and challenges. *Field Crops Research* 69, 93-132.

Strategies to Overcome the Competition for Crop Residues in Southern Africa: Some Light at the End of the Tunnel

Patrick C. Wall

*CIMMYT, P.O. Box MP163, Mount Pleasant, Harare, Zimbabwe
(Email: p.wall@cgiar.org)*

Most small-holder farmers in southern Africa rely on maize as their staple food and manage mixed crop/livestock systems where maize is the major crop and maize residues provide a vital source of livestock feed during the dry season when grazing areas are limited. Conservation agriculture on the other hand relies on ground cover with crop residues to achieve its potential to increase crop yields under rainfed conditions and increase soil health and system sustainability. The competition between the soil and animals for the scarce crop residues thus has become a major point for discussion and often disagreement. However, most analyses of total farm productivity during a transition to conservation agriculture from tillage-based agriculture assume that all of the farm will be converted to the new system in a relatively short period of time. This strategy, while conceptually simple, also results in the maximum competition for residues, and as a result tends to force a decision against CA before its promise of increased yields and system sustainability can be achieved. If the farm is converted gradually to CA, then competition is less, the farmer can learn to manage the new system properly under his/her conditions, and soil degradation on the farm can gradually be reverted while crop productivity increases. The reduced risk of crop failure with CA also allows diversification of crops on the farm, and may include the production of forage crops with markedly better nutritional quality than cereal crop residues. Using examples from farmer managed plots in southern Africa the paper will explore the effects on total productivity. However, there are other difficulties with surface residue retention, principally communal grazing rights after harvest and the prevalence of wild fires or bush fires. Both of these need to be taken into account and while the farmer can control aspects of the solution, overcoming the problems will involve important policy decisions at the community and district levels.

Key words: Crop Residues, Conservation Agriculture, Southern Africa

Conservation agriculture (CA) is a sustainable production system that is based on three principles: minimal soil movement, retention of crop residues on the soil surface and crop rotation. Other principles of productive crop systems also need to be followed such as the use of adapted varieties, replenishment of soil nutrients, good control of weeds, pests and diseases, and generally good crop husbandry and management. However, the three principles set CA apart from much of the world's agriculture which relies on intensive soil tillage, removal and/or burning of crop residues and often monoculture.

Relatively little of the 95 million hectares (Derpsch, 2008) of no-tillage agriculture worldwide, much of which would classify as CA, is managed by smallholder farmers. However, there are important areas of CA on small farms in Brazil, Paraguay, China, Ghana, Zambia and increasingly in Zimbabwe. While there is as much as 2 million ha of wheat sown without tillage in the rice-wheat system of the Indo-Gangetic Plains (www.rwc.cgiar.org), most farmers still intensively till the land for the rice crop.

The principles of CA are equally applicable to large and small farmers, but the techniques and technologies to put the principles into practice depend on farmer circumstances as well as the biophysical conditions. For instance, the equipment utilised in CA by large and small farmers is very different in scale and draught source. This system and circumstance specificity poses a considerable problem for traditional research and extension systems based on a linear flow of knowledge from research to extension to the farmer, as it is impossible for research to develop systems that are adapted to all circumstances. This has resulted in considerable agreement on the need for the development of innovation systems that incorporate multiple agents, including farmers themselves, in a network that focuses on developing systems that function on the fields of innovative farmers (Wall et al., 2002).

Functional CA systems provide multiple benefits to the farmer and the environment. The relative importance of these benefits depends on the most limiting components of the agricultural system, but includes both short-term benefits and others which accrue over time. Short term benefits include increased water infiltration, reduced evaporation, reduced surface crusting, reduced water run-off and soil erosion, and reduced labour demand and fuel use: together these may lead to increased productivity in the first seasons of application of the new system as well as important off-farm environmental benefits. Longer term benefits include: increased soil organic matter levels resulting in improved

nutrient use efficiency; improved soil biological activity which results in improved soil structure, aeration and drainage; increased crop productivity; and increased biological pest control. The incorporation of adequate crop rotations can also result in higher yields, reduced peaks of labour use, and reduced level and frequency of crop diseases.

Most of the benefits of CA result entirely or partially from surface residue cover: not only do the residues protect the surface soil from raindrops and radiation thereby reducing surface sealing, soil crusting and moisture evaporation, and increasing infiltration, but they provide a food source for the soil fauna and flora leading to the increase in soil biological activity that is one of the main drivers of increased system productivity, resilience and sustainability. Obviously, therefore, trying to manage no-tillage systems without surface residue cover will not result in the benefits that accrue to CA systems, and the yield of crops direct-seeded into bare soil is often considerably lower than that of crops sown with conventional tillage practices (Wall, 1999; Sayre et al., 2001).

Because of the importance of soil cover, successful establishment of the system is increasingly difficult in low productivity systems where enough crop residues cannot be produced to achieve adequate levels of ground cover for the following crop. Therefore no-input or low-input strategies are not compatible with CA: sufficient inputs need to be applied not only to achieve increased economic yield but also to produce sufficient residues for “adequate” ground cover for the future. The necessary amount of crop residues or the level of ground cover needed will no doubt be different under different circumstances, and is still a relevant question in many systems, including those semi-arid areas where the principal benefit from CA is generally improved crop water balance. For conditions where soil erosion by water is the major limitation, 30% of ground cover by residues is generally accepted as a target level given that in many studies it reduces soil erosion by at least 75% (Allmaras and Dowdy, 1985; Erenstein, 1997). This level of ground cover can be achieved with as little as 1 t ha⁻¹ of maize residues, whereas 3 t ha⁻¹ of maize stover gives approximately 50% ground cover and a 90% reduction in soil erosion (Erenstein, 1997).

However, smallholder farmers in developing countries generally manage intensive, mixed crop-livestock systems where animals are extremely important components of the system: they contribute to the food security of the household, provide for system diversification, generate cash, spread risk, recycle nutrients, provide draft power and transportation, and are important assets for investment and/or savings (de Haan et al., 1997). Crop residues are an important source of feed, albeit often of low nutritional quality, or of extra income: in South Asia a kilogram of straw is worth from 13 to 32% of a kilogram of grain (O. Erenstein, personal communication). Therefore the need to leave crop residues on the soil surface in CA systems implies direct competition for a scarce and/or valuable resource. As pressure on the land increases, more arable land is dedicated to crops, intensifying the interactions and conflicts between crops and animals (Mueller et al., 2001).

In more marginal environments, crop productivity is lower and therefore crop residues are scarcer and competition for them greater. In areas with prolonged dry seasons, the demand for residues for feed is the greatest (McDowell, 1988; Sandford, 1989; Quiroz et al., 1997). Thus in the irrigated areas of the Indo-Gangetic plains where production levels are high and two or more crops per year are feasible, competition for residues between the needs of soil conservation and livestock feed is less of a problem (Teufel et al., 2008) than in the drier environments of northern and southern Africa, west Asia and parts of the Andes. The adoption of CA in these marginal environments will only advance when it can be demonstrated to farmers that leaving at least part of the residues on the soil surface gives a greater benefit to system productivity than feeding these to animals. That these increases in total system productivity are possible is evident in the results of Sayre et al. (2001): after several years of CA practices in central Mexico, productivity had increased sufficiently that more residues could be removed from the system for animal feed than in the conventional system, while still leaving sufficient for soil cover. However, managing feed supplies over the transition period from conventional agriculture to an established CA system is a problem that several authors quote as a major limitation to the feasibility of CA for smallholder farmers.

The use of residues for animal feed also has a social component. In many regions, especially in rainfed areas, communal grazing rights apply after crop harvest. Thus an individual farmer does not have exclusive rights to the residues on his land, and attempts to conserve them can lead to violent confrontation. For example, in central Mexico, Tripp et al. (1993) report several cases where farmers fenced their fields to keep residues, only to have the residues deliberately burned by irate neighbors. This complex issue can only be resolved by community understanding and involvement in the issue of land degradation, which itself involves considerable investment in information sharing and knowledge development in rural communities.

Strategies

Gradual Conversion to CA

Most evaluations of the problem of feed in the transition from conventional to conservation agriculture assume that the farmer will, or needs to, convert the whole farm to CA at the same moment. This is not necessary, and in fact is not advisable as it is important that the farmer learns to manage the new system properly under his/her circumstances and conditions before converting the farm to CA: in South America it is recommended that the farmer start with only about 10% of the farm, learn to manage the system properly and then gradually incorporate the rest of the farm to CA (Derpsch, 2001).

In Table 1 field data from large-scale farmer-managed demonstration plots at two sites in southern Africa has been used to calculate the impact of converting 10% of the farm to CA on grain production on the farm and stover available for feed. An average farm size for the region of 3 ha (Mekuria and Siziba, 2008) has been assumed. The two sites represent the extremes of productivity levels in the 43 communities in which we are working in southern Africa: Zimuto has extremely sandy soils (93% sand) and relatively low rainfall (mean of 631mm yr⁻¹) while Zidyana soils are generally sandy loams and annual rainfall is approximately 1200mm. Two strategies of use of the crop residues are considered: a) all residues are left on the land in CA and removed in the conventionally tilled part of the farm; and b) residue production above 3 t ha⁻¹ is used for feed from the CA plots (this situation does not occur in Zimuto, Zimbabwe). In all cases there is a slight reduction in the feed available on the farm, but this is offset to some degree by extra grain production. In the harsh environment of Zimuto, grain yields under CA have increased over time relative to the conventionally tilled check, and so in the first season of CA the “break-even” value of the stover (the value of the stover relative to the grain that would economically offset the loss of feed) was only 6% of the value of the grain, whereas by the third year of CA on the field, the break-even value was over 50% of the value of the grain. There is little marketed stover in the communities in which we work in southern Africa, but assuming an average value of that in India, quoted earlier, of 20% of the farm gate price of grain, it would take until the third year of establishment of CA on part of the land before the increase in grain production offsets the reduction in the value of the stover available for feed. At the same time the costs of production of CA are slightly lower than the conventionally tilled fields, and the variable costs of the CA treatment analysed were US\$10 ha⁻¹ lower than the costs in the conventionally tilled treatment, largely due to the opportunity cost of the animals involved in the tillage operations. This saving in costs results in equal benefits even in the first year of conversion of 10% of the farm to CA, and increasing benefits in subsequent years.

In the more productive environment of Zidyana, Malawi, the break-even value of the stover to offset the extra grain production was very high in the first two seasons of CA, but was lower in the third season when yield levels were generally higher and total feed production was higher than in the other years. Thus in this year, feed availability would

Table 1. Differences in grain and stover (feed) production calculated for three years on a 3 ha. farm in two sites in southern Africa after conversion of 10% of the farm to conservation agriculture. Data calculated from farmer managed demonstration plots at the two sites 2004-2008

		Zimuto, Zimbabwe			Zidyana, Malawi				
		Grain kg	Feed kg	Stover break-even value	Strategy 1 ^a			Strategy 2 ^b	
					Grain kg	Feed kg	Stover break-even value	Feed kg	Stover break-even value
Year 1	Conventional	3217	3450		9454	10136		10136	
	10% CA	3239	3105		9767	9123		9572	
	Difference	22	-345	0.06	313	-1014	0.31	-564	0.56
Year 2	Conventional	3621	3882		8413	9020		9020	
	10% CA	3677	3494		8679	8118		8406	
	Difference	56	-388	0.14	266	-902	0.30	-615	0.43
Year 3	Conventional	4432	4752		10957	11749		11749	
	10% CA	4711	4277		11038	10574		10935	
	Difference	279	-475	0.59	81	-1175	0.07	-813	0.10

^a Strategy 1. All residues left on the field in CA.

^b Strategy 2. Partial residue removal from CA plots. Remove residues above 3 t/ha

not be a limiting factor. An economic analysis of results at the Zidyana site shows that the Marginal Rate of Return of the extra investment (mostly due to the costs involved in the application of glyphosate herbicide) in the CA plots was an impressive 426%, largely because of a saving of 21.5 hours of labour per hectare. For this reason, and the fact that in reality farmers in the community own very few large ruminants, CA is spreading rapidly in Zidyana.

Diversification and Fodder Crop Production

Maize is the staple food in southern Africa and smallholder farmers tend to ensure their family food security before venturing into the production of cash crops. Because of the variability of annual rainfall and the frequency of mid-season droughts, farmers tend to define the area they will seed to maize based on the area they will need to provide for their family food needs in a drought year. The limited nutrients available (both in organic and inorganic fertilizers) also tend to be spread over this area. Although this strategy may be the best under conventional tillage in dry years, in a good season with adequate rainfall, farm families do not have the labour necessary to weed the area, crop nutrition is sub-optimal, and yield levels are often just as low as they are in poor rainfall seasons, adding to the riskiness of agriculture.

Although we do not yet have the data to model the best farm strategies, maize yields in all the communities in which we are working with national partners are higher under CA, even in dry seasons. Therefore the risk of economic losses and/or crop failure is reduced. This reduction in risk affects optimum economic fertilization levels: effectively the risk of moisture stress is reduced by CA and so the optimum economic level of fertilization is higher. This is important for the functionality of CA systems. Under conventional agriculture the optimum strategy for the use of scarce nutrient resources is to spread the available nutrients over the whole area that can be weeded (Tabo et al., 2006) because, due to the law of diminishing returns, the productivity of a low rate of fertilizer is higher than the productivity of the same amount of fertilizer applied to a smaller area. This fertilization strategy, often called microdosing, assumes that the effects of applied fertilizer are for the current season only. However, because of the importance of the residues for soil cover in CA, the fertilizer strategy needs to take into account residue production and therefore effects in future seasons. The optimum fertilization strategy under CA is to concentrate nutrients on a smaller area, taking advantage also of the reduced risk of crop loss or failure due to moisture stress under CA. This strategy has the added advantage of reducing the area that needs to be weeded, reducing the cost of labour required to keep the crop weed free: an extremely important aspect for southern African farmers where more than 60% of the labour required to produce a crop is invested in hand weeding (Ellis Jones et al., 1998).

The reduction in risk and labour use under CA, together with the concentration of the maize crop on a smaller area, permit diversification of the farming enterprise. This has been a feature of the adoption of CA on small farms in Paraguay (Sorrensen et al., 1998) and is likely in southern Africa as well. Diversification may involve using the labour freed up by CA for other enterprises, including education and off-farm employment, and/or using the land freed up by the greater productivity of the staple crop for other crops, including the production of fodder crops with far higher nutritive value than the cereal crop residues. This fodder production then replaces the crop residues that are left on the soil surface, and at the same time results in better animal nutrition. Quantification of some of the possibilities under this strategy is currently underway: there is evidence from legume green manure cover crop (gmcc) production that far more biomass and protein can be produced on a relatively small area than is produced though the residues of the maize crop.

Local Policies and Communal Grazing

Communal grazing rights after harvest is one of the major problems experienced by smallholder farmers in many parts of the world who want to maintain their residues on the soil surface. In some countries and regions, this leads to tensions between crop producers and livestock producers, where the latter feel that they have the right to the otherwise “useless” and therefore “free” crop residues. Under these circumstances, where society places no monetary value on the crop residues, it is exceptionally difficult for individual farmers to retain their crop residues on their own fields. Obviously to change these norms, or local policies, involves a change in mind-set or paradigm, which makes the lifting of the communal grazing rights a difficult and time-consuming process. In the Zimuto Communal Area described earlier, some farmers have decided to remove the residues from the field, store them to avoid grazing by roving animals, and then return them to the field at seeding time once animals in the community have to be confined or sent to more distant grazing areas. However, we believe that this strategy is unlikely to succeed because of the labour involved and because it reduces the efficiency of capture of the early rains. We believe that it will be more important to

change the way communities understand and view resource degradation, involving an understanding that crop residues are not an un-needed and free resource, but that they are vital to agricultural sustainability.

Although the change in attitudes about residues, land degradation and communal grazing will undoubtedly be slow and difficult, there are some emerging examples of success. Near the town of Karatu in northern Tanzania, one early adopter of CA convinced his neighbours of the benefits of the system and the importance of the crop residues as soil cover. This group of neighbouring farmers then decided to stable their animals and restrict free grazing of their lands, leading to a community where residues are retained on the soil surface year round (W. Mariki, personal communication). In another village near Karatu, free grazing of animals has been disallowed by the local council (B.Sims, personal communication) because they have seen the benefits of residue retention. Another example comes from the Shamva District of Zimbabwe where a local policy maker observed the benefits of residue retention on our CA Project demonstration plots and re-enacted forgotten regulations which permit farmers to deny access to their fields to grazing animals. This latter example is important in that it shows the need to include local policy makers in the CA innovation system.

Other possibilities for restricting communal grazing involve fencing, either with wooden, wire or live fences. In theory the idea of live fences that also provide nutritive fodder should combine well with CA. However, to date we have not found farmers very receptive to the idea of live fences because of the space they occupy, but we need to invest more time with partners in exploring this option. The cost of wire fencing is generally prohibitive to smallholder farmers, but where wooden or wire fences do exist we advise farmers to initiate CA in these areas so that grazing can be controlled.

Fire and Residues

Fire has been a part of the natural ecosystems in southern Africa throughout history largely due to lightning initiated fires. However, anthropogenic fire is also widely used in the region to regenerate natural pasture and to hunt wild animals, from small antelope to mice. Fire poses a threat to farmers who want to keep their crop residues, and as in the example of Mexico quoted earlier, needs community awareness and commitment, and the intervention of local policy to help change attitudes towards the importance of crop residues for the sustainability of agriculture and land degradation in general.

Conclusion

The success of Conservation Agriculture under many conditions depends on soil cover with crop residues, a resource often used by smallholder farmers for other ends, especially for animal feed. Overcoming the competition for crop residues will not be easy, especially in low-productivity rainfed environments such as southern Africa where competition tends to be most intense. Animals are generally very important components of smallholder farms where they provide sources of income and draught power, as well as serving as a savings repository. Livestock often may be more important than crops in the farming system, and so reductions in feed availability provoke serious system incompatibilities. However, there are several strategies proposed that can allow for residues to be retained on the land while limiting the impact on total farm productivity. These include:

- A gradual transition to CA on the farm so that the impact on total farm feed production is small, and strategies for increasing fodder production over time (below) can be utilised. CA should be initiated only on a small part of the farm (10%) and gradually incorporated into the farming system.
- Taking advantage of increasing crop productivity, and therefore both economic yield and residue production, a portion of the residues can be used for feed and the remainder left on the soil
- Using some of the land freed up for producing other crops by the increased productivity and reduced risk of production of the staple crop, some area can be dedicated to the production of more productive and nutritive fodder crops.
- Control of free grazing of residues by animals through changes in attitude towards degradation and natural resources, combined with local policies
- Agroforestry and live fences that provide sources of high quality feed.

Obviously overcoming competition for residues in systems that are very resource-constrained will not be easy. However, the alternative of continuing with crop residue removal, tillage, and land degradation is not sustainable, and I believe it is unethical to continue to propose short-term solutions to smallholder farmers that will eventually lead to

their, or their descendants, demise. The time for “silver bullets” has gone – we need to look at the principles on which agriculture is based and realise that returning undigested organic matter to the soil is a key to sustainability.

References

- Allmaras, R. R. and Dowdy, R. H. 1985. Conservation tillage systems and their adoption in the United-States. *Soil Till. Res.* 5, 197-222.
- de Haan, C., Steinfeld, H. and Blackburn., H. 1997. *Livestock and the environment: Finding the balance*. European Commission, Directorate-general for Development. Brussels, Belgium. 115p.
- Derpsch, R. 2001. Frontiers in conservation tillage and advances in conservation practice. In: D.E.Stott, R.H.Mohtar and G.C.Steinhardt (eds), 2001. *Sustaining the Global Farm*. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24 -29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory, p 248-254
- Derpsch, R. 2008. No-Tillage and Conservation Agriculture: A Progress Report. In: *No-till Farming Systems*. T. Goddard, M.A. Zöbisch, Y.T. Gan, W. Ellis, A. Watson and S. Sombatpanit (Eds.). Special Publication No. 3, World Association of Soil and Water Conservation, Bangkok, Thailand. 544 pp.
- Ellis-Jones, J., Gatsi, T., Mazhangara, E., Chaizwa, I., Twomlow, S. and Riches, C. 1998. Tillage and weed control interactions on a semi-arid granitic catena. III. Economic assessment of options. In: CIMMYT and Ethiopian Agricultural Research Organization (Editors). *Maize Production Technology for the Future: Challenges and Opportunities: Proceedings of the Sixth Eastern and Southern Africa Regional Maize Conference, 21-25 September, 1998, Addis Ababa, Ethiopia*. 322-326
- Erenstein, O. 1997. ¿Labranza de conservación o conservación de residuos? Una evaluación del manejo de los residuos en México. NRG Reprint Series 97-02. México, D.F.: CIMMYT. 10pp.”
- McDowell R.E. 1988. Importance of crop residues for feeding livestock in small-holder farming systems. In J.D. Reed, B.S. Capper and P.J.H. Neute (eds.) *Plant Breeding and the Nutritive Value of Crop Residues*. Proceedings of a workshop. ILCA, Addis Ababa (Ethiopia), pp 3-27
- Mekuria, M. and Siziba, S. 2008. Understanding the smallholder maize-based farming systems of southern Africa for developing Conservation agriculture technologies: A baseline survey report. CIMMYT Southern Africa Regional Office, Harare, Working paper. 54 pp.
- Mueller, J.P., Pezo, D.A., Benites, J. and Schlaepfer, N.P. 2001. Conflicts between conservation agriculture and livestock over the utilization of crop residues. In: *Conservation Agriculture: A Worldwide Challenge*. García-Torres, L., Benites, J., Martínez-Vilela, A. (Eds.) . ECAF/FAO, Córdoba, Spain. Vol I pp 211-225
- Quiroz, R.A., Pezo, D.A., Rearte, D.H. and San Martin, F. 1997. Dynamics of feed resources in mixed farming systems of Latin America. In: C. Renard (ed) *Crop residues in sustainable mixed crop/livestock systems*. CABI, Wallingford, U.K.. Pp 149-180
- Sandford S.G. 1989. Crop residue / livestock relationships. In “Soil. Crop and Water Management in the Sudano-Sahelian Zone. Proceedings of an Internattional Workshop. Jan 11-16, 1987. ICRISAT Sahelian Center, Niamey, Niger. ICRISAT, Patancheru. pp169-182
- Sayre K.D., Mezzalama, M. and Martinez, M. 2001. Tillage, crop rotation and crop residue management effects on maize and wheat production for rainfed conditions in the altiplano of central Mexico. In: *Conservation Agriculture: A Worldwide Challenge*. García-Torres, L., Benites, J., Martínez-Vilela, A. (Eds.) . ECAF/FAO, Córdoba, Spain. Vol II pp 575-580
- Sorrenson, W.J., Duarte, C., López Portillo, J., 1998: Economics of No-till compared to conventional cultivation systems on small farms in Paraguay, policy and investment implications., Report Soil Conservation Project MAG – GTZ, August 1998
- Tabo, R., Bationo, A., Diallo, Maimouna, K., Hassane, O. and Koala, S. 2006. Fertilizer micro-dosing for the prosperity of small-scale farmers in the Sahel: Final report. Global Theme on Agroecosystems Report No. 23. P.O. Box 12404, Niamey, Niger: International Crops Research Institute for the Semi-Arid Tropics. 28 pp
- Teufel, N., Erenstein, O., Samaddar, A., 2008a. Will conservation agriculture harm livestock? Poster presented at ILRI Annual Programme Meeting 2008, Nairobi, Kenya, 31/03-04/04/2008.
- Tripp R., Buckles, D., van Nieuwkoop, M. and Harrington L. 1993. Land classification, land economics and technical change. Awkward issues in farmer adoption of land-conserving technologies. Seminar presented in “Seminario/Taller Internacional para la Definición de una Metodología de Evaluación de Tierras para una Agricultura Sostenible en México”, El Batán, México, 10-13 August, 1993
- Wall, P.C. 1999. Experiences with crop residue cover and direct seeding in the Bolivian highlands. *Mountain Research and Development*, 19:4, 313-317
- Wall, P.C., Ekboir, J.M. and Hobbs, P.R. 2002. Institutional aspects of Conservation Agriculture. Paper presented at the International Workshop on Conservation Agriculture for Sustainable Wheat Production in Rotation with Cotton in Limited Water Resource Areas, Tashkent, Uzbekistan, October 13-18, 2002.

The Importance of Crop Residue Management in Maintaining Soil Quality in Zero Tillage Systems; A Comparison between Long-term Trials in Rainfed and Irrigated Wheat Systems

Nele Verhulst^{1,2}, Bram Govaerts^{1*}, Els Verachtert², Fabian Kienle³, Agustin Limon-Ortega⁴,
Jozef Deckers², Dirk Raes², Ken D. Sayre¹

¹International Maize and Wheat Improvement Centre (CIMMYT), Mexico, D.F., Mexico

²Department of Earth and Environmental Sciences, Katholieke Universiteit Leuven,
Celestijnenlaan 200 E, 3001 Leuven, Belgium

³Colegio de Postgraduados, Km 36.5 Carr. México -Texcoco, CP 56230, Montecillo, Mexico

⁴INIFAP-CEVAMEX, AP10, Km 17.5 Carr. México-Lechería, CP 56230, Chapingo, Mexico
(*Corresponding author (Email: b.govaerts@cgiar.org))

CIMMYT is committed to improving livelihoods in developing countries by improving the productivity and profitability of farming systems while sustaining natural resources. This paper focuses on the influence of crop residue management on soil quality in zero till systems and includes results from two long-term trials established in the early 1990's in different agro-ecological systems in Mexico: (1) a low-input, semi-arid, rainfed system in the rainfed central highlands (2240 masl) with zero tillage on the flat and (2) a high-input, arid, irrigated system in the northwestern part of the country with zero tilled permanent raised beds. In both zero till systems, the (partial) retention of the crop residues was necessary to maintain soil quality. In the rainfed semi-arid zero tillage system, mean weight diameter obtained by dry sieving, aggregate stability, infiltration, soil moisture content, soil microbial biomass and nutrient status were lower with residue removal than with residue retention. In the irrigated permanent raised bed system, burning of all crop residues resulted in a degradation of soil structure, lower direct infiltration, irrigation efficiency, soil moisture content, soil microbial biomass, lower total N and greater soil sodicity as compared to retaining crop residue at the surface. Practices with partial retention of crop residue showed soil quality similar to practices with retention of all residues. The retention of at least part of the crop residue is essential for the sustainability of zero till systems, although it may be possible to remove part of the residue for other uses, especially in irrigated conditions where biomass production is high.

Key words: zero tillage, permanent raised bed planting, residue management, soil quality

Human efforts to produce ever-greater amounts of food leave their mark on our environment. Persistent use of conventional farming practices based on extensive tillage, and especially when combined with in situ burning of crop residues, have magnified soil erosion losses and the soil resource base has been steadily degraded (Montgomery, 2007). Nowadays, people have come to understand that agriculture should not only be high yielding, but also sustainable (Reynolds and Borlaug, 2006). Farmers concerned about the environmental sustainability of their crop production systems combined with ever-increasing production costs have begun to adopt and adapt improved management practices which lead towards the ultimate vision of sustainable conservation agriculture. Conservation agriculture addresses a concept of the complete agricultural system, combining three basic principles (1) reduction in tillage, (2) retention of adequate levels of crop residues and surface cover of the soil surface and (3) use of economically viable crop rotations. These conservation agriculture principles are applicable to a wide range of crop production systems. Obviously, specific and compatible management components will need to be identified through adaptive research with active farmer involvement for contrasting agro-climatic/production systems.

This paper includes results from two long-term trials operated by the International Maize and Wheat Improvement Centre (CIMMYT) in different agro-ecological systems in Mexico. The first experiment is located near El Batán, approximately 30 km northeast of Mexico City, in the subtropical highlands of Mexico. Rainfed cropping predominates in the area, with rainfall (350–800 mm) occurring during a four to six months summer period, followed by dry, frosty winters. The climate of El Batán makes it representative of many highland areas in the West Asia and North Africa region, the Southern Cone and Andean Highlands of South America, the central highlands of Ethiopia, the Mediterranean coastal plains of Turkey and the highlands of central Mexico. Each area has its specific conditions and problems, but some overall trends are recognisable. The tropical and subtropical highlands (central Mexico, Ethiopia, ...) have been densely populated and intensively cropped for centuries resulting in agricultural sustainability problems related to soil erosion and fertility decline (Scherr and Yadav, 1996). The agricultural system is under stress due to shrinking cultivated area per household, reduced fodder availability and land degradation (Aune et al., 2001). Rainfall is inadequate and

unpredictable, hence crop production is threatened by chronic soil moisture stress. Precipitation is usually intensive and short, leading to high runoff and temporal water logging. Cereal grain yields are low ($<2 \text{ t ha}^{-1}$). Moreover, fields are often weedy and crops are N deficient, soil structure is poor, and sheet and gully erosion are widespread (Nyssen et al., 2000, 2005).

The second experiment is located in the Yaqui Valley in the arid, northwestern part of Mexico. In the Yaqui Valley over the past 25 years, more than 95% of the region's farmers have switched from using flood irrigation on the flat to planting on raised beds (Aquino, 1998). One to four rows are planted on top of the bed, depending on the bed width and crop, with irrigation applied in the furrow. Farmers growing wheat on beds obtain 8% higher yields and save nearly 25% in production costs, compared with the flood irrigation systems (Aquino, 1998). Grain yields in the area exceed 6 t ha^{-1} and input levels are high, e.g. the average N rate for wheat is 275 kg N ha^{-1} . Widespread burning of crop residues often accompanies tillage, although some residues are baled-off for fodder and incorporated during tillage (Sayre, 2004). Bed planting provides a natural opportunity to reduce compaction by confining traffic to the furrow bottoms. The next logical step to increase the sustainability of beds is to make them permanent, avoiding tillage (only reshaping the beds as needed) and retaining and distributing crop residues on the surface.

A simple operational definition of soil quality is given by Gregorich et al. (1994) as 'The degree of fitness of a soil for a specific use'. Within the framework of agricultural production, high soil quality equates to the ability of the soil to maintain high productivity without significant soil or environmental degradation. Evaluation of soil quality is based on physical, chemical and biological characteristics of the soil. Management factors that can modify soil quality include e.g. tillage and residue management systems, and sowing crop rotations (Karlen et al., 1997). This paper focuses on the influence of residue management on soil quality parameters in zero till systems. A comparison is made between conservation agriculture systems in two contrasting agro-ecological areas: (1) a low-input, semi-arid, rainfed system with zero tillage on the flat and (2) a high-input, arid, irrigated system with zero till permanent raised beds.

Materials and Methods

The Rainfed Long-term Trial in Central Mexico

The rainfed experiment is located in El Batán in the semiarid, subtropical highlands of Central Mexico (2240 m a.s.l.; 19.3°N, 98.5°W). The soil has good chemical and physical conditions for farming. The major limitations are periodical drought, periodical water excess and wind and water erosion. The mean annual temperature is 14°C (1990-2001) and the average annual rainfall is 600 mm y^{-1} , with approximately 520 mm falling between May and October. Short, intense rain showers followed by dry spells typify the summer rainy season and the total yearly potential evapotranspiration of 1900 mm exceeds rainfall throughout the year. The El Batán experiment station has an average growing period of 152 days. The soil is a fine, mixed, thermic Cumulic Haplustoll (Soil Survey Staff, 2003) (Cumulic Phaeozem (IUSS Working Group WRB, 2006)). The experiment was started in 1991 as described in Fischer et al. (2002). Individual plots are 7.5 m by 22 m. Standard practices include the use of recommended crop cultivars, with maize planted at $60,000 \text{ plants ha}^{-1}$ in 75 cm rows and wheat planted in 20 cm rows at $100 \text{ kg seed ha}^{-1}$. Both crops are fertilized using urea at 120 kg N ha^{-1} , with all N applied to wheat at the 1st node growth stage (broadcast) and to maize at the 5-6 leaf stage (surface-banded). Weed control is done using appropriate, available herbicides as needed and no disease or insect pest controls are utilized, except for seed treatments applied by commercial seed sources. Planting of both maize and wheat depends on the onset of summer rains but is usually done between June 5 and 15.

The experimental design consists of a randomized complete block with two replications. There are 32 treatments in all. The core set of 16 management practices was based on variation of (1) crop rotation (monocropping vs. a maize/wheat rotation); (2) tillage (conventional vs. zero tillage); (3) residue management (retention vs. removal). A second set of treatments was established in 1996 and includes treatments with partial residue retention and planting on permanent raised beds. In this paper only treatments with zero tillage on the flat and crop rotation will be considered.

The Irrigated Long-term Trial in Northwestern Mexico

The experiment was initiated in 1992 near Ciudad Obregón, state of Sonora, Mexico (Lat. 27.33° N, Lon. 109.09° W, 38 masl). The mean annual temperature is 24.7 °C and average annual precipitation 384 mm, with 253.1 mm in a rainy season from June until August (1971-2000) (<http://www.inegi.gob.mx>). The soil is a coarse sandy clay, mixed montmorillonitic Chromic Haplotorrert (Vertisol Calcaric Chromic), low in organic matter ($< 1\%$) and slightly alkaline (pH 7.7). A detailed description of plot management has been reported in Limon-Ortega et al. (2000). Wheat and maize

are irrigated and managed in an annual rotation: wheat as a winter crop planted in late November to early December and harvested in May, followed by maize as summer crop planted in June on the same whole plots and harvested in October. Both crops are planted on 0.75 m raised beds with wheat in two rows seeded 20 cm apart and maize in one row. Irrigation is applied in furrows. The experiment includes three replicates of each treatment in a randomized complete block design with a split plot treatment arrangement. Main plots consist of tillage-straw factors as follows: (1) *CTB-straw incorporated*: Conventionally tilled raised beds (conventional tillage with beds formed after each crop); wheat and maize residues are plowed under; (2) *PB-straw burned*: Permanent raised beds (zero tillage with continual reuse of existing beds, which are reformed as needed); residues of both wheat and maize are burned; (3) *PB-straw removed*: Permanent raised beds; residues of wheat and maize are removed by baling; (4) *PB-straw partly removed*: Permanent raised beds; maize residues are removed by baling and wheat straw is retained on the soil surface; (5) *PB-straw retained*: Permanent raised beds; maize and wheat residues are kept on the soil surface. Only the permanent raised bed treatments will be included in this paper.

Split plots during the winter comprise seven N fertilizer levels, but for this paper we chose a set of three N treatments (0, 150, and 300 kg N ha⁻¹). Maize receives a uniform application of 150 kg N ha⁻¹. The N fertilizer is applied as urea in the bottom of the furrow and incorporated through irrigation. Each year wheat and maize receive 45 kg P₂O₅ ha⁻¹ banded in the furrow and incorporated through cultivation when reshaping beds.

Soil Quality Parameters

Aggregate size distribution and stability were determined during the 2006 growing season in El Batán as described in Govaerts et al. (2006) and in Ciudad Obregón as described in Limon-Ortega et al. (2006). Time-to-pond, the time it takes before water runs-out of a specific area in the field, was measured during the 2006 growing season in El Batán and during the 2007-2008 season in Ciudad Obregón as described in detail in Govaerts et al. (2006). Small ring infiltration was determined in El Batán as reported in Govaerts et al. (2007a). Infiltration during irrigation was measured for the third auxiliary irrigation in the 2007-2008 season in Obregón. Inflow was measured with a calibrated bucket at the beginning of one furrow per main plot at regular time intervals. Outflow was monitored per main plot with a V-notch weir of 30°. Soil moisture content was determined volumetrically once a week during the 2007 season in El Batán and the 2007-2008 season to a depth of 60 cm. Soil microbial biomass C and N were measured as reported in Govaerts et al. (2007b) and Limon-Ortega et al. (2006).

Results and Discussion

Soil Aggregation

As well in the rainfed trial as in the irrigated trial, the mean weight diameter (MWD) of both dry and wet sieving was the highest when all residues were retained on the surface of the zero till fields. The removal of crop residue in rainfed conditions and the burning of residue in irrigated conditions degraded soil structure as compared to the (partial) retention of the residue (Figure 1). Chan et al. (2002) also found that stubble burning significantly lowered the water stability of aggregates in the fractions >2 mm and < 50 µm. Govaerts et al. (2007c) obtained similar results in a rainfed permanent raised bed planting system in the subtropical highlands of Mexico, where the MWD of dry and wet sieving decreased with decreasing amounts of residues retained, although partial residue removal by baling kept aggregation within acceptable limits. This indicates that total removal of residues has to be avoided, but it is not always necessary to retain all crop residues in the field to achieve the benefits of permanent raised beds or zero tillage on the flat systems. The management of previous crop residues is key to soil structural development and stability since organic matter is an important factor in soil aggregation. Fresh residue forms the nucleation centre for the formation of new aggregates by creating hot spots of microbial activity where new soil aggregates are developed (De Gryze et al., 2005). In addition, the retention of crop residue on the soil surface decreases the breakdown of aggregates by protecting them against raindrop impact (Le Bissonnais, 1996).

Water Infiltration

Time-to-pond

Time-to-pond is a measure for the direct infiltration in the soil. In the rainfed trial, time-to-pond was lower for zero tillage with removal of residue than with (partial) residue retention, but the difference was only significant in the maize

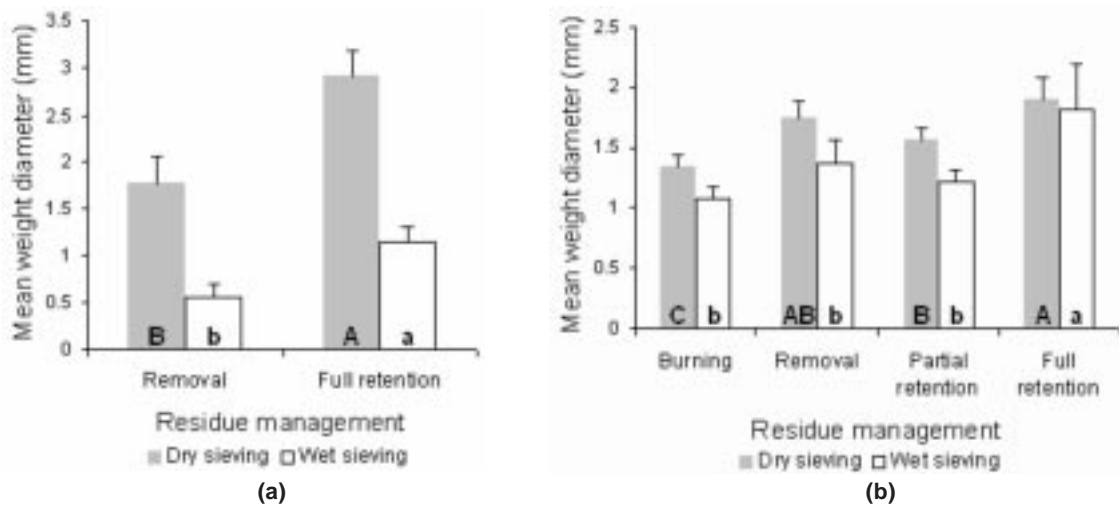


Figure 1. The effect of residue management on mean weight diameter obtained by dry and wet sieving (mm) in the zero till treatments of (a) the rainfed trial in El Batán and (b) the irrigated trial in Ciudad Obregón (Adapted from Limon-Ortega et al. 2006). Values with different letters differ significantly at 5% based on least square difference grouping. Bars indicate standard error.

phase of the rotation (Figure 2). In plots with wheat time-to-pond was higher than in plots with maize and differences between treatments were smaller. The standing crop induces a ‘vertical’ mulching effect that is smaller in maize plots since plant density is lower. In irrigated conditions, time-to-pond increased with increasing retention of residue at the soil surface. Burning of residue resulted in the lowest direct infiltration (Figure 2). The retention of crop residue at the surface prevents surface crust formation by increasing aggregate stability compared to zero tillage with residue removal or burning (Figure 1; Li et al. 2007; Chan et al. 2002) and protecting aggregates from direct raindrop impact (Le Bissonnais 1996). In addition, the residues left on the top soil with zero tillage and crop retention act as a succession of barriers, reducing the runoff velocity and giving the water more time to infiltrate. The residue intercepts rainfall and releases it more slowly afterwards (Scopel and Fideling 2001).

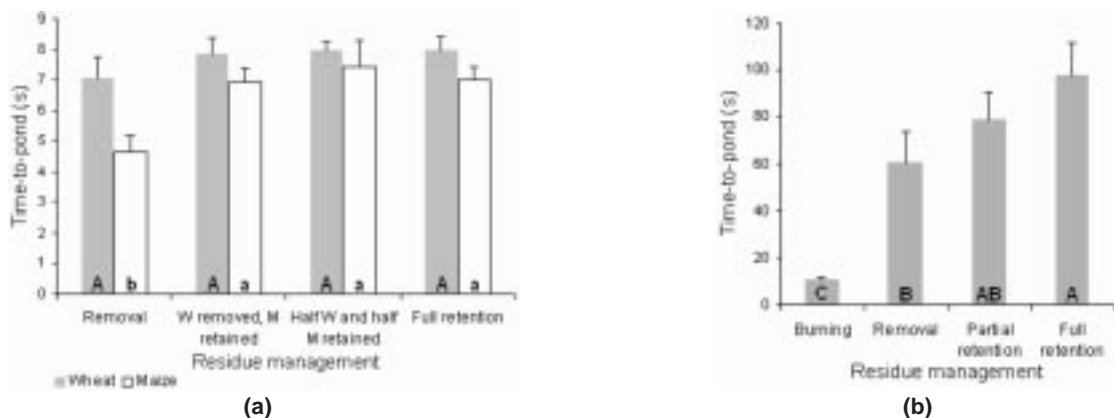


Figure 2. The effect of residue management on time-to-pond (s) in the zero till treatments of (a) the rainfed trial in El Batán during the maize and wheat phase of the rotation and (b) the irrigated trial in Ciudad Obregón during the wheat phase of the rotation. Values with different letters differ significantly at 5% based on least square difference grouping. Bars indicate standard error.

Small Ring Infiltration in Rainfed Conditions

The small ring infiltration measurements in the rainfed trial showed similar results than the time-to-pond. When residue was removed, the time to infiltrate a volume of 250 ml was higher than when residue was retained, before sowing as well as after harvest (Figure 3). The retention of residue stimulates biological activity by earthworms, increasing the connectivity of macropores, an important factor in infiltration (McGarry et al., 2000).

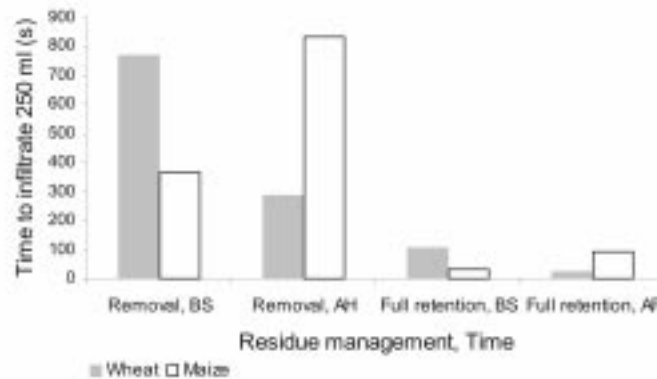


Figure 3. The effect of residue management on the time (s) needed to infiltrate 250 ml of water in the zero till treatments of the rainfed trial in El Batán during the wheat and maize phase of the rotation (Adapted from Govaerts et al. 2007a) with *BS* before sowing and *AH* after harvest.

Infiltration during Irrigation

In irrigated conditions, the permanent raised beds where residue was burned had an irrigation water outflow that became equal or higher than the irrigation water inflow approximately 6 hours after initiating the irrigation. In contrast, for permanent raised beds where residue was retained at the soil surface the outflow remained lower than the inflow during the whole irrigation (Figure 4). Outflow started sooner where residue was burned than where it was retained, reflecting the faster advance of water in the burned treatment. An increased advance of the water in the furrows will reduce the time for infiltration. Similarly, outflow stopped sooner when the irrigation was stopped where residue was burned than where it was retained (Figure 4). This resulted for permanent raised beds with residue burned in a very low average irrigation efficiency of 24% compared to 52% for permanent raised beds where residue was retained. The low infiltration with residue burning is related to the low aggregate stability in this practice compared to residue retention (Figure 1). The reduction infiltration might be enhanced by the reduced cracking with burning compared to retention (data not shown), since the cracks may be important pathways for infiltration in these heavy clay soils.

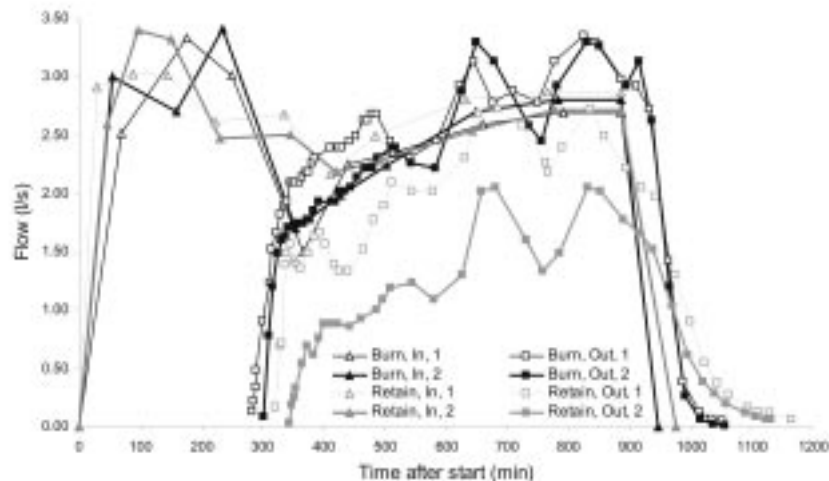


Figure 4. The effect of residue management on infiltration and outflow of irrigation water in the zero till treatments of the irrigated trial in Ciudad Obregón with *In* Inflow (l/s), *Out* Outflow (l/s), *Burn* Residue burning, *Retain* Full residue retention and 1 and 2 field repetitions.

Soil Moisture Content

The increased infiltration with residue retention in zero tillage systems was reflected in the soil moisture content throughout the growing season. In the rainfed trial, soil moisture content in the top 60 cm of the zero till plots was lower when residue was removed compared to when residue was retained. Similarly, in the irrigated trial, soil moisture

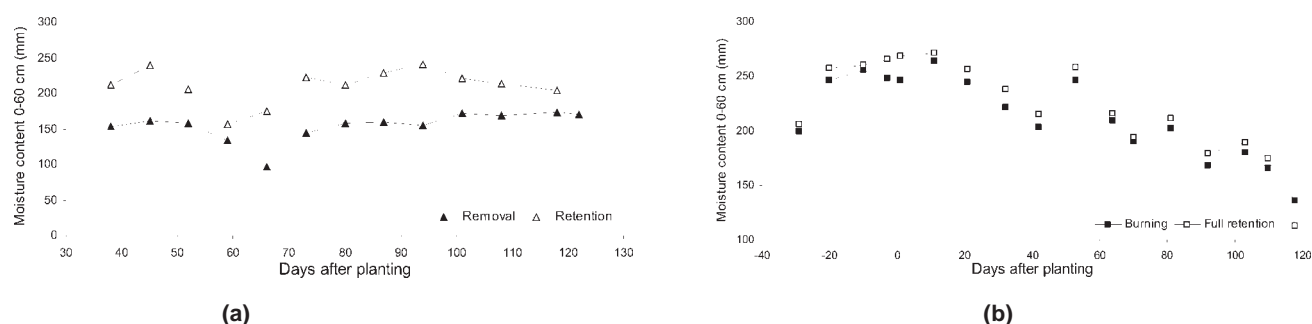


Figure 5. The effect of residue management on moisture content in the profile (0-60 cm) throughout the growing season in the wheat phase of the rotation in the zero till treatments of (a) the rainfed trial in El Batán and (b) the irrigated trial in Ciudad Obregón (irrigations 28 days before and 43, 71 and 95 days after planting).

content was lower when residue was burned than with a surface mulch cover. The difference between practices was smaller in irrigated conditions, probably due to the mitigating effect of irrigation. Also Gicheru et al. (1994) showed that crop residue mulching resulted in more moisture down the profile (0-120 cm) throughout two seasons (a short rains period and a long rains period) within 2 years than conventional tillage and tied ridges in a semi-arid area of Kenya. More soil water enables crops to grow during short-term dry periods and reduces sensitivity to drought stress of the system, which is especially important in rainfed systems.

Microbial Biomass

Soil microbial biomass C and N decreased with decreasing amount of residue retained on the soil surface in the zero till treatments of both the rainfed and the irrigated long-term trial (Table 1). The soil microbial biomass reflects the soil's ability to store and cycle nutrients (C, N, P and S) and organic matter (Dick, 1992; Carter et al., 1999) and plays an important role in physical stabilization of aggregates (Franzluebbers et al., 1999). General suppression is also related to total soil microbial biomass, which competes with pathogens for resources or causes inhibition through more direct forms of antagonism (Weller et al., 2002). Consequently, soil microbial biomass is considered an important indicator of soil quality. The rate of organic C input from plant biomass is generally considered the dominant factor controlling the amount of microbial biomass in soil (Campbell et al., 1997). Franzluebbers et al. (1999) showed that as the total organic C pool expands or contracts due to changes in C inputs to the soil, the microbial pool also expands or contracts. The continuous, uniform supply of C from crop residue retention serves as an energy source for microorganisms.

Table 1. The effect of residue management on soil microbial biomass C and N (SMB C and SMB N) in the wheat phase of the rotation in the zero till treatments of the rainfed trial in El Batán (0-15 cm; Adapted from Govaerts et al. 2007b) and the irrigated trial in Ciudad Obregón (0-7.5 cm; Adapted from Limon-Ortega et al. 2006).

Trial	Residue management	SMB C (mg C kg ⁻¹ soil)	SMB N (mg N kg ⁻¹ soil)
Rainfed, El Batán	Removal	288 B	22 A
	Full retention	453 A	20 A
Irrigated, Cd. Obregón	Burning	540 b	22 c
	Removal	617 ab	25 b
	Partial retention	681 a	25 b
	Full retention	687 a	31 a

Values with different letters differ significantly at 5% based on least square difference grouping.

Chemical Soil Quality

Removing crop residues is associated with a decrease in soil organic matter compared to zero tillage with residue retention (Blanco-Canqui and Lal, 2007), as observed in the rainfed trial. Despite continuous C input in the treatments with residue retention, soil organic matter did not differ from the treatment with residue removal in the irrigated trial. If soil microbial biomass is used as an early indicator of soil organic matter, however, the same trend can be expected in irrigated conditions. In the rainfed trial, removal of residues resulted in a lower nutrient status based on the concentration

of C, N, K and Zn, compared to retention of residues. Only the continuous wheat treatment with residue removal approached the zero tillage treatments with residue retention. In the irrigated permanent raised bed system, total N content was 1.14 times lower in when straw was burned than when straw was retained. The N-mineralization rate was similar for the treatments with straw retained and burned, but greater for the PB-straw partly removed treatment where only wheat straw was retained. This result is presumably related to the C-N ratio of the maize left on the field in PB-straw retained. It has often been reported that during the decomposition of organic matter, inorganic N can be immobilized (Zagal and Persson, 1994), especially when organic material with a large C-N ratio is added to soil. The soil sodicity and P concentration were generally greater when residues were burned compared to the other treatments. Similarly, Govaerts et al. (2007c) observed higher K, N, C and lower Na concentrations with residue retention compared to residue removal in a rainfed permanent raised bed planting system in the subtropical highlands of Mexico.

Implications for Crop Production

In the rainfed, semi-arid zero tillage system, yields were significantly and at least 50% higher with crop residue retention than with residue removal. Zero tillage treatments with partial residue removal gave yields equivalent to treatments with full residue retention (Govaerts et al., 2005). Crop performance was related to soil moisture and the related attributes infiltration, soil structure and organic matter, showing that soil moisture is the main limiting factor of the system (Verhulst et al., 2008). It is therefore essential for the sustainability of any management practice developed for rainfed, semi-arid systems that soil water capture and storage are optimal. Zero tillage with removal of all crop residues resulted in low aggregation and aggregate stability, infiltration and soil moisture content and is not a sustainable management option for the semi-arid highlands. Zero tillage with residue retention will result in higher soil quality and more stable and higher yields in these systems. However, competitive demands for crop residues at farm level (e.g. for use as animal fodder, fuel, or construction material) are high in semi-arid rainfed systems and can constitute serious bottlenecks to the implementation of zero tillage with residue retention (Erenstein, 2002). More research is needed to establish minimum residue retention levels (thresholds).

In the irrigated permanent raised bed system, yield differences between management practices only became clear after 5 years (10 crop cycles), with a dramatic overall reduction in the yield for permanent raised beds where all residues had been routinely burned (Sayre et al., 2005). In contrast to rainfed low rain fall areas, in irrigated agricultural systems (at least in tropical, semi-tropical and the warmer, temperate areas), the application of irrigation water appears to 'hide or postpone' the expression of the degradation of many soil properties associated with continuous residue burning until they reach a level that no longer can sustain high yields, even with irrigation. The difference in soil moisture content between residue management practices was smaller in irrigated than in rainfed conditions due to the correcting effect of irrigation, allowing other factors such as nutrient availability to become more important than in rainfed conditions. Since biomass production is higher in irrigated conditions than in rainfed, semi-arid conditions, there is more scope for the removal of part of the crop residue for other uses. In the permanent raised bed systems where only 25 cm of standing stubble remained in the field (the removal treatment), aggregation, direct infiltration soil microbial biomass and yields remained within acceptable limits (Figure 1, 2 and Table 1; Sayre et al., 2005). Burning all residues resulted in a degradation of soil quality comparable to the removal of all residues in the rainfed semi-arid system, where almost no standing stubble was left in the field in order to simulate the conditions caused by the livestock grazing pressure that is common in these systems.

Conclusions

In both zero till systems, the retention of (part of) the crop residues was necessary to maintain soil quality. In the rainfed semi-arid zero tillage system, mean weight diameter obtained by dry and wet sieving, infiltration, soil moisture content, soil microbial biomass and nutrient status were lower with residue removal than with residue retention. In the irrigated permanent raised bed system, burning of all crop residues resulted in a degradation of soil structure, lower direct infiltration, irrigation efficiency, soil moisture content, soil microbial biomass, total N and greater soil sodicity as compared to retaining crop residue at the surface. Practices with partial retention of crop residue showed soil quality similar to practices with retention of all residues. Especially under rainfed semi-arid production conditions, the best use of crop residues is to retain them in the field as part of the implementation of sound conservation agriculture technologies, although it may be possible to remove part of the residue for other uses. In irrigated conditions where biomass production is higher, there is more scope for the removal of part of the residue. More research is needed to establish minimum residue retention levels (thresholds) with positive impacts on soil quality and crop production.

Acknowledgements

N.V. received a PhD fellowship of the Research Foundation - Flanders. We thank M. Ruiz Cano, J. Gutierrez Angulo, J. Sanchez Lopez, A. Zermeño, C. Rascon, B. Martínez Ortiz, A. Martínez, M. Martínez, H. González Juárez, J. García Ramirez and M. Perez for technical assistance. The research was funded by the International Maize and Wheat Improvement Center (CIMMYT, Int.) and its strategic partners and donors.

References

- Aquino P 1998 The adoption of bed planting of wheat in the Yaqui Valley, Sonora, Mexico. *Wheat Special Report.17a*, CIMMYT, Mexico DF.
- Aune, J.B., Bussa, M.T., Asfaw, F.G. and Ayele, A.A. 2001. The ox ploughing system in Ethiopia—can it be sustained? *Outlook Agr.* **30**, 275–280.
- Blanco-Canqui, H. and R. Lal. 2007. Soil Structure and organic carbon relationships following 10 years of wheat straw management in no-till. *Soil & Till. Res.* **95**: 240-254.
- Campbell, C.A., Janzen, H.H., Juma, N.G., 1997. Case studies of soil quality in the Canadian prairies: long-term field experiments. In: *Soil Quality for Crop Production and Ecosystems Health* (Gregorich, E.G. and Carter, M.R., Eds.), Elsevier, Amsterdam, The Netherlands, pp. 351-397.
- Carter, M.R. 1992. Influence of Reduced Tillage Systems on Organic-Matter, Microbial Biomass, Macro-Aggregate Distribution and Structural Stability of the Surface Soil in a Humid Climate. *Soil Till. Res.* **23**, 361-372.
- Chan, K.Y., Heenan, D.P., Oates, A., 2002. Soil carbon fractions and relationship to soil quality under different tillage and stubble management. *Soil Till. Res.* **63**, 133-139.
- De Gryze, S., Six, J., Brits, C. and Merckx, R. 2005. A quantification of short-term macroaggregate dynamics: influences of wheat residue input and texture. *Soil Biol. Biochem.* **37**, 55-66.
- Dick, R.P. 1992. A Review - Long-Term Effects of Agricultural Systems on Soil Biochemical and Microbial Parameters. *Agr. Ecosyst. Environ.* **40**, 25-36.
- Erenstein, O. 2002. Crop residue mulching in tropical and semi-tropical countries: an evaluation of residue availability and other technological implications. *Soil Till. Res.* **67**: 115-133.
- Fischer, R.A., Santiveri, F. and Vidal, I.R. 2002. Crop rotation, tillage and crop residue management for wheat and maize in the sub-humid tropical highlands. I. Maize and system performance. *Field Crops Res.* **79**, 123–137.
- Franzluebbers, A.J., Haney, R.L., Hons, F.M. and Zuberer, D.A. 1999. Assessing biological soil quality with chloroform fumigation-incubation: Why subtract a control? *Can. J. Soil Sci.* **79**, 521-528.
- Gicheru, P.T. 1994. Effects of Residue Mulch and Tillage on Soil-Moisture Conservation. *Soil Technology* **7**, 209-220.
- Govaerts, B., Fuentes, M., Mezzalama, M., Nicol, J.M., Deckers, J., Etchevers, J.D., Figueroa-Sandoval, B. and Sayre, K.D. 2007a. Infiltration, soil moisture, root rot and nematode populations after 12 years of different tillage, residue and crop rotation managements. *Soil Till. Res.* **94**, 209-219.
- Govaerts, B., Mezzalama, M., Unno, Y., Sayre, K.D., Luna-Guido, M., Vanherck, K., Dendooven, L. and Deckers, J. 2007b. Influence of tillage, residue management, and crop rotation on soil microbial biomass and catabolic diversity. *Appl. Soil Ecol.* **37**, 18-30.
- Govaerts, B., Sayre, K.D. and Deckers, J. 2005. Stable high yields with zero tillage and permanent bed planting? *Field Crop. Res.* **94**, 33-42.
- Govaerts, B., Sayre, K.D. and Deckers, J. 2006. A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico. *Soil Till. Res.* **87**, 163-174.
- Govaerts, B., Sayre, K.D., Lichter, K., Dendooven, L. and Deckers, J. 2007c. Influence of permanent raised bed planting and residue management on physical and chemical soil quality in rain fed maize/wheat systems. *Plant Soil* **291**, 39-54.
- Gregorich, E.G., Carter, M.R., Angers, D.A., Monreal, C.M. and Ellert, B.H. 1994. Towards A Minimum Data Set to Assess Soil Organic-Matter Quality in Agricultural Soils. *Can. J. Soil Sci.* **74**, 367-385.
- IUSS Working Group WRB 2006. *World Reference Base for Soil Resources 2006*. FAO, Rome, Italy, pp. 128.
- Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F. and Schuman, G.E. 1997. Soil quality: A concept, definition, and framework for evaluation. *Soil Sci. Soc. Am. J.* **61**, 4-10.

- LeBissonnais, Y. 1996. Aggregate stability and assessment of soil crustability and erodibility .1. Theory and methodology. *Eur. J. Soil Sci.* **47**, 425-437.
- Li, H.W., Gao, H.W., Wu, H.D., Li, W.Y., Wang, X.Y. and He, J. 2007. Effects of 15 years of conservation tillage on soil structure and productivity of wheat cultivation in northern China. *Austr. J. Soil Res.* **45**, 344-350.
- Limon-Ortega, A., Govaerts, B., Deckers, J. and Sayre, K.D. 2006. Soil aggregate and microbial biomass in a permanent bed wheat-maize planting system after 12 years. *Field Crops Res.* **97**, 302-309.
- Limon-Ortega, A., Sayre, K.D. and Francis, C.A. 2000. Wheat and maize yields in response to straw management and nitrogen in a bed-planting system. *Agron. J.* **92**, 295–302.
- McGarry, D., Bridge, B.J. and Radford, B.J. 2000. Contrasting soil physical properties after zero and traditional tillage of an alluvial soil in the semi-arid subtropics. *Soil Till. Res.* **53**, 105-115.
- Montgomery, D. R. 2007. Soil erosion and agricultural sustainability. *PNAS* **104**: 13268-13272.
- Nyssen, J., Poesen, J., Mitiku Haile, Moeyersons, J., Deckers, J., 2000. Tillage erosion on slopes with soil conservation structures in the Ethiopian highlands. *Soil Till. Res.* **57**, 115–127.
- Nyssen, J., Vandenreyken, H., Poesen, J., Moeyersons, J., Deckers, J., Mitiku Haile, Salles, C. and Govers, G. 2005. Rainfall erosivity and variability in the Northern Ethiopian Highlands. *J. Hydrol.* **311**, 172–187.
- Reynolds, M. and Tuberosa, R. 2008. Translational research impacting on crop productivity in drought-prone environments. *Curr. Opin. Plant Biol.* **11**: 171–179.
- Sayre, K.D. 2004. Raised-bed cultivation. In: *Encyclopedia of Soil Science*. (R Lal Ed.) Marcel Dekker, Inc, New York.
- Sayre, K.D., Limon-Ortega, A. and Govaerts, B. 2005. Experiences with permanent bed planting systems CIMMYT/Mexico. In: *Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico* (Roth, C.H., Fischer, R.A., Meisner, C.A. Eds.), Proceedings of a workshop held in Griffith, Australia. ACIAR Proceedings 121. ACIAR, Griffith, Australia, pp. 12-25.
- Scherr, S.J. and Yadav, Y. 1996. Land degradation in the developing world: implications for food, agriculture, and the environment to 2020. *Food, Agriculture, and the Environment Discussion Paper 14*, International Food Policy Research Institute, Washington, DC.
- Scopel, E. and Findeling, A. 2001. Conservation tillage impact on rainfed maize production in semi-arid zones of western Mexico. Importance of runoff reduction. In: *Conservation Agriculture a worldwide challenge. I World Congress on Conservation Agriculture Madrid*. XUL, Cordoba, Spain, pp. 179-184.
- Soil Survey Staff 2003. *Keys to Soil Taxonomy*, United States Department of Agriculture, Natural Resources Conservation Service, Washington, D.C., USA, pp. 332.
- Verhulst, N., Govaerts, B., Sayre, K.D., Deckers, J. and Dendooven, L. 2008. Using NDVI and soil quality analysis to assess influence of agronomic management on within-plot spatial variability and factors limiting production. *Plant Soil*, In Press, DOI 10.1007/s11104-008-9787-x.
- Weller, D.M., Raaijmakers, J.M., Gardener, B.B.M. and Thomashow, L.S. 2002. Microbial populations responsible for specific soil suppressiveness to plant pathogens. *Annual Review of Phytopathology* **40**, 309-348.
- Zagal, E. and Persson J. 1994. Immobilization and remineralization of nitrate during glucose decomposition at four rates of nitrogen addition. *Soil Biol. Biochem.* **26**, 1313-1321.

Conservation Agriculture – Constraints, Issues and Opportunities in Rainfed Areas

B. Venkateswarlu, K.L. Sharma and J.V.N.S. Prasad

*Central Research Institute for Dryland Agriculture, Hyderabad, 500 059, Andhra Pradesh, India
(Email: director@crida.ernet.in/vbandi_1953@yahoo.com)*

In India, out of 142.2 m ha net cultivated area, about 87 m ha is unirrigated. While the irrigated area produces about 56% of total food requirement, remaining 44% of the total food production is supported by rainfed agriculture. Most of the essential commodities such as coarse cereals (90%), pulses (87%), and oil seeds (74%) are produced from the rainfed agriculture. In view of the stagnating productivity levels of irrigated agriculture, the contribution from the rainfed agriculture should increase to meet the requirements of the growing population. In India, the total degraded area accounts to 120.7 m ha, of which 73.3 m ha was affected by water erosion, 12.4 m ha by wind erosion, 6.64 m ha by salinity and alkalinity and 5.7 m ha by soil acidity (Anonymous 2008). Land degradation is a major threat to our food and environmental security and the extent of degradation is more pronounced in rainfed regions.

Due to growing resource degradation problems world wide, conservation agriculture has emerged as an alternative strategy to sustain agricultural production. Conservation agriculture (CA) is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment (FAO 2007). CA is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes. CA is characterized by four principles that are linked to each other. They are (i) minimum mechanical soil disturbance for erosion control, (ii) maintenance of permanent organic soil cover, (iii) diversified crop rotations for pest and disease control, conserving bio-diversity and (iv) controlling in field traffic for reducing the compaction. However, in practice, zero tillage and residue retention have emerged as the two cardinal principles of CA.

Conservation agriculture is practiced on over 96 m ha area world wide, most of it is in USA, Brazil, Argentina, Canada and Australia. CA became an acceptable practice for the farmers in these countries due to decades of research and extension and concerns of the farmers, scientists and the public on soil erosion. Due to the efforts of the Rice-Wheat Consortium and several institutions of the national agricultural research system, zero till technology has been introduced into India and neighboring countries and it is currently adopted by farmers in over 2 million ha largely in the Indo-Gangetic plains. World-wide, CA or no-till farming has spread mostly in the rainfed agriculture. However, in India its success is more in irrigated belt of the Indo-Gangetic plains. Considering the severe problems of land degradation due to runoff induced soil erosion, rainfed areas particularly in arid and semi-arid regions require the practice of CA more than the irrigated areas in order to ensure a sustainable production. This chapter reviews the constraints and scope of CA in areas other than the Indo-Gangetic plains of the country, focusing on arid and semi arid zones.

Rainfed Production Systems

Unlike the homogenous growing environment of the IGP, the production systems in arid and semi-arid regions are quite heterogeneous and diverse in terms of land and water management and cropping systems. These include the core rainfed areas which cover upto 60-70% of the net sown area and the irrigated production systems in the remaining 30-40% area. The rainfed cropping systems are mostly single cropped in the red soil areas while in the black soil regions, a second crop is taken on the residual moisture. In rabi black soils, farmers keep lands fallow during kharif and grow rabi crop on conserved moisture. The rainfall ranges from >500 mm in arid to 1000 mm in dry sub-humid. Alfisols, Vertisols, Inceptisols and Entisols are the major soil orders. Soils are sloppy and highly degraded due to continued erosion by water and wind. Sealing, crusting, sub-surface hard pans and cracking are the key constraints which cause high erosion and impede infiltration of rainfall. The choice and type of tillage largely depend on the soil type and rainfall. Leaving crop residue on the surface is another important component of CA, but in rainfed areas due to its competing uses as fodder, little or no residues are available for surface application.

The key principles of rainfed agriculture rely on soil and water conservation, both essential components of the CA. Tillage in rainfed areas is mostly carried out for seed bed preparation and interculture operations for weed control and does not use heavy equipment. Though conserving both soil and water are equally important; in low to medium rainfall regions, more priority is given for conservation of rainfall by facilitating better infiltration and reduced runoff. That is why, deep tillage once in three years is suggested to promote greater infiltration of rainwater and control weeds. This also breaks the sub surface hard pan. However, practices like chiseling can meet the objective of breaking the hard pan without soil inversion associated with deep tillage.

Experience from several experiments in the country showed that minimum or reduced tillage does not offer any advantage over conventional tillage in terms of grain yield without incorporation of surface residue. Leaving surface residue is key to control runoff, soil erosion and hard setting in rainfed areas which are the key problems. In view of the shortage of residues in rainfed areas in arid and semi-arid regions, several alternative strategies have emerged for generation of residues either through *in situ* cultivation and incorporation as a cover crop or harvesting from perennial plants grown on bunds and adding the green leaves as manure cum mulching. Agroforestry and alley cropping systems are other options where biomass generation can be integrated along with crop production. This indicates that the concept of CA has to be understood in a broader perspective in arid and semi-arid areas which includes an array of practices like reduced tillage, land treatments for water conservation, on-farm and off-farm biomass generation and agroforestry. Here, conservation tillage with residue retention on surface are more appropriate than zero tillage which is emphasized in irrigated agriculture. Experiences on zero or reduced tillage, residue incorporation, stubble mulching, green leaf manuring and land treatments for water conservation from rainfed cropping systems within the arid and semi arid regions are presented below.

Conservation Tillage in Rainfed Cropping Systems

As mentioned earlier, conservation tillage is a more appropriate strategy for rainfed production systems to promote CA. Conservation tillage is a generic term encompassing many different soil management practices. It is generally defined as 'any tillage system that reduces loss of soil or water relative to conventional tillage; mostly a form of non-inversion tillage, allows protective amount of residue mulch on the surface. According to Lal (1989), conservation tillage i) allows crop residues as surface mulch, ii) is effective in conserving soil and water, iii) maintains good soil structure and organic matter contents, iv) maintains desirably high and economic level of productivity, v) cut short the need for chemical amendments and pesticides, vi) preserves ecological stability and vii) minimizes the pollution of natural waters and environments. In other words, the basic principles of conservation tillage and dryland agriculture are essentially same.

Several experiments were conducted to assess the impact of tillage, land treatments and mulching on different rainfed crops across the country. Under semi-arid conditions at Hyderabad, summer tillage helped in higher soil moisture retention by 20%, reduced weed infestation by 40% and contributed to higher yields (Table 1).

Table 1. Effect of off-season tillage on grain yields of sorghum and castor in Alfisols at Hyderabad

Practice	Sorghum grain yield* (t/ha)	Castorbean** (t/ha)
Without off-season tillage	1.87	0.32
With off-season tillage	2.60	0.31

* Mean of three seasons; ** Mean of two seasons

Table 2. Effect of land shaping on the yields of wheat and chickpea in sub- montane soils at Ballawal-Saunkhri and pearl millet in alluvial soils of Agra

Land shaping	Wheat and chickpea mixture, 3 seasons (t/ha)	Pearlmillet (t/ha)	
		Rainfall 320 mm	Rainfall 660 mm
Normal planting	1.05	1.34	2.22
With land leveling	1.65	1.63	2.31

In sub-montane region of Hoshiarpur in Punjab and in the Inceptisols at Agra, land shaping resulted in higher crop yields. The benefits were seen mostly in low rainfall years owing to even distribution of soil moisture due to leveling (Table 2).

Practices like contour cultivation, and cultivation on graded bunds help in effective conservation of moisture. These practices reduce runoff up to 40% and contribute to yield increments up to 25-35% depending on the rainfall situation. The most important conservation practice acceptable to farmers is the ridge and furrow system of planting. Several trials across different soil types and rainfall zones conclusively proved the advantages of ridge and furrow systems over flat planting. Ridges and furrows reduce runoff and help in *insitu* moisture conservation. Response to ridges and furrows in a number of coarse cereal and legume crops was more in moderate rainfall regions than either severely drought prone or high rainfall regions (Table 3).

Table 3. Response of coarse cereal and legumes crops to land treatments under different intensities of drought

Crops (seasons)	Grain (t/ha)		Response (%)
	Flat planting	Ridges - Furrows	
Severe Drought			
Coarse cereals (19)	1.73	2.02	17
Legumes (24)	0.71	0.78	10
Moderate Drought			
Coarse cereals (12)	1.51	1.92	28
Legumes (1)	0.30	0.42	40
Less Prone to Drought			
Coarse cereals (1)	0.79	0.91	15

Straw and soil mulching are other simple practices that conserve moisture. The effect of mulching is seen more in *rabi* crops than *kharif* crops. Advantages of mulching was noted both under adequate and sub-optimum soil moisture. Shallow and fibrous rooted crops benefit more than deep rooted crops from mulching. In deep Vertisols, cracks are common due to swelling and shrinking properties of these soils. Once the cracks are sealed due to rainfall, the soil does not allow any further infiltration. Under such conditions, vertical mulching is recommended which helps in maintaining the gaps between the cracked surfaces and protects the soil from sealing. Trials showed that crop like *rabi* sorghum was benefited significantly from vertical mulching.

However, experiments on reduced or zero tillage in arid and semi arid climatic regions did not give encouraging results so far. Farmers generally adopt a system of plough planting which can be considered as minimum tillage. However, this practice is not suitable for deep black soils due to heavy weed infestation and reduction in infiltration of water. In arid regions, zero tillage was found to be significantly inferior to conventional tillage with pearl millet. Pearl millet yields were higher under conventional tillage over no tillage for four years continuously (Table 4). In the fourth year, the crop completely failed in the no-till plot. The root growth was poor and considerable reduction in biomass production was noted due to reduction in initial plant population. The benefits of residue on the surface have not been tried as the authors suggest that pearl millet residues are highly prized as fodder in arid regions which face acute scarcity of fodder. Alternatively, the use of residues of mustard and sesame are suggested which are not used as fodder.

In a long term experiment (8 years) carried out under semi-arid conditions at Hyderabad, conventional tillage and minimum tillage (plough planting) were compared for their effect on yields and sustainable yield index of sorghum and castor in a rotation. Minimum tillage was inferior to conventional tillage due to heavy weed infestation and reduction in infiltration of water due to compaction of the surface soil (Table 5).

Table 4. Yields of Pearl millet under conventional and no-tillage conditions Under arid conditions at Jodhpur

Year	Pearl millet yield (q/ha)	
	Conventional Tillage	No-tillage
1995	6.48	5.84
1996	9.09	2.26
1997	7.14	2.26
1998	3.83	-

Source: Aggarwal et al 1998

Table 5. Long-term effects of land management on crop yields and sustainable yield index (8 years)

Residues	Sorghum (kg/ha)		Castor (kg/ha)		SYI	
	Conventional tillage	Plow planting	Conventional tillage	Plow planting	Conventional tillage	Plow planting
Sorghum	1127	810	820	477	0.49	0.35
Gliricidia loppings	1201	895	925	507	0.50	0.37
No residue	1103	840	840	448	0.48	0.31
Mean	1144	848	862	477	0.49	0.34
Tillage	**	**	*			
Residue	**	**	*			
T x R	NS	NS	NS			

SYI - Sustainability Yield Index, NS - Non-significant at $P > 0.05$

*Significant difference at $P = 0.05$, **Significant difference at $P = 0.01$

Source: Sharma et al, 2005

In another experiment involving sorghum and mung bean rotation, conventional and reduced tillage were compared in a 8-year study (1998-2005). The pooled analysis indicated that reduced tillage across all integrated nutrient management treatments remained consistently lower in terms of sorghum grain yield but at the end of 8 years, the yields came close to the conventional tillage indicating that it takes long period under semi-arid conditions before reduced tillage comes on par with the conventional tillage (Fig.1).

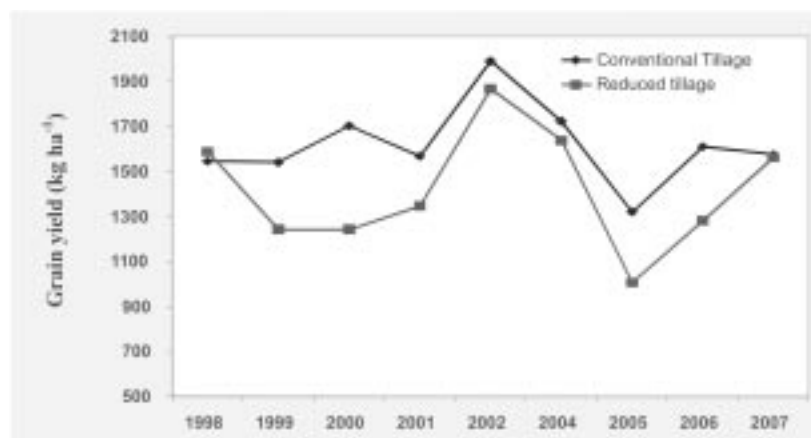


Figure 1. Sorghum grain yield over years (1998-2007) as influenced by conventional and reduced tillage under semi arid conditions at Hyderabad. (Sharma et al 2009)

In a network project on tillage conducted since 1999 at various centers of the All India Coordinated Research Project for Dryland Agriculture, it was found that rainfall and soil type had a strong influence on the performance of reduced tillage (Ramakrishna et al 2005). In arid regions (<500 mm rainfall), low tillage was found on par with conventional tillage and weed problem was controllable in arid inceptisols and aridisols. In semi arid (500-1000 mm) region, conventional tillage was superior. However, low tillage + interculture was superior in semi-arid Vertisols and low tillage + herbicide was superior in Aridisols. In sub-humid (>1000 mm) regions, weed problem was severe depending on the rainfall distribution. In this zone, there is a possibility of reducing tillage intensity by using herbicide. Thus, there is a possibility of greater success of minimum tillage in high rainfall sub-humid regions.

Utera cropping is an important practice followed by farmers in eastern India which has all elements of the conservation farming. Crops like lathyrus and linseed are grown as a relay crops after rainfed low land paddy which minimizes the cost of tillage and takes advantage of the residual moisture. However, the productivity is low due to poor crop stand of *utera* crop. Improvements can be made both through better crop choices and agronomic management of the *utera* crop and manipulation of the stubble height of the paddy crop at harvest.

Critical Gaps and Researchable Issues

- The success of conservation agriculture in rainfed areas depends on two critical elements, viz., residue retention on surface and weed control. Since residues are generally used as fodder in drylands, there is a need to determine the minimum residue that can be retained without affecting the crop-livestock system. Initially, emphasis may be given for crops whose residues are not used as fodder.
- More research on weed management under minimum tillage in a cropping system perspective.
- Identification of alternative sources of fodder for livestock to spare crop residue for conservation farming.
- Identification of critical thresholds of tillage for various rainfall, soil and cropping systems, such that the main objectives of rainwater conservation are not compromised. This will balance the need for conserving soil and capture rainwater in the profile.
- Farm implements needed for seed and fertilizer placement simultaneously for ensuring optimum plant stand, early seedling vigour in rainfed crops under minimum tillage.
- Control of termites in order to enhance the value of residue left on surface during long interval period between two crops.

Summary

Conservation agriculture in arid and semi-arid regions has to be understood in a broader perspective. It should involve both soil and water conservation methods mutually reinforcing each other. Conservation tillage appears more appropriate under rainfed agriculture than zero tillage. Tillage alone without residue retention may not be of much utility. Therefore, the real challenge lies in ways and means of sparing the crop residue for conservation farming and find out alternative strategies of meeting fodder requirements of livestock. CA practice has to be adopted holistically so that it minimizes soil loss, conserves water and controls weeds which are essential for success of crop production under rainfed conditions.

References

- Aggarwal RK, Praveen Kumar Singh YV, Lodha S 1998. Enhancing fertilizer use efficiency in conjunction with residue management in dryland crops and cropping systems in low rainfall conditions. Indo-US Project, Consolidated work report, 1990-98.
- Anonymous 2008. Harmonisation of wastelands/degraded lands datasets of India. Published by National Rainfed Area Authority (NRAA), Ministry of Agriculture, Government of India, NASC Complex, DP Sastri Marg, New Delhi-110012, 5 p.
- Food and Agriculture Organization (FAO). 2007. Agriculture and Consumer Protection Department. Rome, Italy Available from <http://www.fao.org/ag/ca/>
- Lal R 1989. Conservation tillage for sustainable agriculture: tropics versus temperate environments. *Advances in Agronomy* **42**: 86–197.
- Ramakrishna YS, Vittal KPR, Sharma KL 2005. Conservation agriculture in rainfed semi arid tropics- Some past experiences. Lessons learnt and future scopes. In: Conservation agriculture-Status and Prospects. Eds. IP Abrol, RK Gupta and RK Mallik. Centre for Advancement of Sustainable Agriculture, New Delhi, pp 242.
- Sharma KL, Kusuma Grace J, Srinivas K, Ramakrishna Y S, Korwar G R, Maruthi Sankar G, Uttam Kumar Mandal, Ramesh V, Hima Bindu V, Madhavi M, and Pravin Gajbhiye 2009. Influence of Tillage and Nutrient Sources on Yield Sustainability and Soil Quality under Sorghum-Mung Bean System in Rainfed Semi-Arid Tropics. *Communications in Soil Science and Plant Analysis* (In Press).
- Sharma KL, Mandal UK, Srinivas K, Vittal KPR, Biswapati Mandal, Kusuma Grace, Ramesh V 2005. Long term soil management effects on crop yields and soil quality in dryland alfisol. *Soil and Tillage Research* **83**:246-259.

Session 1.2: Input Management (Water, Nutrients, Seed and Agro-chemicals)

Perspectives on Nutrient Management in Conservation Agriculture*

Amir Kassam¹ and Theodor Friedrich²

Plant Production and Protection Division, Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00153 Rome, Italy
(*kassamamir@aol.com; ²Theodor.Friedrich@fao.org)

Conservation Agriculture (CA) systems aim at enhancing soil health and function as a precursor to sustainable production intensification. Nutrient management in CA must be formulated within this framework of soil health. Thus, nutrient management strategies in CA systems would need to attend to the following four general aspects, namely that: (i) the *biological processes* of the soil are enhanced and protected so that all the soil biota are microorganisms are privileged and that soil organic matter and soil porosity are built up and maintained; (ii) there is adequate *biomass production and biological nitrogen fixation* for keeping soil energy and nutrient stocks sufficient to support higher levels of biological activity, and for covering the soil; (iii) there is an adequate *access to all nutrients* by plant roots in the soil, from natural and synthetic sources, to meet crop needs; and (iv) the *soil acidity* is kept within acceptable range for all key soil chemical and biological processes to function effectively. The paper discusses in general terms the above four aspects of nutrient management in CA systems.

Key words: Conservation Agriculture, Soil Health, Nutrient Management

Fundamentally, CA is underpinned by biologically-framed management practices, the so called 'second-paradigm approaches' as enunciated by Sanchez (1994). As such, soil organic matter and soil biota are essential components in the complex system of interactions related to soil health and crop productivity. They provide a basis for optimizing the use of inorganic soil amendments and plant nutrients so that there is a positive-sum effect on agricultural productivity and the environment. Since the second-paradigm approaches are relatively new, little systematic research has been done on how to harness the potentials of biologically-framed agricultural production systems. However, an exciting glimpse of the scientific foundations of this emerging biological paradigm for agricultural production systems and its empirical accomplishments can be obtained from the work of a number of scientists presented in a single volume by Uphoff *et al.* (2006).

Conservation Agriculture (CA) systems are defined by three key elements, namely: no or minimal mechanical soil disturbance, permanent organic soil cover specially by crop residues and cover crops, and diversified crop rotations in the case of annual crops or crop associations in case of perennial crops, including legumes. These elements in various combinations aim at establishing and sustaining healthy soil systems that can offer the best crop and livestock productivities and environmental services within the prevailing ecological and socio-economic conditions while optimizing the use of agrochemicals with biological interventions. CA system principles cannot be applied in a standardized prescriptive manner, and therefore in many ways they do represent a radical departure from the prevailing tillage-based mono-cropped production systems that depend dominantly on external inputs of mineral fertilizer and pesticides to maintain crop productivity and output.

Soil health is the capacity of the soil to function as a living system in which soil biological processes or the endogenous inputs are utilised alongside any exogenous inputs required to achieve the desired level of agricultural production that is economically and environmentally sustainable. Thus, with CA systems, the establishment and maintenance of healthy soil condition is inextricably linked to the achievement of effective nutrient management.

This paper elaborates on the notion of soil health in CA system as a precondition for effective nutrient management, and discusses in general terms four broad elements that need to be considered in nutrient management strategies for CA systems.

Soil Health and Conservation Agriculture

For a soil to be productive for agricultural use, it must *inter alia* have the space for plant roots to grow, to hold and make water and nutrients available to plant roots, and provide a conducive biotic and chemical environment for soil microorganisms to function to maintain soil porosity, fix atmospheric nitrogen, hold and mineralize nutrients. All these dimensions must operate together and form the basis of soil health as defined below (Derived by combining

*The views expressed in this paper are the personal opinions of the authors and do not necessarily quote the official policy of FAO

Doran and Zeiss; Wolfe; and Trutmann, quoted together on http://ppathw3.cals.cornell.edu/mba_project/moist/TropSCORE.html.)

“Soil health is the capacity of soil to function as a living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. It emphasises a unique property of biological systems, since inert components cannot be sick or healthy.

Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots (e.g., nitrogen-fixing bacteria and mycorrhizal fungi); recycle essential plant nutrients; improve soil structure (e.g., aggregate stability) with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production.

Examples of management practices for maximizing soil health would include maintaining vegetative cover on the land year-round to increase organic matter input and minimize soil erosion, more reliance on biological as opposed to chemical approaches to maintain crop productivity (e.g., rotations with legume and disease-suppressive cover crops), and avoiding physical (mechanical) interventions which might compact, alter or destroy the biologically-created porous structural arrangements of soil components.”

In many parts of the world soils are acknowledged to be sick, in poor health, and falling in potential for self-sustaining productivity. While there is much talk of ‘soil quality’ as if it were a static and sufficient characteristic, there is less-frequent mention of ‘soil health’, referring particularly to the biological dynamics of soil quality. (A relevant definition of Soil Health has been given above).

If plants we see above-ground don’t thrive because soil is in poor condition, then probably the life below ground doesn’t thrive either (= is ‘sick’), for the same reasons, jeopardizing the effectiveness of the mutual interdependence of the above-and below-ground parts of the soil/plant system. It is easy to see the symptoms above-ground, but more difficult (as yet) to discern and characterize them below the surface.

Soil in ‘good condition’ (static) or ‘good health’ (dynamic) benefits from the following key components of CA (Shaxson *et al.* 2008):

Minimum disturbance of optimum porous soil architecture, which provides/maintains: (a) Optimum proportions of respiration gases in the rooting-zone, (b) Moderates organic-matter oxidation; (c) Porosity to water movement, retention and release at all scales, and (d) Limits re-exposure of weed seeds and their germination.

A permanent covering of sufficient organic matter (esp. crop residues) over the soil surface, which provides: (a) Buffering against severe impact of solar radiation and rainfall; (b) A substrate for soil organisms’ activity; (c) Raised cation-exchange capacity for nutrient capture, retention and slow-release; and (d) Smothering of weeds

Cropping sequences and rotations which include legumes, providing: (a) Minimal rates of build-up of populations of pest species, through life-cycle disruption; (b) Biological N-fixation in appropriate conditions, limiting external costs; (c) Prolonged slow-release of such N from complex organic molecules derived from soil organisms; (d) Range of species, for direct harvest and/or fodder; and (e) Soil improvement by organic-matter addition at all depths reached.

In light of the above elaboration of soil health and CA, it is clear that scope of the topic of nutrient management in CA systems is extremely wide and complex. Nor do we believe that enough scientific research has been done on nutrient management aspects to explain most of the productivity-related ecological process at work. Instead, the following sections offer some general perspectives on four elements of nutrient management in CA.

Elements of a Nutrient Management Strategy in CA

Being a biologically-based practice with an agro-ecological perspective, CA does not focus on a single commodity or species. Instead, it addresses the complex interactions of several crops to particular local conditions capitalizing on the complex systems of interactions involved when managing soil systems productively and sustainably. An illustration of soil system dynamics under CA developed from the work of Lucien Séguéy and CIRAD researchers in several countries is given in Uphoff *et al.* (2006).

Therefore nutrient management practices in CA systems cannot be reduced to simple physical input-output model. While there is much new work that needs to be done to formulate nutrient management strategies in CA

systems, it would seem to us that all such strategies would need to ensure that soil health as elaborated above becomes the means of meeting crop nutrient needs in an optimum and cost-effective way within the prevailing ecological and socio-economic conditions.

Nutrient management strategies in CA systems would need to attend to the following four general aspects, namely that: (i) the *biological processes* of the soil are enhanced and protected so that all the soil biota are microorganisms are privileged and that soil organic matter and soil porosity are built up and maintained; (ii) there is adequate *biomass production and biological nitrogen fixation* for keeping soil energy and nutrient stocks sufficient to support higher levels of biological activity, and for covering the soil; (iii) there is an adequate *access to all nutrients* by plant roots in the soil, from natural and synthetic sources, to meet crop needs; and (iv) the *soil acidity* is kept within acceptable range for all key soil chemical and biological processes to function effectively.

The above four elements are elaborated below but without engaging in a comprehensive discussion regarding how they are affected by the level of production, climate and seasonality, water supply, soil type, clay content and type etc, or by farm size and resources, or type of farm power and mechanization, etc. Based on our assessment of the situation, it would be true to say that not enough is known about these four elements to formulate a comprehensive framework for nutrient management in CA systems.

Managing Soil Biological Processes – Soil as a Living System

From many physical landscapes, we expect the three-dimensional catchments which are clothed in soil to yield sufficient crops and other vegetation of various types and, simultaneously, volumes of clean water from streams and boreholes regularly on a repeated annual basis.

Plants, rivers and groundwater depend on water penetrating into soil which is porous from the surface downwards. Insufficiency of water for plants hinders the interacting functioning of the other components of soil productivity: biological, physical, and chemical. The rate of entry of water into and through and its movement within the soil is governed by soil's porosity, both micro and macro, which in turn is governed by the volume and inter-connectedness of pores able to transmit water. The volume and availability of water which plants can use is determined by the proportion of soil pores which can retain water against the force of gravity and yet can release that water in response to 'suction' exerted through roots as dictated by the plants' physiology and atmospheric demand. Water management in soil is intrinsically linked to nutrient management.

Insufficiency of water and/or of various nutrients required by plants for growth processes diminish the derived productivity of the soil in which they are growing, inhibiting full interactions in the plant-soil system. Inadequacy of plant nutrients hinders plant growth and development; severe water-stress stops the whole system.

Soil porosity is damaged or destroyed by compaction, pulverization, and/or collapse due to degradation and loss of organic matter. Net loss of organic matter is caused by tillage of the soil, which results in accelerated oxidation of the carbon in the materials to carbon dioxide gas and its loss to the atmosphere. Following such damages, appropriate soil porosity is regained and maintained chiefly through biotic transformation of the non-living fraction of organic matter by its living fraction - soil-inhabiting fauna and flora - from micro-organisms such as bacteria to macro-organisms such as worms, termites and plants themselves. Their metabolic activity contributes glue-like substances, fungal hyphae etc. to the formation of irregular aggregates of soil particles, within and between which are the all-important pore-spaces in which water, oxygen and carbon dioxide flow and roots grow. These substances also contribute markedly to the soil's capacity to capture and retain nutrient ions on organic complexes, and provide a slow-release mechanism for their liberation back into the moisture in the soil. For this activity and its effects to be maintained, a sufficient supply of new organic matter needs always to be available as a source of energy and nutrients to the soil organisms – not just to the plants alone.

If the conditions are kept favourable for biotic activity in the soil, this dynamic process of formation and re-formation of the porous soil architecture will continue from year to year, maintaining the capacities of landscapes thus treated to continue yielding vegetation and water on a recurrent basis, contributing to sustainability of such production processes. Here lies the significance of maintaining 'soil health'. For the purposes of deciding how best to manage the land and nutrients to maintain its productivity, it is more appropriate to think of the soil primarily as a living porous biological entity interpenetrating the non-living components, and forming from the top downwards, rather than as a geological entity forming from the bottom upwards with living things in it at the top (Shaxson *et al.* 2008).

Managing Biomass Production and Biological Nitrogen Fixation

CA systems require higher levels of biomass production within the rotation to develop and maintain an adequate mulch cover, to raise soil organic matter level, to enhance soil biodiversity and their functions, to raise moisture and nutrient holding capacities, to enhance nutrient supplies, to enrich the soil with nitrogen in the case of legumes, and to protect the soil surface.

Practices that enhance soil organic matter are built into CA principles and include one or more of the following, including: minimal or no-till; diversifying cropping systems; planting trees; mulching; using cover crops and green manures, using crop rotations; and using nitrogen fixing crops.

Nitrogen is fixed from the atmosphere by all kinds of free living organisms in undisturbed soils, and also by rhizobia in root nodules in legume crops as well as in herbaceous and woody legumes. Soil organisms including protozoa and nematodes in the root rhizosphere also fix atmospheric nitrogen, and so the nitrogen cycle has multiple pathways to restore nitrogen to the soil and supply to crops. For crop growth and for soil microorganisms to function, and for soil organic matter to build up, adequate nitrogen supply is needed. No-till and planted fallows and pastures in the rotation can preserve soil integrity and soil organic matter, and various herbaceous and tree legumes can make a contribution to maintaining a positive nitrogen balance for the cropping system (Boddey *et al.* 2006). Equally, failure to compensate for any net nutrient outputs can lead to losses in soil organic matter and soil nutrient reserves in the short run, and to soil erosion and soil system degradation in the long term.

Farmer and research experience have demonstrated the long-term benefits of a CA system. Research in Canada has shown, that after 20 years of continuous no-till with full stubble retention, higher yields can be obtained compared with a short-term (2-year) no-till system. Major increase in soil organic matter content is assumed to be responsible for these benefits (Derpsch 2007a). The evolution of a long-term CA system is described by Sá (2004) and is quoted by Derpsch 2007a as follows:

“In the initial phase (0-5 years) the soil starts rebuilding aggregates and measurable changes in the carbon content of the soil are not expected. Crop residues are low and nitrogen needs to be added to the system. In the transition phase (5-10 years) an increase in soil density is observed. The amounts of crop residues as well as carbon and phosphorus contents start to increase. In the consolidation phase (10-20 years) higher amounts of crop residues as well as higher carbon contents are achieved, a higher cation exchange capacity and water holding capacity is measured. Greater amount of nutrient cycling is observed. It is only in the maintenance phase (>20 years) that the ideal situation with the maximum benefits for the soil is achieved and less fertilizer is needed.”

A constraint that can be critical for many of these biologically-driven innovations is the availability of biomass. We are reminded in Uphoff *et al.* (2006), that little thought and little investment have been devoted to reducing biomass production and biological nitrogen as a constraint.

Managing Access to a Balanced Nutrient Supply

The more common notion regarding crop nutrition is based on maintaining overall quantities or concentrations of nutrients in the soil. At the practical level, this is reduced to a simple output-input nutrient balance equation so that what is taken out by the crop is or must be replaced by application of nutrients from inorganic fertilizer or other sources. Invariably, this approach is combined with intensive soil tillage that reduces, over time, soil organic matter and porosity, and therefore also its water and nutrient holding capacity as well as all the beneficial soil biological processes.

Neal's Kinsey's book “Hands-on Agronomy” (Kinsey and Walters 2006) clearly shows from direct field experience across many years and many countries, that what is important is that not only is each element necessary individually, but a balance of all soil elements is necessary collectively. If there is too much of a given nutrient, it is going to tie up something else that is needed, e.g. too much potassium ties up boron, too much phosphorus ties up zinc, too much nitrogen ties up copper, too much calcium could tie up all the other nutrients, depending on their availability. Also, imbalances in nutrients can lead to unbalanced plant metabolism making plants vulnerable to all kinds of pathogens as elaborated by Chaboussou (2004).

In a CA system there is no compact subsoil plough layer. Instead there is another type layer, a surface layer of mulch enriched with organic plant residues and nutrients, and altering the dynamics of the organic matter of the soil and the cycling and flows of nutrients (Séguy *et al.* 2006). In a sense, in CA systems, forest floor conditions are

emulated and nutrient cycling through cover crops act as 'nutrient pumps' to enhance and conserve pools of nutrients from which plant roots feed. Nutrients are returned to the system via mulch mineralization, regulated by C:N ratio and lignin content of the aboveground and root parts of the crops. Much of the system's nutrients are held in the biomass in a semi-closed manner rather than in the soil.

The continuous increase in surface and soil biomass and in soil biological processes in CA facilitate the formation and existence of a nutrient balance as proposed by Kinsey and which leads to crop plants that are healthier. At least 18 mineral nutrients are necessary for plant growth, and maintaining access to a balanced supply of nutrients to crops in CA system is clearly helped by the biologically-oriented processes in the system that has a higher level of biomass and soil organic matter. Organic soil amendments have the advantage of providing more or less a full range of nutrients in contrast to mineral fertilizers. Where there are likely to be serious deficiencies of mineral nutrients, these have to be corrected from the start to avoid disrupting the development of the soil biological processes.

In a fully established CA system the aim of fertilizer nutrient management is to maintain soil nutrient levels, replacing the losses resulting from the nutrients exported by the crops. Because CA systems have diverse crop mix including legumes, and nutrients are stored in the soil organic matter, nutrients and their cycles must be managed more at the system or crop mix level. Thus, fertilization would not anymore be strictly crop specific, with the exception of nitrogen top dressing (if required at all), but will be given to the soil system at the most convenient time during the crop rotation. With the management of legume crops, either as previous crop in the rotation or as component in a cover crop before the next cash crop "top" dressing with nitrogen can be replaced by the N captured by the legumes and released during the following cropping cycle at the required time (more legume content – earlier release, more grass content in cover crop, later release). Additionally, undisturbed soils are habitats for free living nitrogen fixing bacteria and there is rhizospheric fixation of nitrogen (Sprent and Sprent 1990).

Conventional soil analysis data are not necessarily valid as a basis of fertilizer recommendations for CA, since the available soil volume and the mobility of nutrients through soil biological activities tend to be higher than in tillage-based systems against which the existing recommendations have been calibrated. In established CA systems, most nutrients are concentrated and maintained in the top 0-10 cm. For example, phosphorus often identified as a key constraint to crop production, is actually abundant in most soils, with much less than 10% of the total supply "available" at any one time (Uphoff *et al.* 2006). In CA systems, soils show a higher concentration of available phosphorus in the upper soil layer, and roots will grow right to the soil surface under the mulch. There is much potential for phosphorus solubilization and mobilization through biological processes as influenced by soil moisture changes. Also, the role of mycorrhizas, which are obligate symbionts, in foraging, absorption and translocation to the roots of associated plants of a range of nutrients, and imparting resistances and tolerances against soil pathogens, drought and salinity, aluminum and heavy metals is extensively documented and so is their ability to induce changes in root morphology. Mycorrhiza associations therefore allow larger volume of soil to be exploited for nutrients, particularly those which do not move readily through mass flow or are in relatively immobile form particularly phosphorus, ammonium nitrogen, copper and zinc (Habte 2006). However, micorrhiza diversity and activity is severely curtailed by soil tillage and intensive use of agrochemicals, and soil tillage destroys the hyphal networks of micorrhiza fungi thus affecting nutrient mobilization and uptake. Similar to the way rhizobia are linked with leguminous plants, so are symbiotic micorrhizas related to plant nutrition and development in general (Rivera and Fernandez 2006), and these relationships need to be incorporated into nutrient management strategies in CA systems as elaborated in Turner *et al.* (2006).

Managing Soil Acidity

Soil pH is critical for several reasons. It has a major influence on the availability of elements, including primary nutrients like nitrogen, phosphorus and potassium, as well as secondary nutrients, micronutrients and potentially toxic elements like aluminum. Most soil microorganisms are sensitive to soil acidity, which has an influence on nutrient availability (especially nitrogen), soil organic matter and general soil health. The most beneficial soil fungi, for instance, do not like a high pH, and soil bacteria have problems at lower pH. One of the main reasons for managing soil pH by application of lime is to reduce such toxic effects. However, soil acidity becomes self-adjusting at 6.2 or 6.3 when all four cations — calcium, magnesium, potassium and sodium — are in proper equilibrium (Kinsey and Walters 2006). Any one of them in excess can push pH up, and any one of them in lower amounts can take pH down.

CA systems are based on building and breaking down organic matter to maintain soil health and productivity. As microorganisms decompose soil organic matter, organic acids are continuously being formed. If these acids are not neutralized by free bases, then soil acidity will increase. There are other reasons why soil can be acidic, due to leaching of basic cations by rainfall, or to soil being formed from acid parent materials, or to biological nitrogen fixation. Where soils are acidic particularly in humid and sub-humid soils and may have toxic levels of aluminum, the effectiveness of broadcast lime application without incorporation has been long proven in CA systems, as lime moves into deeper soil layers, especially when applied in small quantities each year in combination with green manure cover crops (Derpsch 2007b). Experience Brazil shows that aluminum toxicity tends to disappear over time under CA systems.

Towards CA-Based Nutrient Management Practices

Integrated Soil Fertility Management (ISFM) and Integrated Natural resources Management (INRM) approaches of various types and nomenclature have been in vogue in recent years in certain sections of the scientific community. Generally, such approaches are focused more on meeting crop nutrient needs rather than managing soil health and land productivity as is the case with CA systems. Also, most of the work that is couched under the rubric of ISFM or INRM over the past 15 years or so has been geared towards tillage-based systems which have many unsustainable elements, regardless of farm size or the level of agricultural development. Unless the concepts of soil health and function are explicitly incorporated into ISFM or INRM approaches, sustainability goals and means will remain only accidentally connected, and sustainable crop intensification will be difficult to achieve particularly by resource poor farmers.

We believe that CA systems have within them their own particular sets of ISFM or INRM processes and concepts that combine and optimize the use of organic with inorganic inputs integrating temporal and spatial dimensions with soil, nutrient, water, soil biota, biomass dimension, all geared to enhancing crop and system outputs and productivities but in environmentally responsible manner. There is empirical evidence to show that CA-based ISFM or INRM processes can work because of the underpinnings of soil health and function.

Focusing on soil fertility but without defining the tillage and cropping system, as often proposed by ISFM or INRM approaches, is only a partial answer to enhancing and maintaining soil health and productivity in support of sustainable production intensification, livelihood and the environment. Over the past two decades or so, empirical evidence from the field has clearly shown that healthy agricultural soils constitute biologically active *soil systems within landscapes* in which both the soil resources and the landscape must operate with plants in an integrated manner to support the various desired goods and services (e.g., food, feed, feedstock, biological raw material for industry, livelihood, environmental services, etc) provided by agricultural land use.

Consequently, successful nutrient management strategies as part of any ISFM or INRM approach must pay close attention to issues of soil health management which means managing the microscopic integrity of the soil-plant system particularly as mediated by soil living biota, soil organic matter, soil physico-chemical properties, available soil nutrients, adapted germplasm as well as to managing the macroscopic dimensions of landscapes, socioeconomics and policy. Given that CA principles and practices offer substantial benefits to all types of farmers in most agro-ecological and socio-economic situations, CA-based ISFM and INRM approaches to nutrient management and production intensification would be more effective for farmer-based innovation systems and learning processes such as those promoted through Farmer Field School networks.

Adopting a CA-Based Nutrient Management Framework

CA has now emerged as a major “breakthrough” systems approach to crop and agriculture production with its change in paradigm that challenges the status quo. However, as a multi-principled concept, CA translates into knowledge-intensive practices whose exact form and adoption requires that farmers become intellectually engaged in the testing, learning and fine tuning possible practices to meet their specific ecological and socio-economic conditions (Friedrich and Kassam 2009).

In essence, CA approach represents a highly biologically and biogeophysically-integrated system of soil health and nutrient management for production that generates a high level of “internal” ecosystem services which reduces the levels of “external” subsidies and inputs needed. CA provides the means to work with natural ecological processes

to harness greater biological productivities by combining the potentials of the endogenous biological processes with those of exogenous inputs. The evidence for the universal applicability of CA principles is now available across a range of ecologies and socio-economic situations covering large and small farm sizes worldwide, including resource poor farmers (Goddard et al. 2007, FAO 2008).

There are many different ecological and socio-economic starting situations in which CA has been and is being introduced. They all impose their particular constraints as to how fast the transformation towards CA systems can occur. In the seasonally dry tropical and sub-tropical ecologies, particularly with resource poor small farmer in drought prone zones, CA systems will take longer to establish, and step-wise approaches to the introduction of CA practices seem to show promise (Mazvimavi and Twomlow 2006). These involve two components: the application of planting 'Zai-type' basins which concentrate limited nutrients and water resources to the plant, and the precision application of small or micro doses of nitrogen-based fertilizer. In the case of degraded land in wet or dry ecologies, special soil amendments and nutrient management practices are required to establish the initial conditions for soil health improvement and efficient nutrient management for agricultural production (Landers 2007). What seems to be important is that whichever pathway is followed to introduce CA practices, there is a need for a clear understanding of how the production systems concerned should operate as CA systems to sustain soil health and productivity, and how nutrient management interventions that may be proposed can contribute to the system effectiveness as a whole both in the short- and long-term.

Concluding Remarks

Many of the CA related soil processes, e.g. increased soil organic matter content and soil porosity, or increased biological nitrogen fixation by legumes in rotation, or exploitation of the deeper soil layers through crops with deep and dense root systems, have a significant bearing on nutrient management. Evidence shows that in CA systems, nutrient requirements are lower, nutrient efficiencies are higher and risks of polluting water systems with mineral nutrients lower.

However, systematic research into CA systems and their nutrient management requirements are of relatively recent origin as can be seen from the research work reported in Uphoff *et al.* (2006) or in the Goddard *et al.* (2007) compendium. Both these volumes imply that nutrients as a production input are a necessary condition but not a sufficient condition for sustainable production intensification. In CA systems, the focus is on managing soil health and productivity simultaneously and which depends on many complex cropping system relationships in space and time and on biodiversity and organic matter within soil systems when they are enlisted on behalf of agricultural production.

Ultimately, the management of nutrient input-output relationships in CA systems must balance the nutrient accounts which means that the levels of outputs of biological products that are aimed at will dictate the levels of inputs, and ongoing nutrient balances must remain positive. The major difference with CA systems is that the management of the multiple sources of nutrients and the processes by which they are acquired, stored and made available to crops are more biologically mediated. Much more research needs to be done on the different aspects of soil health and nutrient management in CA-system as is now beginning to occur as more countries begin to adopt and integrate CA concepts and practices into commercial production activities at both small and large scale as a basis for future sustainable production intensification strategies.

As an appropriate ending to this paper we would like to quote Derpsch 2007b:

"Experience has shown that most things learned at university about fertilization and liming should be revised, and new concepts of fertility management for no-till systems need to be developed and applied. The main principle to keep in mind is that farmers should fertilize their soils rather than their crops."

References

- Boddey, R.M., Bruno, J. R. A. and Segundp, U. 2006. Leguminous biological nitrogen fixation in sustainable tropical agroecosystems. In: *Biological Approaches to Sustainable Soil Systems* (Uphoff, N. *et al.*, Eds.), pp 401-408. CRC Press, Taylor & Francis Group.
- Chaboussou, F. (2004). *Healthy Crops: A New Agricultural Revolution*. Jon Carpenter Publishing. 244 pp.
- Derpsch, R. 2007a. No-tillage and Conservation Agriculture: A Progress Report. In: *No-Till Farming Systems* (Goddard, T. *et al.*, Eds.), pp. 7-39. WASWC Special Publication No. 3, Bangkok.

- Derpsch, R. 2007b. Critical Steps in No-till Adoption. In: *No-Till Farming Systems* (Goddard, T. *et al.*, Eds.), pp. 479-495. WASWC Special Publication No. 3, Bangkok.
- FAO, 2008. Investing in Sustainable Agricultural Intensification: The Role of Conservation Agriculture – A Framework for Action' FAO Rome, August 2008 (available at www.fao.org/ag/ca/).
- Friedrich, T. and Kassam, A.H. 2009. Adoption of Conservation Agriculture Technologies: Constraints and Opportunities. Invited paper, IV World Congress on Conservation Agriculture, 4-7 February 2009, New Delhi, India.
- Goddard, T., Zoebisch, M., Gan, Y., Ellis, W., Watson, A. And Sombatpanit, S. (2007) (Eds.). *No-Till Farming Systems*. WASWC Special Publication No. 3, Bangkok, 544 pp.
- Habte, M. 2006. The Roles of Arbuscular Mycorrhizas in Plant and Soil Health. In: *Biological Approaches to Sustainable Soil Systems*. (Uphoff, N. *et al.* Eds.), pp. 131-147. CRC Press, Taylor & Francis Group.
- Kinsey, N. and Walters, C. 2006. *Neal Kinsey's Hands-On Agronomy: Understanding Soil Fertility & Fertilizer Use*. Acres USA. 391 pp.
- Landers, J. 2007. Tropical Crop-Livestock Systems in Conservation Agriculture: The Brazilian Experience. Integrated Crop Management Vol. 5. FAO, Rome.
- Mazvimavi, K. and Twomlow, S. 2006. Conservation Farming for Agricultural Relief and Development in Zimbabwe. In: *No-Till Farming Systems* (Goddard, T. *et al.*, Eds.), pp. 169-175. WASWC Special Publication No. 3, Bangkok.
- Rivera, R. and Fernandez, F. 2006. Inoculation and Management of Mycorrhizal Fungi within Tropical Agroecosystems. In: *Biological Approaches to Sustainable Soil Systems* (Uphoff, N. *et al.*, Eds.), pp 479-489. CRC Press, Taylor & Francis Group.
- Sanchez, P.A. 1994. Tropical soil fertility research: towards the second paradigm. In: *Transactions of the 15th World Congress of Soil Science*, Acapulco, Mexico, pp. 65-88. Mexican Soil Science Society, Chapingo, Mexico.
- Séguy, L., Bouzinac, S. and Husson, O. 2006. Direct-seeded Tropical Soil Systems with Permanent Soil Cover: Learning from Brazilian Experience. In: *Biological Approaches to Sustainable Soil Systems* (Uphoff, N. *et al.*, Eds.), pp 323-342. CRC Press, Taylor & Francis Group.
- Shaxson, F., Kassam, A.H., Friedrich, T., Boddey, B. and Adekunle, A. 2008. Underpinning Conservation Agriculture's Benefits: The Roots of Soil Health and Function. Main background document for the Workshop on Investing in Sustainable Crop Intensification: The Case for Improving Soil Health, 22-24 July, FAO, Rome.
- Sprent, J. I. and Sprent, P. 1990. *Nitrogen Fixing Organisms: Pure and Applied Aspects*. Chapman and Hall Ltd. 272 pp.
- Turner, Benjamin L., Frossard, Emmanuel and Oberson, Astrid (2006) Enhancing Phosphorus Availability in Low-fertile Soils. In: *Biological Approaches to Sustainable Soil Systems* (Uphoff, N. *et al.*, Eds.), pp 191-205. CRC Press, Taylor & Francis Group.
- Uphoff, N., Ball, A.s., Fernandes, E., Herren, H., Husson, O., Laing, M., Palm, C., Pretty, J., Sanchez, P., Sanginga, N., and Thies, J. (2006) (Eds.). *Biological Approaches to Sustainable Soil Systems*. CRC Press, Taylor & Francis Group. 764 pp.

Opportunities and Challenges for Water and Nutrient Management in Conservation Agriculture Farming Systems of Asia and Africa

Christian H Roth¹, Merv Probert², Jack McHugh³ and Greg Hamilton⁴

¹ Australian Centre for International Agricultural Research ACIAR, Canberra, Australia, roth@aciar.gov.au; ² CSIRO Sustainable Ecosystems, Brisbane, Australia, merv.probert@csiro.au; ³ University of Southern Queensland, Toowoomba, Australia, mchugha@usq.edu.au; ⁴ Department of Agriculture and Food Western Australia, Perth, Australia, g.hamilton@agric.wa.gov.au

Building on the positive experiences in Brazil, Australia and the USA, over the past decades conservation agriculture (CA) has seen increasing acceptance by farmers in Asia, and to a lesser extent in Africa. Research in these evolving systems has generated a considerable amount of data and knowledge about the contribution of CA to increased water and nutrient use efficiency. In order to more systematically evaluate how effective the different CA systems in Asia and Africa are in reducing input requirements we propose a framework to broadly categorise the main types of CA systems, before we take a water and nutrient balance approach to discuss the performance of these systems with respect to key water and nutrient (mainly N) fluxes. The outcome of this analysis is that while there are major opportunities for a range of CA systems to increase water and nutrient input efficiencies, there are also some long term environmental risks. In addition, we argue that there is a discrepancy between a large proportion of the body of work and the theoretical benefits in water and nutrient savings on the one hand, and the reality on the ground on the other hand.

We attempt to illustrate this in greater depth by presenting the results of two case studies. One study looks at the role of residue retention in the long-term evolution of organic matter in no-tillage systems for a range of semi-arid rainfed soil and climate conditions. Using a cropping systems modeling approach, we demonstrate that there are significant interactions between water and nutrients that determine whether CA in these conditions will or will not contribute positively to soil health and crop productivity as well as water and nutrient use efficiency. Importantly, failure to recognize that most semi-arid systems are in fact low-input, mixed crop-livestock systems with low levels of residue retention, can lead to an overestimation of organic matter build-up and water and nutrient efficiencies to be gained from CA in these farming systems.

In the second case study we investigate irrigated, permanent raised bed maize-wheat systems in Pakistan and China. We demonstrate that measured and modeled savings in irrigation water can potentially lead to salt accumulation in the beds. Managing the salt build-up is relatively straight forward, but requires maintaining higher leaching fractions, at the expense of the water savings and with the risk of higher N leaching rates. This in turn diminishes the perceived benefits of CA in these conditions.

Polymicrobial Formulations for Enhanced Productivity of a Broad Spectrum of Crops

C.A. Reddy* and J.Lalithakumari

Department of Microbiology and Molecular Genetics, Michigan State University,
East Lansing, MI, 48824-4340, USA
(*Email: reddy@msu.edu)

Our principal aim in this research is to develop stable, efficacious, and eco-friendly microbial formulations containing naturally occurring diverse phylogenetic groups of microbes with complementary functions designed to enhance productivity of a broad spectrum of crops. The formulation is designed to provide the observed beneficial effects through enhancement of nitrogen fixation, direct or indirect inhibition of plant pathogens, solubilization and mobilization of minerals such as P, and production of plant growth stimulants. We constructed two such formulations (F1 and F2) using humate (12%, pH 7.0) as a carrier. F2 formulation was found to be more effective than F1 in enhancing the productivity of a broad spectrum of crops and was the focus of this study. Substantial increase in productivity was observed with the following crops: *Zea mays* (corn), *Sorghum bicolor* (sorghum), *Glycine max* (soybean), *Phaseolus vulgaris* (Garden bean), *Pisum sativum* (pea), *Phaseolus sp.* (wonder bush bean), *Arachis hypogea* (peanut), *Oryza sativa* (rice), *Lycopersicon esculentum* (tomato), *Solanum melongena* (eggplant), *Hibiscus esculentus* (okra), and *Cucurbita maxima* (squash). For example, when compared to controls, corn height increased by 65%, eggplant 41%; wonder bush beans 40%, tomato 91%, soybeans 96%, pea purple hull 50%, and okra 16%. Significant increase in yield was also observed. For example, mean yield of tomato increased by 88%, okra yield increased by 50%, and rice yield by 40%. In general, the F2-treated plants appeared healthier and showed early flowering and fruiting with good root nodulation in legumes. Yields obtained in field trials were consistent with those from the greenhouse experiments. The results indicate that polymicrobial formulations such as F2 reduce input for nitrogen fertilizers and pesticides, enhance productivity of a broad spectrum of crops, non-polluting, and contribute to the conservation of soil health.

Key words: Microbial formulation, enhanced crop production, polymicrobial, nitrogen fixation, phosphate mobilization, biological control

Facing a steep rise in the price of energy, a growing concern over global warming, and a quickly growing world human population (estimated at 6.9 billions in 2010), the need has never been greater for an increase to crop productivity on a long-term, sustainable basis in an energy efficient and eco-friendly manner (Triplett et al. 2007). Therefore, the working hypothesis is that it is possible to develop stable, efficacious, and ecofriendly microbial formulations containing diverse groups of microbes with complementary functions designed to enhance productivity of a broad spectrum of plants including legumes, non-legumes, vegetables, cereals, ornamentals, and fodder crops with little or no input of nitrogen fertilizers and chemical pesticides. The formulations are expected to provide the observed beneficial effects by multiple mechanisms including but not limited to the following: enhancement of nitrogen fixation; control of plant pathogens either directly or indirectly by inducing systemic resistance in plants against the pathogens; solubilization and mobilization of minerals such as P and others; and production of growth stimulants. While the idea of microbial inoculants for stimulating crop production is not new, careful and deliberate design of a formulation to contain multiple naturally occurring phylogenetic groups of organisms with complementary functionalities and putting them together in a manner that they retain viability over a long period of time at ambient temperature and with little or no need for added chemical fertilizers and pesticides is innovative.

Symbiotic N₂-fixing bacteria such as *Rhizobiales* (associated with leguminous crops) and free-living N₂-fixing bacteria such as the *Azospirillum* group (associated with the roots of cereal crops such as rice, wheat and corn, and certain forage grasses) account for a major portion of biological nitrogen fixation on earth (Bashan et al.2004;; O'Hara et al., 2003; Rai, 2006; Xavier et al. 2004). These beneficial bacteria decrease the need for added nitrogen fertilizers for crop production, contribute to conservation of fossil fuel energy resources that are currently used for manufacturing N-fertilizers, and help reduce pollution and public health problems associated with the high use of chemical fertilizers. Other free-living microbes that contribute to N₂-fixation in soils include: *Acetobacter* and *Herbaspirillum* strains associated with sugarcane, sorghum and maize (Balachandar et al., 2007; Boddey et al., 2000) and *Alcaligenes*, *Bacillus*, *Enterobacter*, *Klebsiella* and *Pseudomonas* strains associated with a range of crops such as rice and maize (Somasegaran and Hoben, 1994). Moreover, rhizosphere bacteria such as *Paenibacillus*, *Burkholderia*, and (α-, β-, γ-) proteobacteria were reported to give 'positive plant growth response attributed to their ability to fix N₂ and/or their ability to produce secondary metabolites and phytohormones (Polianskaia et al., 2003; Petersen et al., 1996; Rai, 2006; Rudresh et al., 2005.). Phosphate-solubilizing bacteria (PSB) such as *Pseudomonas*,

Bacillus, *Azospirillum*, *Rhizobium*, *Alkaligenes*, *Paenibacillus*, and *Penicillium digitatum* contribute to plant growth by producing organic acids and make insoluble P compounds soluble for uptake by the plant (Sundara et al. 2002; Rodriguez and Fraga, 1999).

An array of pesticides belonging to different chemical classes is used for controlling a variety of plant diseases. A number of pesticides are recalcitrant to degradation, persist in the environment, and enter the human/animal food chain constituting a threat to public health and a potential hazard to the environment. Some are toxic to humans even at parts per billion levels. Therefore, there is increasing public concern regarding the continued use of chemical pesticides at high levels and there is a growing need for developing environmentally friendly approaches to control common plant diseases and contribute to the goal of sustainability in agricultural production. In this regard, there is much ongoing research on bio-control agents (bio-pesticides) for inhibiting pathogenic fungi, bacteria, and even nematodes and small insects that cause crop losses. Soil-borne, non-pathogenic bacteria and fungi that are able to control different plant pathogens are attractive alternatives to the use of chemical pesticides. A number of bacteria and fungi that serve as biological control agents (BCAs) as well as plant growth-promoting rhizobacteria (PGPR) are catabolically versatile, have excellent root-colonizing abilities, and have the capacity to produce a wide range of metabolites that act against plant pathogens. Soil-borne fluorescent pseudomonads have received particular attention. Some of these have been shown to elicit induced systemic resistance in plants. Strains of *Bacillus subtilis* are known to suppress soil-borne fungal diseases and nematodes, produce metabolites that stimulate plant and root growth, and colonize the root zone resulting in exclusion of some of the pathogens by 'competitive exclusion' (Walsh et al., 2001).

Trichoderma are free living and fast growing fungi in soil and root ecosystems of many plants. *Trichoderma* have been demonstrated to inhibit a broad spectrum of root and foliar pathogens by one or more of the following mechanisms (Harman et al. 2004; Mathivanan et al. 2000; Carver et al. 1996): antibiosis, antagonism, and competitive exclusion. Furthermore, *Pseudomonas* and *Trichoderma* species that function as bio-control agents do not inhibit nitrogen fixers, arbuscular mycorrhizal fungi, and other beneficial microbes that positively impact plant growth (Walsh et al. 2001; Rudresh et al. 2005; Mathivanan et al. 2000). *Trichoderma* species have also been reported to serve as plant growth promoters by producing phytohormones and solubilize/mobilize phosphates (Yedidia et al. 2001).

There is much published information on the benefit of individual microbes to plants (Xavier et al. 2004; Somasegaran and Hoben, 1994; Kannaiyan, 2000), but there is hardly any commercial product that is capable of conferring all the beneficial effects on crop productivity mentioned above. Our overall objective in this study was to construct a microbial formulation containing multiple groups of functionally complementary microbes (bacteria and fungi) that hold promise in enhancing productivity of a broad spectrum of plants including legumes, cereals, vegetables, and forage crops. Many of the commercial microbial inoculants have not lived up to their claims in that Brockwell and Bottomley (1995) reported that 90% of all inoculants have no practical value whatsoever on the productivity of legumes. A desirable microbial growth promotant should have good efficacy, ease of application, eco-friendly, stable, and safe for use. Furthermore, rhizobial species in the inoculant must be able to nodulate diverse legumes under various soil and environmental conditions.

Results

Construction of Polymicrobial Formulations

The research presented here highlights a rational approach to the use of diverse groups of organisms with complementary functionalities to confer multiple beneficial effects on growth and yield of a broad spectrum of crops. As a first step, numerically predominant bacteria from the root nodules of various leguminous plants as well as from soil and rhizosphere samples collected from diverse environmental sources were isolated and characterized. Dominant rhizobial as well as the non-rhizobial species were isolated from the root nodules of pea, cow pea (*Vigna sinensis*), green gram (*V. radiata*), black gram (*V. mungo*), red gram (*Cajanus cajan*), soybean, and agati (*Sesbania grandiflora*) collected from temperate and tropical regions using established procedures (Hung et al. 2005; Kannaiyan, 2000; O'Hara et al. 2003; Pandey et al., 2004). The microbial isolates were identified based on morphological, physiological and biochemical characteristics as well as their 16S rDNA sequencing data. Functional characteristics such as nitrogen fixation, phosphate solubilization/mobilization, root nodulation using different leguminous plants, and growth under acidic and alkaline conditions were used in further grouping of the isolates. Isolates were also characterized as to their saprophytic competence (Weaver and Frederick, 1972). Similarly, a large number of bacteria isolated from various soils were isolated and identified and key functional characteristics were determined.

A number of *Trichoderma* species isolated from different soil samples (representing cultivated and uncultivated agriculture soils, tropical, subtropical, and temperate climates) because of their reported beneficial effect in positively influencing productivity of different crops. Individual strains were isolated using single spore isolation technique using plates of potato dextrose agar. Identification was based on macro-microscopic features, colony color, and rate of growth, using standard procedures (Sariah et al. 2005). *Trichoderma* isolates were then screened for their potential as biocontrol agents against known plant pathogenic fungi such as *Alternaria alternata* and *Curvularia Sp.*, *Bipolaris oryzae*, *Magnaporthe grisea*, *Rhizoctonia solani* using dual plate technique (Carver et al. 1996). Also, all the *Trichoderma* strains were tested for their saprophytic competence in soil.

Species representing several genera of *Rhizobiales*, several root-nodulating non-rhizobial species (consisting of both α -, β -, and γ - proteobacteria), a number of phosphate solubilizing bacteria, microbes (both bacteria and fungi) with proven ability as biocontrol agents, and other beneficial bacterial species with growth-promoting properties were used in constructing two bacterial formulations F1 and F2 using 12% humate as the base. The microbial species composition of F1 and F2 was different but each contained over 20 different microbial strains representing selected combinations of bacteria and *Trichoderma* strains with the beneficial characteristics mentioned above.

The PCR amplification and sequencing of 16S rDNA of the isolates revealed both nodulating *Rhizobia* such as *Ensifer meliloti* (*Rhizobium meliloti*; *Sinorhizobium meliloti*), *R. trifoli*, as well as *Azorhizobium caulinodans*, *Sinorhizobium fredii*, and non-Rhizobial nitrogen fixers including *Pseudomonas spp.*, *Burkholderia spp.*, and *Paenibacillus polymyxa*. Other bacterial isolates included in the formulations were *Pseudomonas fluorescens*, *P. striata*, and *Bacillus subtilis* representing multiple functions such as phosphate solubilization/mobilization, nutrient uptake, and phytohormone production. Nodulation experiments confirmed the nodulating ability of bacteria in the polymicrobial formulation (Fig. 1). *Trichoderma* isolates included strains of: *T. harzianum*, *T. viride*, *T. virens*, and *T. longibrachiatum*.

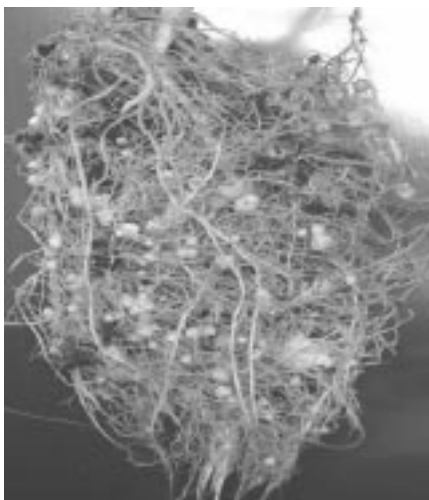


Figure 1. Nodulation observed on roots of garden bean grown in the presence of polymicrobial formulation, F2

Green House Evaluation

Baccto premium potting soil (Michigan peat Company, Houston, TX) was used for growing the selected test plants in the greenhouse experiments. A randomized replicated design was used to set up growth experiments for testing the efficacy of F1 and F2 formulations. For each 12"X12"X12" pot, two split applications of the liquid formulations (10^{10} cfu per pot) were given during the crop period. The first application was given as soil treatment at the time of sowing and the second application was given at the base of the plant one month after the first application. The experiments were set up in such a way to compare the efficacy of F1 and F2 formulations in comparison to a control (HG) containing 12% humic acid alone without any added microbes. Hence, 3 treatments, i.e. F1, F2, and control (HG), each with 4 replications were tested. Exogenous fertilizers or pesticides were not added to any of the three treatments during the crop period. Most inoculant standards contain a minimum number of viable microbial cells of at least 10^9 rhizobia /gram soil (Brockwell and Bottomley, 1995; Xavier et al. 2004). Plant minerals (minus N) was added to each treatment 15 days after germination. A broad spectrum of crops which includes cereals,

vegetable crops, legumes, forage grasses and also biofuel grasses were tested. Plants including garden beans, wonder bush beans, purple hull beans, pea, cowpea, green gram, black gram, soybean, tomato, eggplant, okra, squash, zucchini (*Cucurbita pepo*), corn, sorghum, rice, and peanut were tested to compare the efficacy of F1 and F2 in enhancing productivity. Observations were made at monthly intervals during the entire crop period. In a separate experiment, the efficacy of F1 and F2 on germination and growth of commercially available forage legumes seed mixture (Tecomate Monster Seed Mix, Todd Valley Farms, Nebraska) was tested. Plant height, total number of leaves, leaf area, leaf color, flowering time, fruiting time, shoot and root biomass, and the incidence of pests and diseases were monitored.

The results (Table 1, Fig. 2 to 5) showed a significant increase in plant height with F2 treatment followed by F1 and control. For example, when compared to controls, corn height increased by 65%; egg plant 41%; wonder bush beans 40%; tomato 91%, soybeans 96%, pea purple hull 50%, and okra by 16%. Yield also significantly increased in F2 treatment. For example, mean yield of tomato increased by 88% as compared to the control. Okra yield increased 50% and rice increased by 40%. With rice, both F1 and F2 showed an increase in seedling vigor, plant height, number of tillers and their carry over effect on grain yield. All legumes tested showed early flowering and fruiting, good root nodulation, and no disease was observed in both the experimental and control plants during the crop period. (results not shown).

Table 1. Green House evaluation of polymicrobial formulations F1, F2, and control (C)

Crop	Plant Height [cm]			Yield [g]		
	F2	F1	C	F2	F1	C
Corn	142	125	101.2	-	-	-
Sorghum	74	68.5	49	-	-	-
Rice	65	60	55	20.85	15.76	5.2
Tomato	77	72	66	1900*	755*	380
Soybeans	167.7	160.5	98	11.58*	7.9	5.1
Pea	45	38	33	13.99*	10.48*	7.52
Okra	130	93.7	98	138.7*	100*	38.7
Peanut	42	42	35	21.62*	14.67*	6.48
Pea purple hull	60.96	46.48	40.64	14.75*	12.23*	10.75
Garden beans	135	128	102	48.6*	42.6*	23.5
Wonder bush beans	88.9	76.2	63.5	72.9*	63.6	35.6
Squash	57	41	36	650*	230*	0

*Significant, P = 0.022

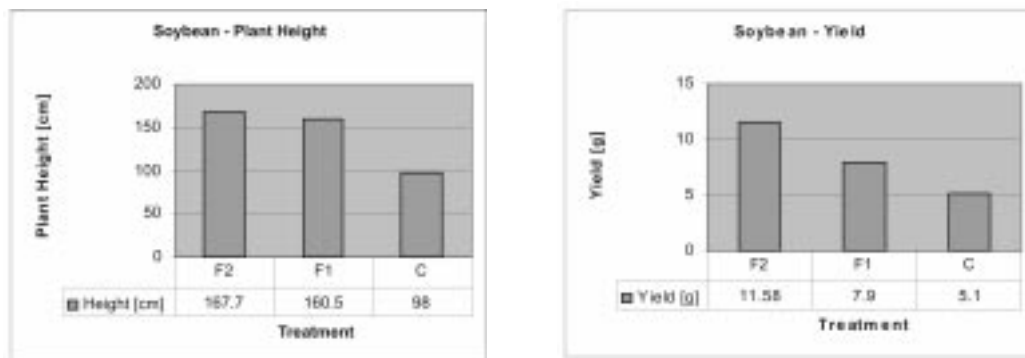


Figure 2. Plant height (2a) and yield (2b) of soybean grown in the presence of polymicrobial formulations F1 and F2 as compared to a control with no formulation added

There is a significant commercial interest in products that substantially increase productivity of forage crops. The present results further confirm that F2 formulation enhances the growth of a commercial seed mixture of forage crops called Tecomate Monster Mix, as compared to humate alone as control (Fig. 6)

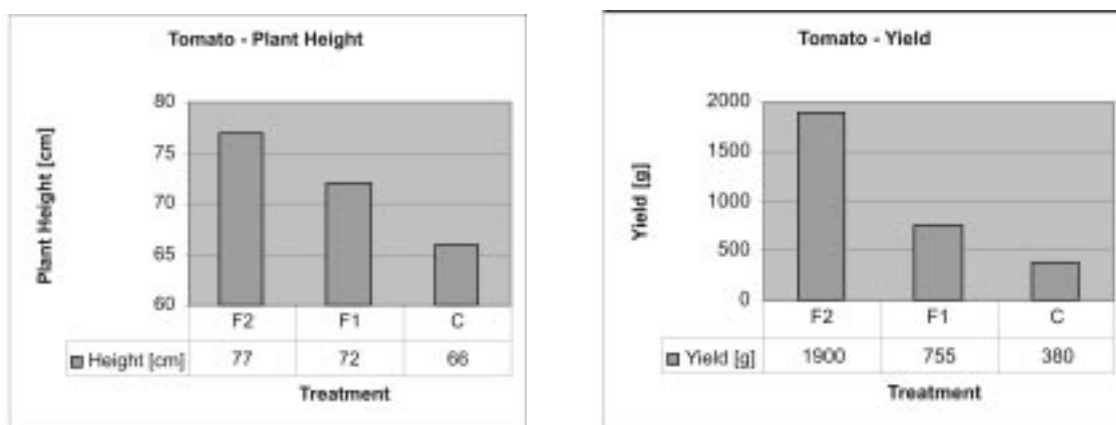


Figure 3. Plant height (3a) and yield (3b) of rice grown in the presence of polymicrobial formulations F1 and F2 as compared to a control with no formulation added

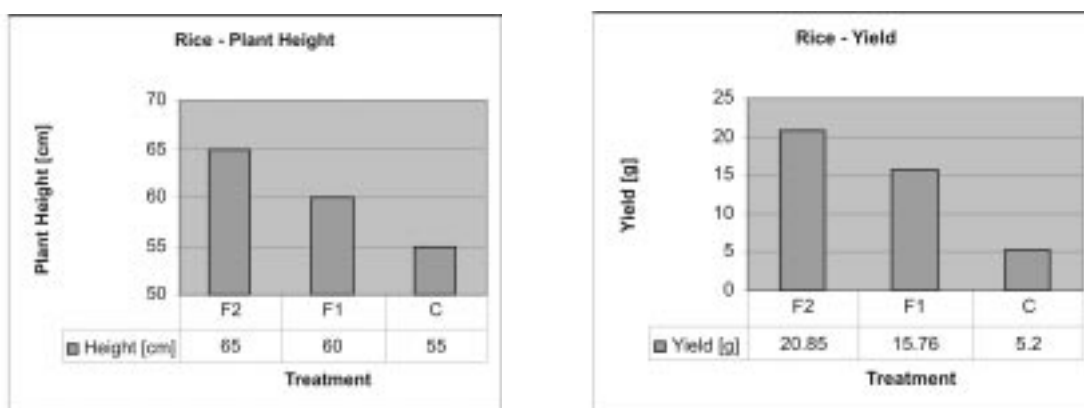


Figure 4. Plant height (4a) and yield (4b) of tomato grown in the presence of polymicrobial formulations F1 and F2 as compared to a control with no formulation added

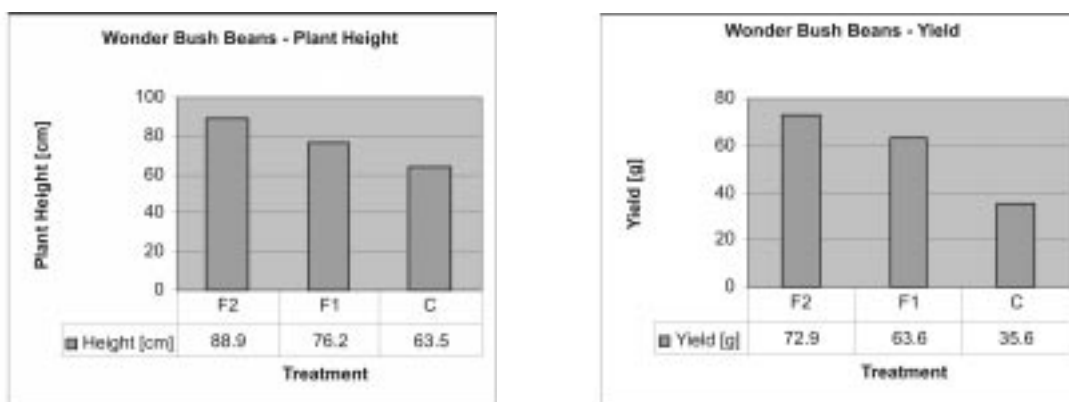


Figure 5. Plant height (5a) and yield (5b) of wonder bush beans grown in the presence of polymicrobial formulations F1 and F2 as compared to a control with no formulation added

Field Evaluation

Field trials were conducted with the cooperation of BioSoil Enhancers (Hattiesburg, Mississippi) to test the efficacy of the polymicrobial formulations on soybean, corn, cotton, yellow squash, tomato, green beans, bell pepper (*Capsicum annuum*) and banana pepper (*Capsicum spp.*). The yield data obtained in field trials were



Figure 6. Growth observed with a commercial forage seed mixture (Tecomate Monster Mix) in the presence of formulation F2 (right) and control (left)

consistent with results of green house experiments in showing a distinct increase in yield of all the crops tested. For example, crops treated with polymicrobial formulation F2 showed 75% increase in yield for tomatoes; 27% for bell peppers; 40% for banana peppers; and 61% for yellow squash (Table 2). Increase in corn yield was 30.0% and cotton plants treated with the polymicrobial formulation also showed increased plant height, good branching, and large sized healthy bolls when compared to control (results not shown). Both green house and field trials indicate that appropriately formulated polymicrobial formulations have excellent potential to enhance productivity of a broad spectrum of crops. Moreover, the need for nitrogen fertilizers and pesticides greatly decreased, which substantially contribute to the conservation of soil health, and conservation of fossil fuel energy sources. Further research progress in this area would be a substantial contribution to boosting crop production compatible with sustainable agriculture practices.

Table 2. Field evaluation of polymicrobial formulations

Crops	F2 formulation (oz)	F1 formulation (oz)	Contro (oz)	F2 - % increase in yield over control
Squash	1559	1414	963	61
Tomato	836	514	477	75
Banana Pepper	35	15	25	40
Bell Pepper	102	87	80	27

Discussion

The results showed much better growth with F2 in terms of increased plant height, total number of leaves and total biomass of tested crops. It was expected that leguminous plants which support symbiotic nitrogen fixation such as soybean, garden bean, wonder bush bean, pea and other legumes would give better performance with F2 formulation as it contains symbiotic nitrogen fixers, as well as some free-living nitrogen fixers, and biocontrol agents. However, it is noteworthy that even non-leguminous plants such as tomato, eggplant, zucchini, squash, rice, corn, and sorghum, which are not associated with symbiotic nitrogen fixation, showed impressive growth response. These results suggest that free-living N_2 fixers, biocontrol agents, and organisms that produce nonspecific growth stimulating compounds in the formulations are contributing to the observed positive growth response. These results appear to validate our hypothesis that enhanced plant growth and productivity can be obtained with a broad spectrum of plants when grown with microbial formulations containing microbes representing several different complementary functional groups. It is also remarkable that the growth response with rice and corn, two of the most important food crops worldwide, was quite encouraging suggesting that either non- N_2 fixers that give a growth response by producing metabolites/micronutrients that boost plant growth or hither to not well characterized nonconventional N_2 -fixers (Balachandar et al. 2007) may be contributing to the observed positive growth response. For example it has earlier been reported that association of *Pseudomonas sp.* and *Trichoderma sp.* with cereal crops such as rice will result in increased productivity (Rudresh et al. 2005). *Pseudomonads* and *Trichoderma* not

only act as biocontrol agents but also produce metabolites that enhance plant growth (Yedia et al 2001). Furthermore, Yanni et al (1997) report that *Rhizobium leguminosarum* bv. trifolii shows endophytic association with rice and increase productivity of the latter. It is also possible that other free living N₂-fixers such as *Paenibacillus* and *Burkholderia* may be contributing in part by providing fixed nitrogen to the plant (Balachandar et al.2007). In addition to nitrogen, phosphorous made available by phosphate-solubilizing bacteria may also be contributing to increased growth of cereals (Sundara et al. 2002). These possibilities need to be tested in future. The results presented above further suggest that other non-nitrogen fixing microbes in our formulations are able to confer substantial boost in productivity.

Conclusions

To the best of our knowledge there is no microbial formulation on the market today that is specifically designed to contain a comprehensive set of microbial groups with multiple complementary functions and with documented efficacy for substantially increasing productivity of such a broad spectrum of important pulses, cereals, vegetable, and forage crops as reported here. Heavy use of chemical fertilizers and pesticides that are often employed for increasing crop productivity now result in leaching of nitrates which at high levels pose a health hazard to humans. Further more, when soils become anaerobic, nitrate (NO₃) is reduced to nitrous oxide N₂O, which is over 300 times more potent than CO₂ as a greenhouse gas. Polymicrobial formulations decrease the need for nitrogenous fertilizers (by almost 50%) and pesticides. Therefore, polymicrobial formulations similar to F2 (or even more improved future products) have the potential to greatly increase crop productivity with less dependence on chemical fertilizers and pesticides, greatly reduce the cost of cultivation, and alleviate negative health and environmental consequences associated with the use of the latter compounds. Polymicrobial formulations also help solubilize key plant nutrients such as phosphate and make it more available for uptake by the plant. Moreover, products such as F2, consisting of microbes that naturally occur in nature, are eco-friendly, conserve soil health in increasing the number of bacteria beneficial to crop productivity, ensure better utilization of our natural resources, and are highly compatible with sustainable agricultural practices.

Acknowledgements

We acknowledge partial support from the Michigan Agriculture Experiment Station and from BioSoil Enhancement Inc. We acknowledge Poorna Viswanathan for her help with the 16S rDNA analyses.

References

- Balachandar, D., Raja, P., Kumar, K. and Sundaram, S.P. 2007. Non-rhizobial nodulation in legumes. *Biotechnology Molecular Biology Reviews* **2**, 49-57.
- Bashan., Y, Holguin G, and de-Bashan L.E. 2004. *Azospirillum*-plant relationships: Physiological, molecular, agricultural, and environmental Advances (1997-2003). *Canadian Journal of Microbiology* **50**, 521-577.
- Boddey, R. M., DaSilva, L.G., Reis, V., Alves, B. J. R. and Uргуига, S. 2000. Assessment of bacterial nitrogen fixation in grass species. In: *Prokaryotic Nitrogen Fixation: A Model System for Analysis of a Biological Process*, (E.W. Triplett, ed.), pp. 705-726, Horizon Scientific Press, Wymondham, UK.
- Brockwell, J. and Bottomley P.J. 1995. Recent advances in inoculant technology and prospects for the future. *Soil Biology and Biochemistry* **27**, 683-697.
- Carver, C. E., Pitt, D. & Rhodes, D. J. (1996): *Aetiology* and biological control of Fusarium. wilt of pinks (*Dianthus caryophyllus*) using *Trichoderma aureoviride*. *Plant Pathology* **45**, 618-630.
- Harman, G. E., Howell, C. R., Viterbo, A., Chet, I. and Lorito. M. 2004. *Trichoderma* species-opportunistic, avirulent plant symbionts. *Nature Review Microbiology* **2**, 43-55.
- Hung, M-H., Bhagwath, A. A., Shen, F-T., Devasya, R. P. and Young, C-C. 2005. Indigenous rhizobia associated with native shrubby legumes in Taiwan. *Pedobiologia* **49**, 577-584.
- Mathivanan, N., Srinivasan, K. and Chellaiah. S. 2000. Biological control of soil borne diseases of cotton, eggplant, okra, and sunflower by *Trichoderma viride*. *Journal of Plant Disease Protection* **107**, 235-244.
- Kannaiyan, S. 2000. *Biofertilizer Technology and Quality Control*. Publication Directorate, Tamilnadu Agricultural University, Coimbatore 641003, India.

- O'Hara, G. W., Howieson, J. and Graham P. H. 2003. Nitrogen fixation and agricultural practice. In: *Nitrogen Fixation at the Millennium*, (G. J. Leigh, ed.), pp 391-410. Elsevier, Amsterdam, The Netherlands.
- Pandey, P., Sahgal, M., Maheswari, D. K. and Johri, B. N. 2004. Genetic diversity of rhizobia isolated from medicinal legumes growing in the sub-Himalayan region of Uttaranchal. *Current Science* **86**, 202-207.
- Petersen, D. J. Srinivasan, M and Chanway, C. P. 1996. *Bacillus polymyxa* stimulates increased *Rhizobium etli* populations and nodulation when co-resident in the rhizosphere of *Phaseolus vulgaris*. *FEMS Microbiology Letters* **142**, 271–276.
- Polianskaia, M.S. Ozerskaia, M. Kochkina, G. A Ivanushkina, N. E. Golovchenko A. V. and. Zviagintsev. D. G. 2003. The quantity and structure of the root-associated microbial complexes of two greenhouse rose cultivars. *Mikrobiologia* **72**, 554-562.
- Rai , M. K. 2006. *Handbook of Microbial Biofertilizers*. International Book Distributing Co., New Delhi.
- Rodriguez, H. and Reynaldo, F. 1999. Phosphate solubilizing bacteria and their role in plant growth promotion. *Biotechnology Advances* **17**, 319-339.
- Rudresh, D. L., Shivaprakash, M. K. and Prasad, R. D. 2005. Effect of combined applications of *Rhizobium*, phosphate solubilizing bacterium, and *Trichoderma* spp. on growth, nutrient uptake, and yield of chick pea (*Cicer aritenium* L.). *Applied Soil Ecology*. **28**, 139-146.
- Sariah, M., Choo, C.W., Zakaria, H. and Norihan, M.S. 2005. Quantification and characterization of *Trichoderma* spp. from different ecosystems. *Mycopathologia* **159**, 113-117.
- Somasegaran, P. and. Hoben, H. J. 1994. *Handbook for Rhizobia*. Springer-Verlag: New York.
- Sundara , B. Natarajan, V. and Hari, K. 2002. Influence of phosphorus solubilizing bacteria on the changes in soil available phosphorus of sugarcane and sugar yields. *Field Crops Research* **77**, 43-49.
- Walsh, U. F., Morrissey J. P. and O'Gara. F. 2001. *Pseudomonas* for biocontrol of phytopathogens: From functional genomics to commercial exploitation. *Current Opinion Biotechnology* **12**, 289-295.
- Weaver R.K. and Frederick L.R. 1972 Effect of inoculum size on nodulation of *Glycine max* (L) Merrill, Variety Ford. *Agronomy journal* **64**, 597-599.
- Xavier, I. J., G., Holloway, G. and Leggett. M. 2004. Development of rhizobial inoculant formulations. <http://www.plantmanagementnetwork.org/pub/cm/review/2004/develop/>
- Yanni, Y. G., Rizk, R.Y., Corich, V., Squartini, A., Ninke, K., Philip-Hollingsworth, S., Orgambide, G., de Bruijn, F., Stoltzfus, D. and J. Buckley. 1997. Natural endophytic association between *Rhizobium leguminosarum* bv. *trifolii* and rice roots and assessment of its potential to promote rice growth. *Plant and Soil* **194**, 99-114.
- Yedidia. I., Srivastava, A. K., Kapulnik, Y. and Chet. I. 2001. Effect of *Trichoderma harzianum* on microelement concentrations and increased growth of cucumber plants. *Plant Soil* **235**, 235-242.

Developing Alternate Tillage and Crop Establishment Strategies for Higher Resource Use Efficiencies in the Rice-Wheat System

J.K. Ladha*

Rice-Wheat Consortium and International Rice Research Institute-India

The rice-wheat cropping systems of the Indo-Gangetic Plains (IGP) are of immense importance for food security for south Asia. However, yield stagnation/decline; water and labour scarcity; and soil, water, and air pollution are the emerging threats to the sustainability of rice-wheat systems. Therefore, the design and implementation of alternative production systems with increased resource use efficiency, profitability and productivity, and reduced adverse environmental impact, are urgently required. One of the strategies to address emerging problems, specifically shortages of water and labour, is to grow rice and wheat on zero or reduced-till land through drill with precision water management. The shift from puddled-transplanted rice on the flat land to raised bed systems affects the productivity and resource use efficiency of the rice-wheat system. Therefore, the potential benefits and constraints of alternative tillage and crop establishment systems need to be quantified on short to long-term basis and optimum layouts and management systems need to be identified to maximize yield and input use efficiency. To answer above questions, numerous farmer participatory trials on various tillage and crop establishment practices were conducted in Bangladesh, India, Nepal and Pakistan during last four years. On-farm data were analyzed using SAS Mixed Unbalanced Model and SAS Macro procedures. In addition, an on-station experiment was conducted for six years to collect detailed long-term data on productivity, resource use efficiency, partial budgeting and global warming potential. Various practices had highly variable responses. However a general trend emerged that crop productivity may or may not have positive response but resource use efficiency and farmers income tend to be superior with several alternate tillage and crop establishment strategies. This paper will analyze the reasons of variable technology response function to develop strategies for improvement and widespread delivery.

* with contribution from Alam M, Chandra P, Gathala M, Gupta RK, Kumar V, Pathak H, Prasad R, Raman A, Regmi AP, Rehman H, Saharawat Y, Sharma S, Singh UP.

Session 1.3: Diversified Farming Systems

Lessons Learned from the Extension of Direct Seeding, Mulch-Based Cropping Systems (DMC) in the Main Agro Ecological Zones of Madagascar

Rakotondramanana, O. Husson and A. Rakotondralambo

¹Executive Director, GSDM lot VA 26 Y Ambatoroka, ANTANANARIVO (101)
(Madagascar: gsdm.de@moov.mg)

²CIRAD/GSDM, GSDM lot VA 26 Y Ambatoroka, ANTANANARIVO (101)
(Madagascar: olivier.husson@cirad.fr)

³Chairman of the Board, GSDM, DG ANAE, Lot II Y 39A bis, Ampasanimalo, BP 5092,
ANTANANARIVO (101 (Madagascar: aralambo@netclub.mg))

Extension of Direct Seeding Mulch-based cropping systems (DMC) among small scale farmers have been tested in the main agro ecological zones of Madagascar for a period of up to 7 years. These agro ecological zones include climates ranging from subtropical climate at sea level to sub-tropical and semi-temperate climates at high altitude. Four main agro ecological zones were identified: (i) the eastern coast of the Country at sea level with high rainfall (1500 to 2500 mm/year) and high temperature, (ii) the medium altitude (800 to 900 m asl) of the Alaotra Lake and the Middle West, with 6 to 7 months of dry seasons and medium rainfall (600 to 1200 mm/year), (iii) the high altitude areas (1000 m to 1500 m asl) with a 6- months long rainy season (1200-1500 mm/year) and a 6-months long dry and cold season, and occurrence of frost in some areas and (iv) the dry area of the South of the Country with 3 to 4 months of rains (300 to 600 mm/year). The extension was decided after more than 10 years of adaptation of DMC systems by the NGO TAFE in the same areas and training of key field extensionists and group of farmers. Reference sites testing different systems compared with conventional tillage are maintained in these areas and are being used for training of all stakeholders. The GSDM which is a group of institutions involved in R and D was created in 2000 and aimed at capitalizing all knowledge on R and D related to DMC. A strategy document was written in 2004 and updated in 2007 for the diffusion of direct seeding on permanent soil cover at national scale. Main focus of the document were: training of all stakeholders, progressive diffusion based on community level (terroir) and taking into account all aspect of the living conditions of the communities after a short survey e.g. main commodities, importance of livestock and main sources of forages, use of inputs (farm manure, fertilizers, pesticides, ..), main constraints, sources of incomes, market, etc.. This strategy document has been approved by all members of the GSDM and its main partners. Starting with a few farmers around the TAFE reference sites in 2001/2002, (5 ha, 29 farmers), the area under DMC is 3.800 ha with 7.700 farmers all over the Country in 2007/2008. The main DMC adopted by farmers in the hills (*tanety*) under rainfed conditions are: i) food crops (maize, rice) associated with legumes (*Dolichos lablab*, *Vigna unguiculata*, *Vigna umbellata*) in Alaotra lake, ii) food crops (rice, maize) on residues of *Stylosanthes guianensis* in the Middle West and eastern coast, iii) cassava associated with *Brachiaria* sp or *Stylosanthes guianensis* in the eastern coast and to a lesser extent, and iv) maize associated with *Vigna unguiculata* followed by cotton in the dry areas.

In the low lands (paddy fields) rotation of rice with vetch (*Vicia villosa*) or with *Dolichos lablab* are very common especially in the Alaotra Lake. In the coastal area, rice is followed by *Vigna unguiculata*. The main effects of DMC are mainly observed after 3 years of good biomass accumulation. The effect is seen as an increase in yield, a drastic decrease of *Striga asiatica* (Middle West) and an increase in soil microorganisms and macro-fauna (lombrics, worms...). Pests like cutworms (*Heteronycus plebejus*) on crops like rice cultivated with DMC techniques increase in some areas (Alaotra Lake), but are reduced in other areas (highlands). A key issue in extension of these knowledge (and know-how) intensive techniques is capacity building. Training on DMC techniques and farm analysis/diagnosis is a necessary, but not sufficient, condition to extension. It usually takes 3 years to build efficient extension teams able to perform a real advice at farm level, to propose efficient solutions to actual farmers' constraints, means and objectives. Extension is largely eased when DMC systems can be proposed to overcome a major constraint to agriculture (like *Striga* infestation in the Middle West), unreliable paddy field irrigation (Alaotra Lake), possibility to reclaim uncultivated land, or systems with very limited inputs (all zones). Inversely, some conditions may slow down their extension: unreliable land tenure, poor access to credit and agricultural inputs, poor marketing channels, very small scale agriculture, etc. Farmers need to be helped to improve local socio-economic situation (promoting farmers' organizations, easing access to credit, etc.). Integration agriculture/livestock may be seen as constraints (in case of very high cattle pressure on natural resources) or an advantage for extension of DMC systems (increase of forages production through DMC). In all cases, the first 2-3 years of transition from conventional systems to DMC are crucial and require proper accompaniment of farmers by extension staff to help them to face new situations. After 3 years, extensionists support to farmers can be reduced.

Madagascar is known as one of the biggest rice consumer per capita in the world. In the past, most of the rice was produced in the lowlands or in terraces under irrigation. Nowadays, due to a rapid population growth, the hills known as *tanety*, which generally have low fertility, high acidity and are very susceptible to erosion, are used for rice

production. Screening of new rice varieties by the FOFIFA¹ has allowed rice production in many part of the Country under rain fed conditions (Alaotra Lake, vast areas of the Mid West, part of the Highlands...). However, fertilizer use is very limited (less than 10 kg ha⁻¹ year⁻¹ on average) and its cost is increasing, when yields of most food crops on the *tanety* are generally low without high input of fertilizer, lime and organic manure.

Besides rice, corn, cassava, sweet potatoes, potatoes and beans are the main food crops. Madagascar is also a country of extensive cattle rearing with an important problem of feeding during the 6 months long dry season. Vegetation cover is also low due to recurrent bush firing. Forest cover, for instance, is only around 20%.

Thus, the main constraints to agriculture are poor and acidic soils, very small scale agriculture with very limited means, high transportation cost (raising costs of inputs and reducing selling price of products), lack of farmers' organizations and agricultural services). Furthermore, in some areas like the Mid West and the South West, cereals production is limited by *Striga asiatica*. For all these reasons, DMC has been experimented and extended to restore soil fertility and to enable farmers to grow crops on the degraded lands, to achieve reasonable yields with minimum inputs.

Based on the ideas of L. Séguy from his experiences in Brazil, the first experiments on DMC were initiated by the NGO TAFE and CIRAD, in the highlands in 1991/92, and progressively extended in various contrasted conditions. In 2000 a workshop was organised in Antsirabe to discuss the main constraints during this first period of research and extension. The GSDM², a group of institutions involved in the diffusion and research on DMC was created with the objectives of capitalizing research and extension results on DMC and finding means to scale up the extension in the main areas of the Country.

Both TAFE and GSDM have been funded by the French Agency for Development AFD³ and the Malagasy Government.

1. Adaptation of DMC for the main agro ecological zones of Madagascar

Different DMC systems were tested in the main agroecological zones of Madagascar comparing zero tillage with conventional tillage on long term experiments conducted by the NGO TAFE (TAFE, 1991 to 2000). These agro ecological zones include:

- The high altitude zones (1000 m to 1500 m asl) with semi-temperate climate (type Antsirabe city) on ferral soils with 6 months long rainy season (1300 mm year⁻¹) and 6 months long dry season with low temperature (frost may occur in July). The first experimental site (1500 m asl) in this zone started in 1991 and three other sites were initiated in 1994 to cover the range of soil fertility, from very unfertile soils to rich volcanic soils. The site of Antsampanimahazo is now in its fifteenth year of continuous DMC practices.
- The dry climate of the South West (rainfall: 300 to 600 mm year⁻¹) with two experiments sites on ferral soil and on fersiallitic soil which have been cultivated for 15 years with DMC techniques.
- The warm and humid climate of the eastern coast (1500 to 2500 mm year⁻¹ of rain) with two experimental sites initiated in 1998.
- The medium altitude climate (Alaotra Lake, 800 to 900 m asl) with 600 to 1200 mm year⁻¹ of rain where 3 experimental sites were initiated in 1998 on ferral soils, on alluvial soil and on alluvial soil in paddy field with very unreliable irrigation (RIA⁴). All these sites are entering their eleventh year with continuous DMC.

In 2005, reference sites and demonstrations plots were also initiated by the GSDM in close cooperation with the French NGO GRET in the driest part of the Country in the South (Ambovombe) where wind erosion and insects damage also are very important.

Thus, a large set of DMC systems was created in each zone, trying to fit as well as possible in the local environment and to propose a range of options for farmers with different means, constraints and ambitions.

¹FOFIFA : National Institute of Agricultural Research and Development

²GSDM : Groupement Semis Direct de Madagascar

³AFD : Agence Française de Développement

⁴RIA : Rizières à Irrigation Aléatoire (Unreliable irrigation paddy Fields)

Results of all these experiments showed significant differences between conventional tillage and DMC systems in terms of yield and soil improvement. For instance, significant amount of C storage was measured in the 0 to 20 cm horizon in the South West (13 years DMC), in the humid climate of the East coast (8 years DMC), and in the Alaotra Lake (8 years DMC) (Razafimbelo *et al*, 2007). However, high variations exist between the many kinds of systems and the different agro ecological zones. Although some very efficient systems show a fast improvement, it usually takes 2 to 3 years to observe marked differences in yield.

The first experiences of extension of these systems (before 2000), with very limited means, showed that:

- DMC systems needed to be locally adapted, to the bio-physical conditions and to the socio-economic environment,
- Training, capacity building and sensitization of top level managers, technicians and farmers were key issues
- There was a need for better information and communication,
- Monitoring extension was important

In 2000, the GSDM was created to address these issues, gathering the main organisms involved in research, training and extension of DMC in Madagascar, aiming at:

- the coordination and programming of research, training and extension activities on DMC
- the capitalization of all scientific knowledge related to DMC;
- the definition of strategies for training of all stakeholders and extension of DMC;
- and the monitoring of all activities in the DMC extension.

From 2004, with the funding of important projects on DMC by AFD (French Agency for Development) and the Ministry of Agriculture, Livestock and Fisheries, and latter other projects (funded by EU, KfW, world bank, etc.) large scale extension of DMC systems could really start, most of these projects being under the umbrella of a large national programme called BV-PI (Bassin Versants-Périmètres irrigués)

2. Extension of DMC in Madagascar

The evolution of areas under DMC in Madagascar is given on figure 1 for the 3 cropping seasons C1, C2 and C3.

C1 is the main cropping season, possible all over the country, during the rainy season. C2, an intermediate season is possible only where the rainy season is long enough (South East, Highlands), or in the low lands under a climate with a long dry season. C3, during the dry season, is possible only where water is available at that time. Logically C2 and C3 represent small areas as compared to C1.

It appears from figure 1 that the area under DMC has steadily increased over the past years, especially for the main rainy season (C1). The fastest extension is observed for upland fields (*tanety*), where erosion and soil degradation is a major threat.

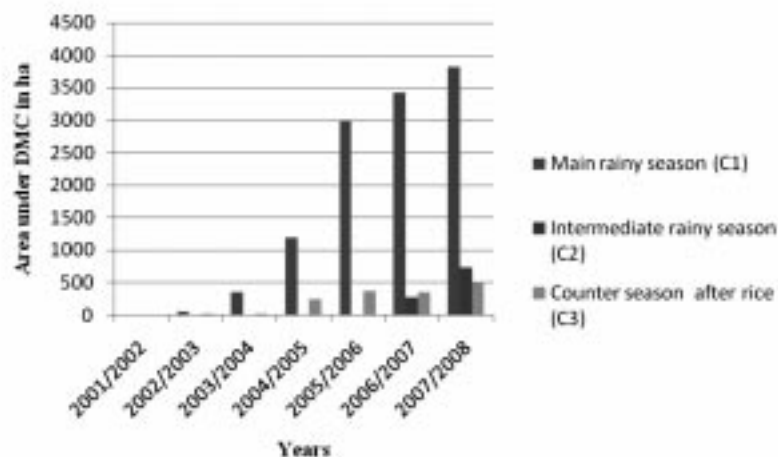


Figure 1. Evolution of areas under DMC in Madagascar

The main DMC systems, adopted preferably by farmers vary with the agro-ecological zone, the socio economic conditions and the plot characteristics. However, some main features can be identified.

- On soils with low fertility, generally on eroded slopes, farmers adopt preferably low input (low risk) commodities: groundnut or peanut, cassava, grown on crop residues (when available) and associated with *Stylosanthes guianensis* or *Brachiaria sp.* to produce a high biomass for the next season. After one to three years (according to the soil and climate conditions, but also the use of the cover plant as forage) of soil regeneration by the cover crop, plants like rice or maize can be cultivated. Thus, the association Cassava + *Brachiaria* is very common (CHARPENTIER H., 2005) on compacted soils, and all associations with *Stylosanthes* are very much appreciated as they allow cultivation of the next crop with very limited inputs and risks.
Trees and forage plantations are other options, especially in milk producing areas.
- On soils with relatively good fertility (soil developed on volcanic parent material, alluvial soils accumulated in the bottom of the hillsides, known as *baiboho*, etc.) the main systems are based on crop rotations and associations: rice can be cultivated on residues of a previous crop associating maize and *Vigna unguiculata*, *Mucuna utilis*, *Dolichos lablab*, *Stylosanthes guianensis* or *Brachiaria ruziziensis*. When the plant associated to maize is perennial, it can be kept for biomass production the following year. The best mulch (>15 t ha⁻¹ DM) is obtained with *Stylosanthes guianensis*: this can be achieved in one season at low altitude but at higher altitude (>800 m asl), *Stylosanthes guianensis* needs two seasons to get such amount of residues.
- In the Mid West where soil fertility is initially rather high (soils from basalt) but *Striga asiatica* is a major problem, rice is grown on a thick mulch of *Stylosanthes* (installed in a crop and grown for two years) which totally suppress *Striga asiatica*.
- On a good stand of *Cynodon dactylon* it is possible to apply glyphosate and to sow directly a legume crop (beans, peanut, groundnut..). This cost effective DMC system works very well (RAKOTONDRAMANANA et al, 2005) but the main constraint is that *Cynodon dactylon* may be used as grazing area during the dry season.

As soon as the climate (or the water availability in low positions) allows it, short cycle cover crops are planted in C2 to increase the total amount of biomass used to provide a better soil cover during the dry season: these are oats (in pure stand or associated with another crop), beans, radish, rye grass. Very valuable crops like potatoes also can be grown.

In the coastal areas where there is only one month of dry season, cover crops like *Stylosanthes* or *Brachiaria* can be planted in C2 season.

The cover crops during the dry season (C3) are mainly *Vicia villosa* (vetch) or *Dolichos lablab* or *oats*. These two cover crops give good residues for the following rice. Vetch is extending very fast in the Alaotra Lake in the last 3 years.

3. Significant results of DMC diffusion in Madagascar

In the process of crop rotations in DMC, the soil is accumulating organic matter over time and normally the yield and the profit of farmers are increasing. In the Alaotra Lake, over a five years period of DMC extension by BRL⁵, the yield of rice and corn is regularly increasing with the number of years under DMC (fig. 2) (BRL/ BVLAC, 2008). Similar tendency is obtained by FAFIALA in the Mid West over a 3 years period only (FAFIALA, 2008).

Farmers' profit also regularly increases, not only due to yield increase (of the main crop and the cover crop) but also thanks to decreasing labour costs (no tillage, less weeding).

The valorization of labour (man.day per ha) for the main systems adopted by farmer in the Alaotra lake is given for 2007 and 2008 on fig.3 (R. DOMAS et al, 2008). It shows a clear increase of the profit obtained from a day of labour with these systems. The longer the cultivation under DMC, the larger the profit per day, with a clear effect from the first year. Similar results were obtained in the mid West by FAFIALA (FAFIALA, 2008).

4. Lessons learned from DMC extension in Madagascar

The rate of DMC adoption by farmers largely varies between the different regions (figure 4):

⁵BRL : diffusion organism operating on DMC in Madagascar

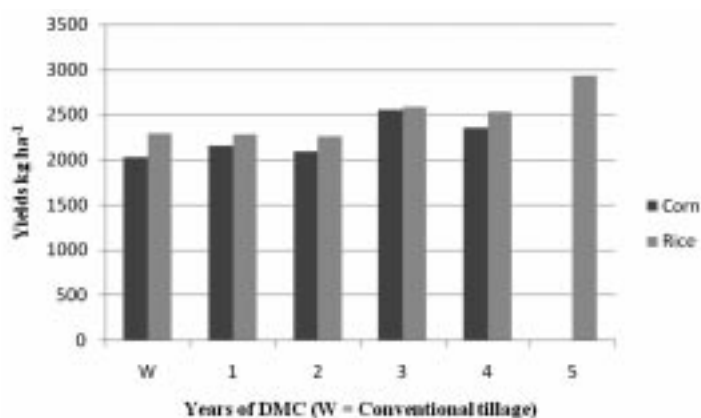


Figure 2. Evolution of yields of Maize and Rice as a function of years of DMC in the Alaotra Lake (adapted from BRL data)

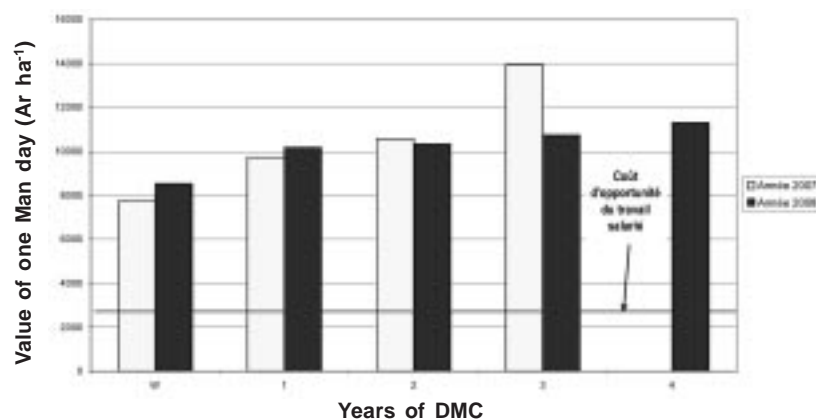


Figure 3. Value of Man day (Ar ha⁻¹), BRL 2007 & 2008

Some lessons can be learned from these experiences:

- The techniques/systems must be locally adapted to fit the bio-physical conditions and the socio-economic environment. As a consequence of this, extension will be easier (and thus faster) in some situations than in others. In the Alaotra Lake, in a rather favorable environment (medium scale farming, some production means, some capacity to invest), the proposed DMC systems are well adapted to the main constraints and propose attractive solutions for farmers (for paddy fields with poor water control, for uplands allowing reclamation of abandoned land and cultivation of upland rice, etc.). On the opposite, more difficult conditions (very small scale farming, no investment capacity, high pressure on crop residues needed for feeding animals and even used as fuel, high population density with very intensive land use, etc) as in the highlands makes it more difficult to adapt DMC systems and propose really attractive solutions, with a rapid and visible impact.
- In any cases, in such conditions, the proposed systems/techniques should aim at reducing risk (especially when risks of failure are high: unreliable climate, thieves, pests,...) putting emphasis on low inputs systems to succeed with small scale farmers (MICHELLON R., 2005, Séguy, 2006, 2007, 2008). In this respect, the rapid extension of *Stylosanthes guianensis* in many conditions can be explained by the possibilities it offers to increase production with very limited work and inputs. Its development is only limited by high altitude (cold temperatures) which reduces its growth and make it not compatible with high population density (thus high pressure on land). Techniques such as soil smouldering also can be very interesting (rapid increase in soil fertility when investment is limited in labour) However, availability of burning materials is often limiting the use of this technique.
- Some situations can be very favorable for the extension of DMC, when a major constraint (which can be overcome by DMC) limits the efficiency of traditional systems. The very rapid extension of DMC in the middle

west can be largely explained by the fact that these systems provide a very attractive solution to the very severe problems of striga, with a rapid impact on yield and profits. On the eastern shore of the Alaotra lake, the lack of paddy fields surely is a reason explaining the rapid extension of DMC, which allow upland rice cultivation with remarkable results.

- Human resources are a key issue. DMC systems/techniques are knowledge intensive. They are not a simple recipe and the choice of the system but should be carefully identified from a clear diagnosis (agronomic, but also socio-economic). Without well trained extension staff, any attempt to extend such techniques cannot be successful. Technical knowledge (and know-how) is important, but also ability to conduct diagnosis, to anticipate and organize logistical aspects (as planting time is very short and a delay is very prejudicial, every operation should be planed carefully), and to establish a real dialogue and exchanges with farmers. It usually takes 2 to 3 years to build efficient teams, as shown in the Alaotra Lake. The first 2 years, the main cause of abandon by farmers was technical failure. With training and experience, the number of abandon after 3 years was largely reduced, and the causes were more socio-economic causes (land tenure, decrease in marketing price due to high production, etc.). A major difficulty is to build teams in time, as the turn-over of extension staff is often rapid as working conditions are often regarded as difficult. As a consequence, rewards and incentives have to be given to motivate the teams.

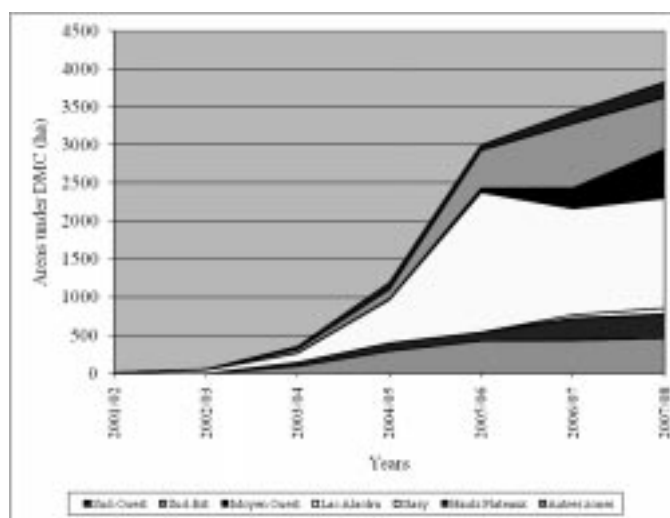


Figure 5. Evolution of areas under DMC in the main agro-ecological zones of Madagascar

- Apart from extension staff training, sensitization of policy makers, top managers and researchers also is important.
- When credit and input provision is organized by development projects, it should be done very carefully, and only on a temporary basis being just an incentive for the first years of transition from traditional to DMC systems. After 1 or 2 years, credit should be transferred to the formal credit organization, and distribution of inputs should be done through farmers organizations dealing with the private sector.
- A major difficulty in extending DMC systems is the availability of the biomass needed for covering the soil. The global biomass production can be increased by several means: plants association, succession, use of fertilizer or soil smouldering, reclamation of abandoned land, etc. However, it will always be limited in some conditions (dry climate, very degraded soils, high altitude). In case of very high pressure on the produced biomass (for animal feeding as in milk producing areas, when population density is very high, etc.), DMC systems have to prove that keeping the biomass on the ground will be more profitable than using it for another purpose. This can take a few years, and makes extension of these systems more difficult, longer and more expensive.
- Production of seeds and planting material for large scale extension should be organized from the beginning as their lack can be a serious obstacle to rapid extension. They should be produced locally as much as possible, by farmers themselves.

- Land tenure, when very unsecure, can be a major problem which should be address cautiously (facilitating the provision of land titles when possible, negotiating long term renting contracts, etc.).

Conclusions

Extension of DMC in Madagascar is going on, but large differences exist between regions. The best results are obtained when a conjunction of factors is achieved: Well adapted DMC systems, providing attractive solutions to major problems faced by farmers (shortage of paddy field, striga, etc.) with limited risk, well trained and motivated extension staff, rather secure land tenure, rather favorable conditions (climate, market opportunities, etc.). This is the case in the Middle West (striga), the eastern part of Alaotra Lake (lack of paddy fields), and the south-east (reclamation of hydromorphous soils) the best progression being observed in the areas where lowland paddy fields are limited. In the other zones, extension is slower, due to lack of human resources (extension started later than in other zones and the teams are still in a learning process), needs of research for more adapted DMC systems with a faster impact on production with available means, and/or need of more time to demonstrate the interests of these systems.

In any case integration with livestock is a big challenge because crop residues are part of the animal forages especially during the dry season.

Furthermore, extension of such techniques is a long term process. The important needs for training and technical support of farmers during the first years (at least 3 years) of transition to DMC systems is costly, especially with small scale farmers. This extension cost is expected to decrease from the 4th year onwards.

References

- BRL/BVLAC. (2008). *Rapport de campagne 2007-2008*. AMBATONDRAZAKA: BRL AMBATONDRAZAKA.
- CHARPENTIER H., R. R. (2005). Intercropping cassava with *Brachiaria* sp on degraded hillsides in Madagascar. *IIIrd World congress in CA*. Nairobi: GSDM.
- FAFIALA. (2008). *Rapport 3ème trimestre 2008*. ANTANANARIVO: FAFIALA.
- GSDM. (2007). *Stratégie du GSDM pour la mise au point, la formation et la diffusion des techniques agro-écologiques à Madagascar*. ANTANANARIVO: Groupement Semis Direct de Madagascar.
- MICHELLON R., R. I. (2005). Conception de systèmes de cultures sur couverture végétale permanente avec minimum d'intrants sur les hautes terres malgaches. *IIIrd World congress on CA*. Nairobi: GSDM.
- R. DOMAS, H. A. (2008). *Rapport de synthèse BRL à la Cellule BV LAC*. AMBATONDRAZAKA: BRL Madagascar.
- RAKOTONDRAMANANA, H. O. (2005). The use of *Cynodon dactylon* as soil cover for direct seeding in Madagascar. *IIIrd World Congress in Conservation Agriculture, Nairobi, Kenya*. Nairobi: GSDM.
- Séguy, L. (2006, 2007, 2008). *Rapport de mission à Madagascar*. Montpellier: CIRAD.
- T. RAZAFIMBELO, A. L. (2007). Stockage de carbone dans les sols sous systèmes en semis direct sous couverture végétal suivant différents contextes pédoclimatiques; Cas du Sud Est, du Centre Nord et du Sud Ouest de Madagascar. *Terre Malgache N° 26, AVRIL 2008, spécial Semis Direct, Université d'Antananarivo, Ecole Supérieure des Sciences Agronomiques* (pp. 21 - 24). ANTANANARIVO: Centre d'Information et de Documentation de l'ESSA.
- TAFA. (1991 to 2000). *Rapports annuels*. ANTSIRABE: TAFA.

Direct Drilling is Behind Agronomy of Opportunity in Tunisia

Moncef Ben-Hammouda*¹, Khelifa M'Hedhbi², Hatem Cheikh M'hame D¹ and Houcine Ghouili¹

¹Laboratory of Crop Physiology/Department of Agronomy and Rural Economy,
Ecole Supérieure d'Agriculture du Kef ; Le Kef 7100, Le Kef – Tunisia

²Centre Technique des Céréales, Tunisia

(*Corresponding author: Benhammouda.moncef@iresa.agrinet.tn)

Tunisian climate is mediterranean, characterized by irregular, sudden, intense and relatively low rain-fall. Land degradation is continuing, water resources are becoming scarce, and energy cost of farm products is continuously getting high. Consequently, cereal producers can hardly make an economic return, while practicing conventional agriculture based on conventional drilling (CD). Conservation agriculture based on direct drilling (CA/DD) gives farmers a chance to protect soils and rebuilt their fertility for an efficient use of any available form of water (rain-fall, irrigation). Such desirable efficiency does not come only by the use of the appropriate crop species, but necessarily by reducing water evaporation. To do so, a permanent mulching on the soil surface is the pivot of CA/DD. Since rain-fall fluctuates from one year to another, crop sequences should parallel with such conditions. Some couloirs have early rains (September-October) and late rains (May-June) too. In Bou-Salem (Governorate of Gendouba), early and late rains accounted for 26.2 % and 19.9 % of the 07/08 total rain for cereal growing season (September/07-June/08), respectively. These rains are not well capitalized in cereal production, when applying conventional agriculture. So, coupling the site specific approach and agronomy of opportunity is imperative to lift up farm productivity.

The climate (rain, heat) of production sites should be characterized to better define growing seasons and make the appropriate agronomic sequence. Then, the agronomy of opportunity (producing the maximum of biomass whenever the climate and the biology of the desired crop are favorable) could be applied in different scenarios, under rain-fed and/or irrigation conditions. There is no static scheme to crop the land, and it is rather a dynamic management of soil, crops, and water. A particular emphasis should be put on use of strictly seasonal (fall, winter, spring, summer) cereals and legumes in order to make a continuing cropping with two-three crops a year. A potential scenario could be a fall-barley/spring-peas/summer short season-sorghum hybrid.

Actually, few crops [barley (*Hordeum vulgare*), oat (*Avena sativa*), sorghum (*Sorghum bicolor*), millet (*Pennisetum glaucum*), african Luzerne (*Medicago sativa*)] are used as cover crops and others still under experimentation. So, AC/DD is a new ag-technology using the same species cropped in conventional agriculture but sometimes for a very different purpose. For example, barley may be sown first to be grazed, then according to the rain-fall a farmer has the choice to keep grazing or remove his flock out of the field and either seed a spring crop or let barley plants go to grain filling stage. Therefore, barley becomes a multipurpose crop when applying agronomy of opportunity. Some agronomic scenarios were successfully conducted. Sorghum was grown after a feed cereal (oat), and a forage biomass of 11 t ha⁻¹ and 3 t ha⁻¹ were produced under rain-fed conditions in 2003 and 2005, respectively. Under irrigation conditions and taking advantage of luzerne winter dormancy, oat was sown and a silage biomass of 25 t ha⁻¹ plus a hay biomass of 7.5 t ha⁻¹ were harvested in two adjacent fields. The previous two agronomic sequences could be considered as two forms of 'relay cropping' where in former case sorghum did benefit of May-June rain and the stock of water left over by the prior winter crop (oat) in addition to leached nitrate. However, in the late case, oat [could be triticale (*Triticum secale*) or barley] did benefit of luzerne biologically fixed nitrogen and rain+irrigation water too.

Key words: Mediterranean climate, Conservation agriculture, Direct drilling, Site specific approach, Agronomy of opportunity

Cereals are strategic crops for Tunisia, a country located in the southern bank of the mediterranean where rain-fall is relatively low, irregular, sudden and intense. Rain variability within and between seasons could be observed within the same year or across years (Sakis et al., 1994). Under rain-fed conditions, food or feed cereals are mostly produced in the semi-arid zones (Figure 1) with a rain-fall average of 400 mm and an estimated variability of 52% over 40 years (M'Hedhbi and Chouen, 2003). In Dahmani (semi-arid zone in the North-West of Tunisia), yearly rain explained 53% of grain yield variability of bread wheat (*Triticum aestivum*), while in Tibar (sub-humid zone in the North-East of Tunisia) explained only 43% (Ben-Hammouda and Marouani, 1997). These kinds of results originated the interest of cereal researchers to study adaptation and yield stability with a special interest to large adaptation types of varieties (Boubaker et al., 1999). As rain, heat (temperature) is a major factor controlling grain yield, and heat units concept can be used in crop production to assess heat requirements of cereals for growth and development so as to fit any species in its appropriate environment (Ben-Hammouda et al., 1997).

Rationale

Actually, there is a growing concern toward a site specific approach for crop/cereals production and transfer of



Figure1. Bio-climatic map of Tunisia.

successful scenarios from one site to another is based on a cluster analysis (Grower, 1967) of an agro-ecological characterization to identify similar sites (DePauw et al., 1997). Some sites/zones are known to have early rain in the fall (September-October) before sowing cereals and late rain (June-July) while most cereal species are harvested or mature enough to be harvested. Under CD and rain-fed conditions both types of rains do not efficiently participate in biomass production as grains or straw (Ben-Hammouda et al., 2007). Consequently, a different way to cereal producers is needed and CA/DD appeared as an appropriate technology to take advantage of any drop of water whether it comes from rain or irrigation. This is the basis for agronomy of opportunity which is defined as the production of maximum biomass when the climate and the cropped species biology are favorable to do so (Ben-Hammouda et al., 2005, Ben-Hammouda et al., 2007). An agro-climatic characterization based on monthly water deficit and seasonal rain-fall curves would help to set up at least two crops a year such as a winter cereal (C-3 crop) and a summer cereal (C-4 crop), an example of an agronomic sequence for a continuing cropping system (Ben-Hammouda et al., 2006). But it is recommended to break up a cereal/cereal sequence by a short season legume to avoid the depressive effect of an allelopathic crop such as barley (Ben-Hammouda et al., 2001) or sorghum (*Sorghum bicolor* L.) (Ben-Hammouda et al., 1995).

Agronomy of opportunity concept could be applied in many scenarios such as the following ones: i) sow a summer cover crop while waiting to harvest a mature (winter, spring) cereal, once receiving a late rain (40-50 mm), ii) for two crops/year: make out benefit of early rain (fall season) for the main crop and late rain (early summer) for the cover crop, or make benefit out of a dormant species to sow on an active one (oat/luzerne, double-purpose-barley/luzerne, triticale/luzerne), iii) for a potential three crops/year: make appropriate combinations out of short season variety-hybrid/species [spring peas (*Pisum sativum*), summer cereal, fall peas] and other cereals with strictly seasonal physiology (fall barley, winter wheat, spring wheat), and iv) use of a deeply rooted species to pump up out reached nutrients by prior superficial rooted species, and especially catch the leached nitrate.

All the above scenarios (i, ii, iii, iv) are possible under rain-fed conditions, but it easier to sow on a mulch/residues of a dormant species when irrigation water is available. Though the first scenario is possible using a handled-bucket for sowing, only the two crops/year scenarios were tested successfully in Tunisia with sorghum on oat mulch under rain-fed conditions (Ben-Hammouda et al., 2005 ; Ben-Hammouda et al., 2006) and oat on luzerne under irrigation conditions (Ben-Hammouda et al., 2007).

Agronomic scenarios in i) and iv) could be considered as cases of a 'take-over cropping' or a 'relay cropping' and the first scenario may be convenient also when the inter-crop season is too short, so a second crop would be sown on the prior one.

Objectives

When applying conventional agriculture based on CD, farmers, technicians and even agronomists deal basically with cereal production as a dependant variable of a simple regression on water whether it comes from rain or irrigation. This kind of attitude leaves little room for soil as water reservoir and physical container for both chemical and microbial activities that are closely tied with soil organic matter (OM) status. In soils with low OM rate, water of little rains either percolates quickly especially in sandy soils or gets back easily to the atmosphere giving a tiny chance to an active growing cereal crop to consume enough water. The same could be true for a cereal crop under irrigation conditions.

Applying the agronomy of opportunity concept in AC/DD is aimed to: i) rebuilt the soil by improving its fertility, ii) improve water use efficiency to produce the maximum biomass, iii) develop new agronomic scenarios with the use of a permanent crop residues/mulch (dry, green), and iv) rethink the purpose of usual cropped species in conventional agriculture.

Methods

The AC/DD was introduced in Tunisia since 1999/00 (Ben-Hammouda et al., 2005) with an innovative approach of experimentation. Yield trials were made in the farm and field lay-outs were set in a way that they handle statistical analysis over time and space (Gomez and Gomez, 1984), but in much larger plots than the ones usually used in standard experimental research stations. Out of tilling, cultural practices applied to cropped species in CA/DD were the practices that farmers use in CD but adjusted with a nitrogen (N) compensation based on N-requirements/immobilization (Harper, 1984) of microbial population and residues decay. Nitrogen was applied at the rate of 10 kg-N t⁻¹-residues ha⁻¹, when cereal residues or weed mulch is left on the soil surface. To meet the cropped species needs, potassium, phosphorus and N were supplied according to soil analysis and target yield of the cropped species. Soils of experimental fields are alkaline (pH = 8.1) with 2%-OM and a clay dominance over sand and silt. Soil moisture profile was monitored by gravimetric technique (Hansen et al., 1979). Climatic data were collected at the nearest meteorological station.

Results

1. Continuing Cropping under Rain-fed Conditions

Sorghum was sown late spring/03 (25/May/03) in a private farm at Krib (Governorate of Siliana), just after harvesting oat for silage and one week before receiving 50 mm of rain-fall (Photo 1). After emergence, sorghum plants were showered three weeks later with 20 mm, then a third time with 15 mm within two weeks interval. The climate was mild and evaporative loss of water was relatively low. Consequently, sorghum vegetative growth was active (Photo 2) enough to let roots develop deep down and sense the moisture that was out of the prior crop (oat) reach, thus giving chance to sorghum plants to take advantage of an eventual overlapping of the former and the later soil moistures. These moisture conditions favored sorghum growth till heading stage, making an estimated forage biomass of 11 t ha⁻¹ in 2003 versus only 3 t ha⁻¹ in 2005. This was an opportunity for cattle to feed on fresh plant material on summer hot days (Photo 3). Nitrogen was applied in fraction following standard recommendations, and



Photo 1. Sowing sorghum on 25/May/03, after harvesting oat for silage



Photo 2. Active growth of sorghum, June/03



Photo 3. Cattle grazing fresh sorghum on a summer hot weather, July-August/03.



Photo 4. Sorghum stands (late-August/03), after being grazed by cattle

grazed sorghum (Photo 4) resumed growth after an early-September/03 rain-fall of 52 mm (Photo 5). At this point, farmer can make a light grazing depending on the biomass volume or use it entirely as a cover crop for preferably a legume (forage, grain).

The above scenario did not cross any farmer or agronomist mind before 99/00, when CA/DD was introduced in Tunisia for the first time. Now, continuing biomass production under rain-fed conditions is not anymore a dream but a reality for many sites known as couloirs of early (September-October) and late (May-June) rain-falls. However, lots of farmers which are not very far from the successful experimental site still burning their residues (Photo 6 vs Photo 7).



Photo 5. Sorghum re-growth after receiving an early rain in the fall (early-September/03)



Photo 6. A summer sorghum biomass in Al-Alya/Krib, where agronomy of opportunity concept was successfully applied

2. A Convenient Production Site to Apply the Agronomy of Opportunity Concept

The rain-fall data in Table N°1 is for Sidi-Ahmed-Essalah (Governorate of Kef) located in a semi-arid zone of the Tunisian North-West.

Over a period of seventeen years (89/90-05/06), the total rain of the fall (September, October, November), the winter (December, January, February) and the spring (March, April, May) is on average equal to 395 mm. For this particular rain-fall distribution, farmers are not able to overpass the level of 13 q ha⁻¹ under rain-fed conditions, and it is basically due to low soil OM rate, hot climate and use of physiological intermediate varieties/species of cereals. In conventional agriculture, farmers usually make one crop a year between November and June to harvest straw and grains, a kind of crop that doesn't profit much from the winter rain-fall due to severe cold. It is almost agronomy of one full year crop, and farmers still have no understanding to the benefit of a physiologically strict seasonal cereal (fall barley, winter wheat, spring wheat ...). Integrating agronomy of opportunity concept in an applied formula with a cereal species of a physiological strict season would change the technical package of cereal production in such site.

Table 1. Characteristics of seasonal rain-fall in Sidi-Ahmed-Essalah, for 89/90-05/06 time period

Item	Fall	Winter	Spring
Maximum	290	322	215
Minimum	41	16	35
Mean	147	129	119
CV (%)	49	67	43

3. Loss of Opportunity

The site of Bou-Salem (Governorate of Gendouba) had relatively high early (October) and late (May) rains that made 26.2% and 19.9% of the total rain-fall for the 07/08 regular cereal growing season (September-May). In conventional agriculture, this kind of rain-fall is not usually productive for a November sowing of oat and March/April harvest as a silage. However in CA/DD, this scenario would allow a farmer to sow a summer cereal crop in May or use May-August period to stock water rain then sow early-September a short season (40 days) legume such as peas and avoid a cereal/cereal sequence. The monthly rain-fall of 07/08 growing season (Figure 2) was suitable to make a continuing cropping under rain-fed conditions as it was successfully done in Krib site (Governorate of Siliana).

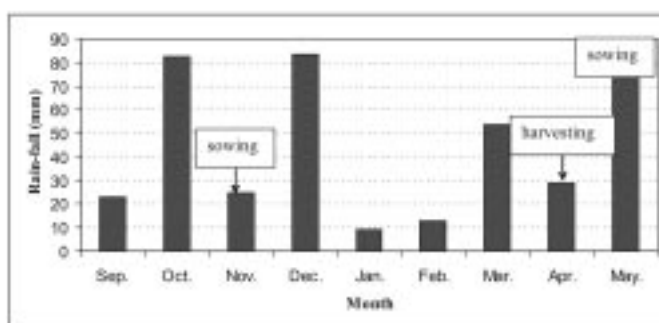


Figure 2. Monthly rain-fall in the experimental site of Bou-Salem, 07/08 growing season.



Photo 7. In a twenty kilometers cross site (Hammam-Byadha/Krib) from Al- Alya/Krib, farmers still burn dry residues/mulch



Photo 8. Growing oat for silage and hay on dormant Luzerne, and it could be barley or triticale instead of oat

4. Continuing Cropping under Irrigation Conditions

When milk is a major product, farmers reserve large fields for luzerne production. However, winter cold inhibited its re-growth/recovery especially after a severe cut in the mid-fall (20/October/03) and consequently it underwent dormancy. When applying conventional agriculture, farmers abandon luzerne fields till comes the spring heat. But when applying CA/DD, access to even wet luzerne field becomes possible with a special drill (direct sowing drill) and oat as a winter cereal was sown. Nitrogen requirement (50 kg ha^{-1} of ammonium nitrate 33%-N) for oat was estimated based on soil OM analysis and residual N from luzerne, therefore only one N application took place mid-November/03. From sowing (20/Octobre/02) to harvesting (15/March/03 , 29/May/03), two adjacent fields of oat/luzerne received 319 mm of rain-fall which was complemented with four irrigations totalizing 125 mm. In one field, a biomass of 25 t ha^{-1} was harvested early (15/March/03) enough to make silage and leave the space for Luzerne to resume early spring growth (Photo 8), and the second field was left till 29/May/03 to produce 7.5 t ha^{-1} of hay, thus delaying luzerne re-growth. This silage and hay productions would not be possible without CA/DD.

Conclusion

In semi-arid zones of Tunisia, cereal producers continue to crop their land applying an horizontal technical itinerary over a wide range of agro-ecologies. Yearly rain variability is relatively high and it goes up to 40% and the same holds for seasonal and monthly rains within a year. In conventional agriculture, monoculture is the ultimate consequence that originated the break-out of soil pathogens and a sharp decline of 'cleaning' organisms. Intensive use of chemicals for high requiring cereal varieties is hazardous to both human health and environment. Soils are tilled during the summer for seed bed preparation, and therefore are exposed to heavy solar radiation which is harmful to microbial activity. Deep tillage intensifies soil oxidation which enhances OM mineralization, thus CO₂ is emitted to the atmosphere and water holding capacity of the soil is reduced. Aggregates of disturbed soils, especially in heavy slopes become fragile to sudden and intense rain-fall that characterizes the mediterranean climate and particularly the semi-arid zones of Tunisia.

To cope with above conditions of conventional agriculture, AC/DD offers opportunities to cereal producers to efficiently use every little drops of water, since the soil surface is permanently covered with crop residues/mulch (dry, green) and dynamic scenarios/sequences are conducted upon given climatic conditions within sites/zones. Cereal production could be viewed as biomass production (forage, straw, grains) with a more rational relationship between farmers and the climate. So, farmers would keep producing the same cereal species they use to crop in conventional agriculture but with flexible attitude when it comes to the choice about what species to crop. This is a site specific approach for crop production. Farmer objective (grains, grazing, cover crop, water storage for a subsequent crop, rebuilt of soil fertility) may change according to rain-fall regime. So, there are no static rotations as is thought in conventional agriculture.

The most important opportunity concerns scientists/researchers, regarding an urgent need to accompany the spreading of CA/DD with basic research on different themes. For example, weeds flora is inversed in comparison to conventional agriculture and the field of phyto-pharmacy has to deal with new population dynamics. It is time also to develop new agronomic terms for AC/DD and ovoid the use of no-till/zero-till which carries over the sound of tillage while being less explicit about the use of a permanent mulching. When a farmer decide to move from conventional agriculture to CA/DD, he has to de-compact (clay pan, hard pan) and drain the soil if necessary, therefore a research is needed to develop cereal varieties with pivot type of rooting systems.

Acknowledgments

Authors are grateful to the Fonds Français pour l'Environnement Mondial (FFEM) for financing the Projet d'Appui au Développement de l'Agriculture de Conservation (PADAC) via the Agence Française de Développement (AFD). Thanks are extended to scientists from the Centre International de Recherche Agronomique pour le Développement (CIRAD-France) for their partnership.

References

- Ben-Hammouda, M., Boubaker, M., Marouani, A. and Hasni, F. 1997. Differential responses of three cereal species to two temperature regimes. *Agricoltura Mediterranea* **127**, 319-322.
- Ben-Hammouda, M., Ghorbal, H., Kremer, R.J. and Oueslati, O. 2001. Allelopathic effects of Barley extracts on germination and seedlings growth of bread and durum wheats. *Agronomie* **21**, 65-71.
- Ben-Hammouda, M., Kremer, R.J. and Minor, H.C. 1995. Phytotoxicity of extracts from sorghum plant components on wheat seedlings. *Crop Science*, **35**, 1652-1656.
- Ben-Hammouda, M. and Marouani, A. 1997. Influence de la pluviométrie annuelle, saisonnière et mensuelle sur la production du blé. *Medit* **4**, 34-36.
- Ben-Hammouda, M., M'Hedhbi, K., Abidi, L., Rajeh, A., Chourabi, H., El-Faleh, J. and Dichiaro, C. 2006. Conservation agriculture based on direct sowing. *Proceedings: The Future of Drylands, International Scientific Conference on Desertification and Drylands Research*. Tunis-Tunisia. pp 647-657.
- Ben-Hammouda, M., M'Hedhbi, K., Nasr, K. and Kammassi, M. 2005. Agriculture de conservation et semis direct: Zone du Kef. *Actes des 12emes Journées Scientifiques sur les Résultats de la Recherche Agricoles*. Hammamet-Tunisie. pp 145-155.
- Ben-Hammouda, M., M'Hedhbi, K., Kammassi, M. and Ghouili, H. 2007. Direct drilling: an agro-environmental approach to prevent land degradation and sustain production. *Proceedings: International workshop on conservation agriculture for sustainable land management to improve the livelihood of people in dry area*. Damascus-Syria. pp 37-48.

- Boubaker, M., BEN-Hammouda, M. and Sakouhi, L. 1999. Adaptation et stabilité du rendement de trois espèces céréalières dans les régions semi-arides et sub-humides de la Tunisie. *Sécheresse* **10 (4)**, 273-279.
- DePaw, E., Ben-Hammouda, M., Mokrane, R., Zçelik, H. and Balaghi, R. 1997. Provisional agro-climatic analysis of climatic stations in North Africa and Turkey using cluster analysis. *ICARDA Report of training workshop on agro-ecological characterisation of the high land of Algeria, Morocco, Tunisia and Turkey*. Ankara-Turkey. 7 pp.
- Gomez, K.A. and Gomez, A.A. (1984). *Statistical Procedures for Agricultural Research*. 2nd Edition. John Wiley & Sons, New York. pp 562-590.
- Grower, J.C. 1967. A Comparison of some methods of cluster analysis. *Biometrics* **23 (4)**, 623-637.
- Hansen, V.E., Israelson, O.W. and Stringham, G.E. (1979). *Irrigation Principles and Practices*. 4th Ed. John Wiley & Sons, New York. pp 53-65.
- Harper, J.E. 1984. Uptake of organic nitrogen forms by roots and leaves. In: *Nitrogen in Crop Production*. (JD Beaton, CAI Goring RD Hauck, RG Hoef, GW Randall and DA Russel, Eds.), pp 175-182. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison-Wisconsin, USA.
- M'Hedhbi, K. and Chouen, S. 2003. Conditions and constraints of testing direct sowing in semi-arid areas (Tunisia). *Proceedings: II World Congress on Conservation Agriculture*. Parana-Brasil. pp 239-245.
- Sakiss, N., Ennabli, N., Slimani, M.S. and Baccour, H. (1994). *La pluviométrie en Tunisie a-t-Elle changé depuis 2000 ans ?*. Imprimerie officielle. Tunis. pp 41-214.

Alternative Land Uses and Farm Diversification Strategies to Strengthen CA

Ademir Calegari

*Agronomic Institute of Paraná-IAPAR, Rod. Celso G. Cid, Km 375, CEP-86047-902,
2101, Londrina, Paraná, Brazil
(Email: calegari@iapar.br)*

Generally the lands in tropical and subtropical regions, all over the world is intensively cultivated, and in the majority of the cases occur an absence of an integrated soil and water management system. Many farming and cropping systems where no orderly crop diversification, including cash crops and cover crops in a crop rotation system are not followed, and a continuous soil disturbance, cannot provide an adequate addition of organic carbon to the system, thus the organic matter decomposition processes are accelerated, which causes a severe decrease in the productive potential of the agricultural soil of these regions.

With the strong evidences of the greenhouse effects, the climatic changes tend to provide alterations in the distributions and precipitation levels, tending in many regions to diminish the number of events (rains) and to increase the intensity, what certainly it will lead to incur into bigger risks of erosion and, consequences losses of soil particles, water and nutrients. In this way, it is basic that the soil surface must be kept with crop residues, minimum soil disturbance (no-tillage or direct drilling the crops) and, that the soil profile presents favorable conditions to water infiltration, including a harmonic integration of soil and water conservation methods: cover crops/green manure, crop rotation, terraces, strip crops, watershed ways, etc.

In Brazil, mainly in South region for many years, water erosion was considered the great environmental problem of the agricultural sector, and the execution of programs having mechanical conservation practices, the main feature of these actions, were insufficient to control the phenomenon. Sorrenson and Montoya, 1984 have reported that in Paraná State (South Brazil) average soil losses of 10 to 40 t ha⁻¹ of fertile soil when a traditional soil tillage system has been used. These greatly contributed to increase awareness of the problem and to lead growers to organize the search for common alternatives and solutions.

Adding organic carbon to the soil through plant cultivation, as well as keeping plant residue, preferably on the soil surface, are important measures to preserve and foster organic matter balance in the soil. Thus, plants used as cover crop, given their high capacity to produce vegetal biomass (shoot and roots) and important direct and indirect effects in the soil-water-plant system, play a fundamental role when they are an adequate part of orderly rotation systems with profitable crops.

Results obtained with winter cover crops in South Brazil including Paraná, show that significant yield increases can be attained if the proper cover crop is included in rotation system (Muzilli et al. 1983; Santos et al. 1990; Derpsch et al. 1991; Calegari et al. 2008). Almeida and Rodrigues (1985); have shown that cover crops like black oats, oil seed radish, hairy vetch, can be effective in reducing weed population in the no-till system and consequently reducing the amount of herbicide needed. According to them there is a linear correlation between the amount of biomass produced by cover crops and effectiveness in suppressing weeds. These effects on weeds may not only be through competition for light but also the allelopathic effects achieved by plant exudates (Altieri 1995; Teasdale et al. 2007).

The positive results obtained throughout the years in Paraná and other parts of Brazil prove that cover crops and cropping rotation in a no-tillage system, are very economically feasible as well as ecologically sustainable; proving not only greater crop productivity, but also conservation, maintenance and/or recovery of soil fertility, greater biologic balance in the soil, decreasing the effects of pests and or disease; in other words they represent a very promising way to manage soils tending to sustainability. The systematization of the areas through work in hydrological micro basins and also in no-tillage today occupies almost 6 million hectares in Paraná and estimates show that the no-tillage covers more than 25 million hectares in Brazil.

Historic of the Soil Management in South Brazil

Paraná State, South Brazil is located between 26° East to 54° 30' West, and 23° 30' North to 26° 30' South, and the process of soil occupation started more or less 60-70 years ago with an absence of adequate occupation planning and use of the territory leading to serious consequences in soil and water use and management.

Unfortunately, the tropical and subtropical forests were dramatically decreased (from 84% to 24% in 1965 and less than 10% to 1984) with agriculture covering both able as well as marginal areas. The total of almost 7 million hectares cultivated with summer species: soybean, maize, beans, cotton, rice, sugarcane, cassava, sorghum, coffee, fruits, vegetables, etc., on the other hand approximately half this area remains uncultivated in the autumn/winter, with serious risks of erosion (soil, water and nutrients losses) and also improving weed infestation and consequently increasing labor and farm production costs.

The traditional or conventional soil management system (ploughing) it was commonly used during almost 3 decades. Fortunately, the minimum soil disturbance (no-tillage), started at 1972 with a farmer experience: Mr. Herbert Bartz in Rolândia, North Paraná State, and this changed totally the history of soil management in South and also it was a positive followed late for many farmers in all country. The main objective at that time it was to control erosion in areas where soybean and wheat were intensively cultivated in southern Brazil. Afterwards, maize also began to be cultivated under this system. After this the research's system started with experiments and also trying to improve this system according different farming systems in South Brazil.

In the eighties, technical data showed that the system shouldn't be a mere new alternate soil management method, but rather evolve into a system integrated to different practices that should develop in an orderly, interrelated and dependent fashion. And so in 1984, there were around 300.000 hectares with No-tillage in Paraná (5% in the state itself), and after, in 1985, it covered an area of 800.000 hectares in southern Brazil. (Derpsch et al., 1991). Now Brazil occupies more than 25 million hectares of no-tillage system, where Paraná State is that present highest area (more than 5.7 million hectares).

The well succeed research's and framer's experience with no-tillage has promoted the dissemination in the majority of the agricultural areas all over the country. The use of cover crops like radish, vetch, lupine, black oat, rye, millet, mucunas, pigeon pea, cowpea, crotalaris, etc. and also crop rotation systems with soybean, maize, wheat, cotton, rice, sorghum, sunflower, etc., are increasing in different regions of Brazil. There are many different experimental studies and farmer results about cotton – wheat rotation which attained 2.26 to 5.0 t/ha of cotton and 1.5 to 4.0 t/ha of wheat, and also 6.0-10.0 t/ha⁻¹ of maize and 3.2-4.5 t/ha⁻¹ of soybean, varying during the years mainly according to the rotation system, and also affected by soil and climate conditions.

The understanding of how crop residues influence nutrient cycling and soil chemical properties combining the integration of residue management strategies into different cropping systems is a key to develop good soil fertility management. The continuous monocropping like maize – maize, rice – rice, cotton – wheat, soybean – wheat, etc., in Brazil and certainly in other regions of the world had provoked pest and disease enhancing, weed infestation, soil degradation and yield decreasing. On the other hand, the no-tillage system associated with cover crops and other soil conservation practices (conservation agriculture –CA) minimizes soil degradation process, promote changes in the soil attributes: chemical, physical and biological and also diminish the chemical external input needed.

The efficiency of the CA is reported by Calegari et al. (2008) in a long term experiment, where after 19 years of different cropping sequences and tillage management, they concluded that the no-till management sequestered 6.84 Mg ha⁻¹ more organic C compared to conventional tillage (64.6%) at the 0 to 10 cm soil depth, 29.4% more at the 0 to 20 cm soil depth, but equivalent amounts as conventional tillage at the 20 to 40 cm soil depth. Greater amounts of soil organic carbon (SOC) were within the 0 to 20 cm depth (i.e., the moldboard plow layer). Also, the results obtained showed that when winter cover crops were used with no-till, in general, greater amounts of organic C were sequestered (Figure 01).

Continuous no-till management combined with the use of winter cover crops resulted in the greatest amount of soil organic matter in the surface soil and was the only cropped treatment that approached the undisturbed forest condition. Thus, the no-till system with winter cover crops stored greater amounts of soil organic C, strengthen the CA and serves as a management model for sustaining the productivity of Oxisols in tropical and subtropical regions of the world, one to be emulated by Brazilian farmers and others who are managing similar soil types.

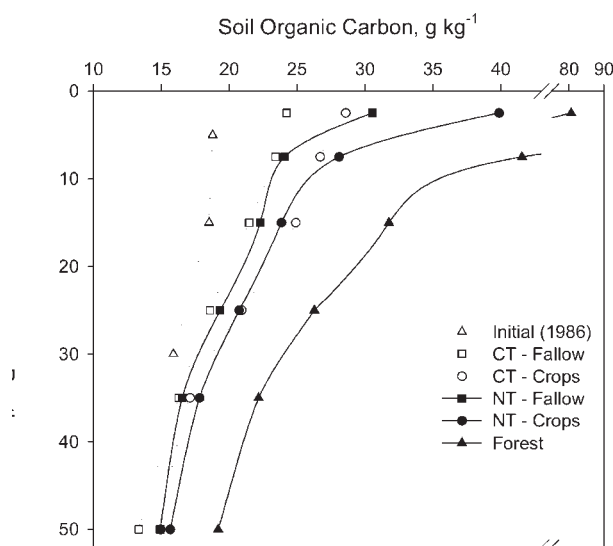


Figure 1. Soil organic carbon for different soil management and cropping systems in a Rhodic Hapludox in southwestern region of Paraná State, Brazil. CT – conventional tillage; NT – no-tillage

The experiences in some temperate climate, shows also that the soil degradation process as a result of soil mismanagement, which has showed favorable results when the implementation of no-tillage system is achieved. Thus, the use of cover crops, crop rotation and no soil disturbance has promoted soil recovering and soil productive capacity enhancing in USA, Australia, Russia, etc.

The results obtained throughout the years in Paraná, South region and other parts of Brazil prove that cover crops, as part of the productive systems, are very economically feasible as well as ecologically sustainable; proving higher water storage into the soil profile avoiding the water evaporation process, and not only greater crop productivity of cotton, soybean, maize, rice, sunflower, sorghum, wheat, rotations, but also conservation, maintenance and/or recovery of soil fertility. In addition to this, they promote economy with nitrogenous fertilizers (leguminous plants), higher weeds control by the mulch effects, greater biologic balance in the soil, higher biodiversity decreasing pests and disease occurrence, represent a very promising way to manage soils tending to sustainability.

Possibilities to Develop a Good Soil Management

In general the lack of infrastructure is a less significant constraining factor in many Global regions, however, as the agricultural input (implements, mineral fertilizers, herbicides), and information requirements are lower than for no-tillage techniques. The switch from conventional (soil ploughing) to minimum tillage is a considerably smaller step than the direct transition to no-tillage. One of the major constraint for small-scale farmer is the increased demand on the farm management, showing the crucial issue of no-and minimum tillage, both weed control and crop residue management (Steiner, 1998). One of the greatest potential for minimum tillage, like many different soil conditions all over the world, is in sub-Saharan African, in dry savannas (800-300 mm), and within those regions in areas where ploughing the soil is widespread.

Generally the principles and concepts of the CA system comprise a holistic approach, which can be adapted for different farming systems according to agro-ecological zones, and the harmonically integration of different components, such as cover crop specie, crop rotation, no-tillage, terracing, intercropping, etc. The main aims of CA is to empower farmers to make more sustainable use of their land in ways that improve their incomes and welfare, and lead to acquire the knowledge and skills to operate systems that save labour, promote soil water retention, enhance soil fertility and improve crop yields (Calegari et al., 2005, 2008).

According to Pieri et al. 2002, the Brazilian and Paraguayan farmers experience, as well in other countries, majority of the America's, shown evidence that the CA has a potential to promote a sustainable and profitable environmental approach to make frent to the challenge of food security and alleviate rural poverty mainly at tropical

environment with vulnerable natural resources. Nevertheless the CA is an extremely complex system, and field experiences and strategies in order to validate farming systems in different agroecological zones, looking for adaptation and ways to facilitate the technologies dissemination process on farm conditions, must be improved in local conditions.

The Use of Cover Crops and Crop Rotation Developed in Paraná State and other Brazilian States

In South Brazil is very common practice the use of different multipurpose cover crops/human food and forage options and this can be promoted, mainly for small scale farmers also in semi-arid areas; they simultaneously protect and recover soil properties and feed humans and animals. Therefore, different species may be used: *Vigna unguiculata* (cowpea), *Dolichos lablab* (lablab), *Cajanus cajan* (pigeon pea), *Mucuna pruriens* (mucuna), and also some other species that improve soil properties: *Pennisetum americanum* (millet), *Brachiaria ruziziensis*, *Stylosanthes sp.* (Stylo), *Clitoria ternatea* (butterfly pea), *Calopogonium mucunoides* (calopo), etc.

Different agroecological zones of Paraná state and also other Brazilian regions, with several farming systems, present a large number of species of cover crops alternatives which had been largely used by farmers. These species grow in many regions in different cropping systems with cash crops such as, maize, wheat, beans, soybean, cotton, cassava, potato, groundnuts, sunflower, vegetables and also intercropped with perennial crops, such as, coffee, citrus, fruits tree, grapes, etc. Besides promote soil properties improvement, and also good response for the next crops, have been used in a multipurpose as like an animal fodder and also some species with potential to be used in a human food.

Plants used as cover crop given their high capacity to produce vegetal biomass and roots, in the soil-water-plant system, play a fundamental role when they are an adequate part of orderly rotation systems with cash and food crops and they are strengthen the CA system

5. Conclusions

The old World experience has shown that the abundance of natural resources leads individuals to immediate actions. In contrast, scarce resources stimulate economical rationality and concern over predictability; in other words, responsible actions for environmental preservation both present and future.

The No-tillage System leads to better work distribution throughout the year, which results in the elimination of soil tilling, harrows and mechanical control over weeds. This condition will provide more time to arrange plant and manage different activities for better land diversification. With this system there is a significant reduction in soil loss, fertility improves, better efficiency in getting soil water, crop yields increase, and there is greater production stability, in addition to the possibility of permanently using the land, thus proving that it also contributes to agricultural system sustainability.

References

- ALMEIDA, F. S.; RODRIGUES, B.N. 1985. Guia de herbicidas. Contribuição para o uso adequado em plantio direto e convencional. IAPAR, Londrina, PR. 482 p.
- ALTIERI, M.A. 1995. Agroecology. The science of sustainable agriculture. Westview Press, Colorado, USA. 2nd ed. 433 p.
- BOLLIGER, A.; MAGID, J.; AMADO, T.J.C.; SKÓRANETO, F.; SANTOS RIBEIRO, M. F.; CALEGARI, A.; RALISCH, R.; NEERGAARD, A. (2006). Taking Stock of the Brazilian "Zero Till Revolution": A Review of Landmark Research and Farmers' Practice. REVIEW ARTICLE. ADVANCES IN AGRONOMY. Vol. 91, Pages 47-110.
- CALEGARI, A. (1995). The effects of tillage and cover crops on some chemical properties of an Oxisol in South western Paraná, Brazil. Dissertation Thesis. University of Aberdeen, Department of Plant and Soil Science. Aberdeen, Scotland, UK.
- CALEGARI, A.; RALISCH, R.; AND GUIMARÃES, M. F. (2005). The effects of winter cover crops and no-tillage on soil chemical properties and maize yield in Brazil. In "III World Congress on Conservation Agriculture". Linking production, Livelihoods and Conservation. 3–7 October, Nairobi, CD-ROOM.
- CALEGARIA, A.; HARGROVE, W. L.; RHEINHEIMER, D. S.; RALISCH, R.; TESSIER, D.; TOURDONNET, S.; GUIMARÃES, M. F. (2008). Impact of Long-Term No-Tillage and Cropping System Management on Soil Organic Carbon in an Oxisol: A Model for Sustainability. Agron. Journal 100:1013-1019 (2008).

- DERPSCH, R.; ROTH, C. H.; SIDIRAS, N.; KÖPKE, U. Controle da erosão no Paraná, Brasil: sistemas de cobertura de solo, plantio direto e preparo conservacionista do solo. GTZ, Eschborn, Alemanha e IAPAR, Londrina, Brasil. 1991, 272 p.
- MUZILLI, O.; OLIVEIRA, E.L.; GERAGE, A.C.; TORNERO, M.T. Adubação nitrogenada em milho no Paraná. 2. Influência da recuperação do solo com a adubação verde de inverno nas respostas à adubação nitrogenada. **Pesquisa Agropecuária Brasileira**, Brasília, DF, 18:23–27, 1983.
- PIERI, C.; EVERS, G.; LANDERS, J.; O'CONNELL, P. & TERRY, E. (2002). No-till farming for sustainable rural development. Agriculture & Rural development working paper. The International Bank for Reconstruction and Development Rural Development Department. Washington, DC, USA. 65p.
- SANTOS, H.P.; REIS, E.M. & PEREIRA, L.R. (1990). Rotação de culturas. Efeitos no rendimento de grãos e nas doenças do sistema radicular do trigo de 1980 a 1987. *Pesq. Agropec. Bras.* Brasília, 25(11):1627-35.
- SORRENSON, W.J. & MONTOYA, L.J. Economic implications of soil erosion and soil conservation practices in Paraná, Brazil. Report on a consultancy, IAPAR, Londrina, GTZ, Eschborn. 1984.
- STEINER, K. G. (1998). Conserving natural resources and enhance food-security by adopting no-tillage – An assessment of the potential for soil-conserving production systems in various agro-ecological zones of Africa, TOEB/GTZ, Eschborn.
- TEASDALE J. R.; BRANDSAETER, L. O.; CALEGARI, A.; SKORANETO, F. (2007). Cover crops and weed management. In "Non-chemical weed management: principles, concepts and technology". Edited by Mahesh K. Upadhyaya & Robert E. Blackshaw. Reading, UK. p. 49-64.

A Model Suiting Small Farm Diversification : A Case Study from India

Gurbachan Singh

Director, Central Soil Salinity Research Institute, Karnal, 132 001, Haryana, India

(Email: director@cssri.ernet.in; gbsingh@cssri.ernet.in)

Nearly 65 percent of the Indian population is dependent upon agriculture to earn livelihood and employment. More than 50 percent of the farmers in India cultivate less than one ha (2.5 acre) land holding. To earn reasonable livelihood from such a small land holding for a family of 5-6 persons and an equal number of cattle is a debatable issue. Further, in the present scenario of increasing human and livestock populations; decreasing land to man ratio; conversion of productive agricultural lands for non-agricultural use; deteriorating natural resources (soil, water, climate and biodiversity) and decreasing total factor productivity (in single crop, commodity and enterprize based farming), a new research and development strategy is called upon to restore livelihoods of small and marginal farmers. Concerns of quality conscious society with increased demand for organic food, increasing indebtedness of farmers; WTO agreement and climate change triggered frequent occurrences of natural calamities like droughts and floods, heat and cold waves are other compelling reasons of a paradigm shift in our approach from single crop, commodity and enterprize based farming to multienterprize agriculture. In the past, vast synergies available with different farm enterprizes remained largely under-exploited due to crop or commodity driven policies. Changing consumption and demand patterns and emerging marketing and trade opportunities are offering ample opportunities for greater diversification of agriculture systems to suit to the declining size of land holdings in India. The potential of integration of dairy, poultry, piggery, duckery, fishery, beekeeping and horticulture with dominant crops/cropping systems needs to be exploited to make judicious use of farm inputs, resource management, regular income and year round employment generation on the small land holding. A comprehensive information about the multienterprize agriculture model tried at the Central Soil Salinity Research Institute (CSSRI), Karnal to improve water, nutrient and energy use efficiency in reclaimed/salt stressed environment is reported in this paper. Two years results indicated that a total gross income of Rs. 600-800/day can be generated from about 0.6 ha land area when fisheries, dairy, horticulture, poultry, duckery and mushroom cultivation are integrated and byproducts of these enterprizes are recycled within the system. Cultivation of vegetables on the dykes of the fish pond yielded about Rs. 300-400/week throughout the year. The model revealed that animal dung from the dairy component can be used as feed for fish, to generate biogas and electricity and to make compost to practice organic agriculture. The compost generated through decomposition of crop residues with cow dung in a series of compost pits was sufficient to meet nutritional requirement of fruit trees and vegetables planted on the dykes of the fish pond. Since no chemicals (fertilizers and pesticides) were used to grow vegetables and fruits during the study period the produce can be graded as organically produced. The preliminary experiences reveal that large scale adoption of such multienterprize agriculture will require an effective network of marketing, post harvest processing, value addition, cold chain, specialized handling and transport system, marketing intelligence, price support and export opportunities. Required research, development and policy initiatives to up-scale this kind of diversification in small farm holdings are also discussed.

Continuous cultivation of rice-wheat cropping system for over four decades in Indo-gangetic alluvial plains has set in the processes of degradation in the natural resources of water, soil, climate and biodiversity. Depletion of under ground water, declining fertility status associated with multiple nutrient deficiencies, increased concentration of green house gasses in the atmosphere owing to large scale burning of rice and wheat residues are some of the end results of this farming system. Most of shallow cavity tube wells (centrifugal pumps) in the Punjab and Haryana states have gone out of use consequently these being replaced with deep bore wells (submersible pumps) which cost now more than one lac rupees that a small farmer do not afford. Apart from these, the average size of land holdings continues to fall, making profits from these crops to decrease and thus causing unsustainability and migration of farmers to urban areas and also selling of agriculture lands. Nearly 50 percent of the farmers in India cultivate less than one ha land holding. A farmer with a family of 5-6 persons and almost equal number of cattle is unable to coup-up with his daily expenditure from rice-wheat rotation. The recent National Sample Survey figures indicated that 40% farmers in India intend to quit farming. Scientific efforts made in the past to improve soil and water quality and to moderate green house gas emissions through better management of inputs and practices have not yielded tangible results to halt this degradation trend. Rice-wheat cropping system provides income to farmers only twice a year when the crops are harvested during early summer or early winter but a farmer needs regular income to meet out his day-to-day needs. This, therefore, calls for an urgent need to reorient the present ways of doing agriculture to those that can improve water productivity, increase use efficiency of nutrients and energy as well as provide regular income to meet farmers daily needs. There is also a need to reverse the natural resource degradation trend and restore the farmers' confidence in agriculture. Increasing income of the farmer per unit land and water by shifting from a crop, commodity and enterprize based agriculture to integrated multi-enterprize system

is called for. Some research efforts made in the country have indicated the superiority of integrated farming system approaches over the single crop and commodity based farming (Ganesan *et al.*, 1990; Jayanthi *et al.*, 2001; Shanmuga-sundram *et al.*, 1995 and Shelke *et al.*, 2001). Integrated farming system with multienterprize may pave the way for realizing increased productivity and profitability in small farms. Multi enterprize agriculture may also have the potential to decrease cultivation cost by synergetic recycling of bi-products/residues of various components within the system and also a regular source of income and employment. Keeping this in view, a multi-enterprize agriculture project was initiated at the experimental form of Central Soil Salinity Research Institute, Karnal in 2006 as a model for 2.0 ha land with interdisciplinary approach. Main theme of this project was to develop farming options/capsules, which the small farmers can adopt to earn livelihood from his one or two ha reclaimed alkali land holding and also the adopted practices contribute to the reversion in degradation of natural resources. The philosophy behind multi-enterprize agriculture is that a farmer can adopt enterprizes such as dairying, horticulture, floriculture, bee keeping, vegetable, poultry, duckery, piggery, mushroom, fisheries, gobar gas plant and solar heater etc. depending upon his resources, marketing and processing options to improve his family income and generate at farm employment for the family.

Materials and Methods

A farming system model has been developed for 2 ha land holding with following enterprizes;

- i) Agricultural crop production on 0.8 ha (0.2 ha rice-wheat, 0.2 ha maize-wheat-moong, 0.2 ha winter maize-soybean and 0.2 ha pigeonpea-mustard-fodder maize).
- ii) Fisheries, dairy, fruits, vegetables (on dykes of the pond), poultry, duckery, mushroom, gobar gas plant and solar heater in an area of about 0.6 ha
- iii) Horticulture, vegetable, horticulture plus vegetables and floriculture on 0.2 ha each. The project has been initiated with the following objectives in view:
 - Comparative evaluation of crop, commodity and enterprize diversification options in the reclaimed sodic land under small farm holding
 - To increase water, nutrient and energy use efficiency through diversified agriculture systems thereby contributing to moderate predicted climate changes
 - To increase farmer income by reducing cost of cultivation through recycling and better use of residues within the system
 - Quantification of chemical, physical and biological changes in soil under different land use options for improved soil health scenario
 - To identify profitable, sustainable and eco-friendly agriculture model for 2 ha reclaimed land holding

Before the start of the experiment, benchmark information on initial chemical, physical and biological properties of the soil was generated from different components of the model. On an average, the initial pH₂ of the cropped area was 8.1 in the upper 60 cm layer and was more than 8.5 in lower layers. The soil was low in available N, but high in P and K in all the systems. The concentrations of DTPA extractable Zn, Fe, Mn and Cu were 0.85 to 2.41; 7.51 to 18.56; 5.56 to 8.40 and 0.81 to 2.18 mg kg⁻¹, respectively. The soil on the dykes of the pond towards west was highly alkaline with pH₂ 10.25 and EC 4.0 dSm⁻¹ while in east direction the pH was 8.3 and EC 1.65 dSm⁻¹, respectively. The surface soil layers were sandy loam in texture and in the deeper layers clay content ranged from 19-25% throughout the depth. The surface bulk density varied from 1.5 to 1.6 g cc⁻¹. Overall, these soils behave as well drained soils with infiltration rate ranging between 5-10 cm day. Being low in organic carbon, they however, are vulnerable to dispersion and crusting especially after rain storm and are thus prone to water stagnation at times. The initial microbial biomass carbon varied from 180 to 281.1 mg C kg⁻¹ soil. Soil respiration from 46.6 to 63.2 mg CO₂ evolved g⁻¹ dry soil and specific metabolic quotient 1.9 to 3.3. Microbial nitrogen and phosphorous flush varied from 44.5 to 72.3 and 0.6 to 2.6 mg kg⁻¹, respectively. Dehydrogenase activity was reported in the range of 42.6 to 172.4 Mg TPFg⁻¹ dry soil. Similarly, acid phosphates varied from 23.3 to 52.4 Mg PNPg⁻¹ dry soil.

The tentative area under pond, dykes and other components is as under:-

Fish Pond 0.2 ha; area of dykes 118 x 8 m (western side), 72 x 30 m (eastern side) and 99 x 10 m (northern side); animal shed 15 m x 21 m; poultry shed 7.2 x 3.7 m; duckery 3 m x 6 m; mushroom 3.5 x 6 m; gobar gas plant 7 m x 6 m and compost Pits (3) 8 m x 4 m; 13 x 2.5 m and 8 m x 5 m.

Hundred plants of banana, 28 of guava, 30 of karaunda and 30 of amla were planted on the dykes during July-August, 2006. Inter-spaces between fruit trees on the dykes were used for raising seasonal vegetables in rotations. No chemical fertilizers and pesticides were used to grow fruits and vegetables throughout the study period. The compost prepared in the compost pits was enough to meet nutritional requirement of plants.

A multi disciplinary research team representing the disciplines of agronomy, soil science, soil water conservation engineering, plant physiology, animal sciences, fisheries and agricultural economics was involved in the in-depth analysis of respective components. The ultimate goal is to work out water, salt, energy, nutrient and gas exchange balance in the individual components and total system for modelling and upscaling.

Results and Discussion

Two years results of this multienterprize agriculture model are presented and discussed as under:

Comparative productivity and economics of the cropping systems

The productivity in different cropping systems was worked out keeping in view the quantity of marketable produce both during 2006-07 and 2007-08. The productivity in case of fodder crops represents the green fodder yield, in grain crops it is the grain yield and in case of vegetables it is the green vegetable production. The productivity obtained in different systems during 2007-08 is presented in Table 1.

Table 1. Productivity of the crops under multi-enterprise agriculture experiment during 2007-2008

Systems	Productivity (t/ha)	Productivity (t/ha)	Productivity (t/ha)	System productivity (t/ha)
Fodder Production				
Sorghum-berseem*	100.0	105.0	-	205.0
Maize-oat-berseem*	75.0	75.0	110.0	260.0
Crop Production				
Maize-wheat-mungbean	Green manured	62.5*	5.25	67.75
Soybean-maize	0.73	2.8	-	3.53
Pigeon pea-mustard-maize	0.28	0.13	29.0*	29.41
Rice-wheat	7.1	4.4	-	11.5
Flower Production				
Babycorn-gladiolus-marigold-sunflower	0.65 Cobs+0.21 t grain+ 2.0 t stover	11,460 sticks	2.9 + 2.8 sunflower	
Vegetable Production				
Ladies finger-tomato-tomato	6.0	2.9	1.3	10.2
Ladies finger-cauliflower-bottleguard	2.0	6.9	1.2	10.1
Bottle guard-tomato-garlic	17.5	10.5	3.3	31.3

* = green fodder yield

Amongst the different enterprizes studied, the fodder crops gave the highest net income followed by vegetables and flowers. The financial analysis of raising different crops is given in Table 2. The results showed that wheat cultivation was more profitable compared to the rice cultivation. On the other hand, Berseem alone gave higher net income in comparison of rice and wheat put together. The benefit cost ratio in case of Berseem fodder cultivation was 5.96. The operational cost of fodder crops, in general, and Berseem in particular was much lower than the grain crops. Performance of soybean and pigeonpea was not satisfactory and proved uneconomical at the existing pattern of resource use. Several factors contribute for variation in economic analysis of each crop each year. The pooled analysis after 5 years will give clear picture of different capsules of this 2 ha model. There were more variations in the economics of fruits, vegetables and flower crops due to fluctuating market prices and availability of such produce at different times of the year. This study is also providing an additional opportunity to judge the marketing behaviour of different crops and enterprizes being tried in the model.

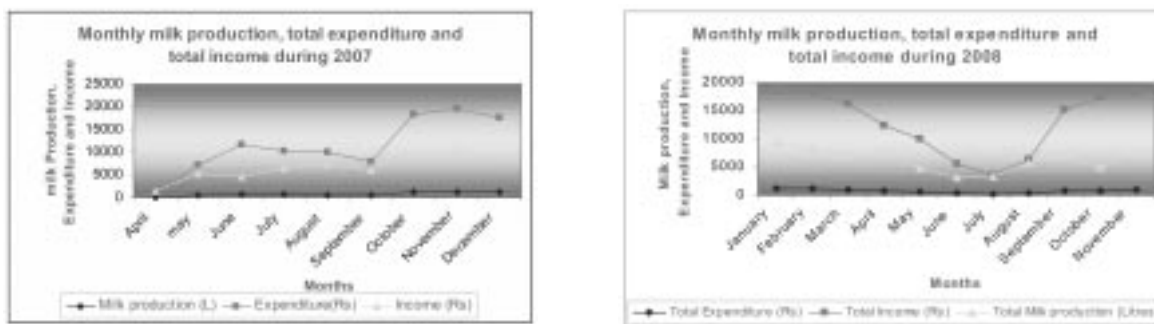
Dairy Component

Four buffaloes were purchased from National Dairy Research Institute (NDRI), Karnal on book value on April, 24, 2007 for a total cost of Rs.66500/-. The total milk production from buffaloes between April 24 to May 17, 2008

Table 2. Economics of crops grown during 2007-08 (Rs./ha)

Crops	Operational Cost	Gross income	Net income	B:C Ratio
Rice	28678.25	46250.00	17571.75	1.61
Wheat	17551.95	51500.00	33948.05	2.93
Winter Maize	18643.50	26560.00	7916.50	1.42
Green gram	10851.50	15800.00	4948.50	1.46
Soybean	14730.60	5355.00	-9375.60	0.36
Pigeonpea	11270.35	750.00	-10520.35	0.07
Mustard	10680.85	16925.00	6244.15	1.58
Baby corn	19815.77	21561.54	1745.77	1.09
Cabbage	18938.75	29610.00	10671.25	1.56
Cauliflower	33987.75	52000.00	18012.25	1.53
Chillies	6826.00	10000.00	3174.00	1.46
Bottle gourd	55624.75	117275.00	61650.25	2.11
Gladiolus	77902.69	109230.77	31328.08	1.40
Marigold	17308.46	38461.54	21153.08	2.22
Berseem	9232.00	55000.00	45768.00	5.96
Oat	8400.50	35000.00	26599.50	4.17
Maize fodder	11550.00	18000.00	6450.00	1.56
Maize+ Cowpea (Fodder)	10351.50	22500.00	12148.50	2.17
Sorghum+ Cowpea (Fodder)	12137.90	16000.00	3862.10	1.32

was 6263.25 litres. The total income from the sale of this milk was Rs. 1,12,834/-. Three cows were purchased from NDRI on 6th October, 2007 on book value for Rs. 41,943/-. Between October 6, 2007 to May 17, 2008, 4834.5 litres of milk was obtained which was sold for Rs. 63,610/-. Milk obtained from buffaloes and cows was sold to the staff members of CSSRI, Karnal on a concessional rate. The total milk production and revenue generated during the study period is given in Figure 1.

**Figure 1.** Monthly milk production, expenditure and income during 2007 and 2008

Starting from April 24, 2007 to May 17, 2008, 5.8 t of feed was given to the animals and the cost of this feed was Rs.48,000/-. Similarly, 73 t of green fodder was given to the animals. The cost of which if it is to be purchased from the market was worked out to be Rs.30,000/-. About 1.1 t of wheat *bhusa* costing Rs.11,000/- was also fed to the animals.

About 82 t of cow dung was obtained from the seven animals during this period. Out of which, 56.9 t was used for generating biogas from the gobar gas plant, 17.3 t for making compost, 1.7 t for making vermicompost and 5.74 t was added in the fish pond as fish feed (Table 3). The dung used in biogas plant, after production of biogas was added into the compost pits. A major part of urine of animals was added directly into the fish pond.

Gobar gas plant was established in August, 2007. The cooking gas production started from September, 2007. It was estimated that the bio-gas available from this plant can meet the cooking needs of a family of 5-6 people per day. The cooking gas was available throughout the year to meet energy and electricity needs. As an alternate/supplement to the commercial electricity supply, three electric lamps can also be lighted using cooking gas to

Table 3. Monthly dung production (t) during 2007 and 2008 and its recycling in the system

Month	Gobar gas plant	Compost pits	Vermi-compost	Pond	Total
April, 07	0.5	-	-	-	0.50
May	2.2	-	-	-	2.20
June	2.8	-	-	-	2.80
July	2.7	-	-	-	2.70
August	2.8	-	-	-	2.80
September	2.7	-	-	-	2.70
October	4.8	-	-	-	4.80
November	5.6	-	-	-	5.60
December	6.0	-	-	-	6.00
January, 08	2.2	1.8	-	2.20	6.20
February	2.1	1.5	-	2.30	5.90
March	3.5	1.4	0.41	0.40	5.71
April	2.5	1.9	-	-	4.40
May	1.3	1.3	0.16	0.16	2.92
June	2.1	0.4	0.46	0.25	3.21
July	1.6	1.2	-	0.01	2.81
August	1.7	1.0	-	-	2.70
September	3.2	2.0	0.69	-	5.89
October	4.0	2.5	-	0.12	6.62
November	2.6	2.3	-	0.30	5.20
Total	56.90	17.30	1.72	5.74	81.66

meet electricity need. Total expenditure on establishment of gobar gas plant was Rs. 12000/-. The government provides subsidy to the extent of 50 to 75% to the farmers for establishment of this facility at their farms.

Fish Production

Fish seed was added in the pond in March, 2006 costing Rs.2000/-. The fish species included *catla*, *mirigal*, *rohu* and grass carp/common carp. The comparative economics of fish production during 2006-07 is given in Table 4. The income is expected to increase in subsequent years.

Table 4. Economics of fish production during 2006-07 in multienterprize agriculture model

Particulars	2006-07
Fixed cost (Rs./year)	4225
Variable cost (Rs./year)	23638
Total cost (Rs./year)	27863
Fish production (kg)	1057
Gross income (Rs./year)	40391
Net income (Rs./year)	12528
B – C ratio	1.45

Bee Keeping

Beekeeping is an economic enterprize that requires less investment and space. Investment is required only in the first year when system is established. As a component of the system, 25 boxes were placed in the farming system model area. The comparative economics of this enterprize is given in Table 5.

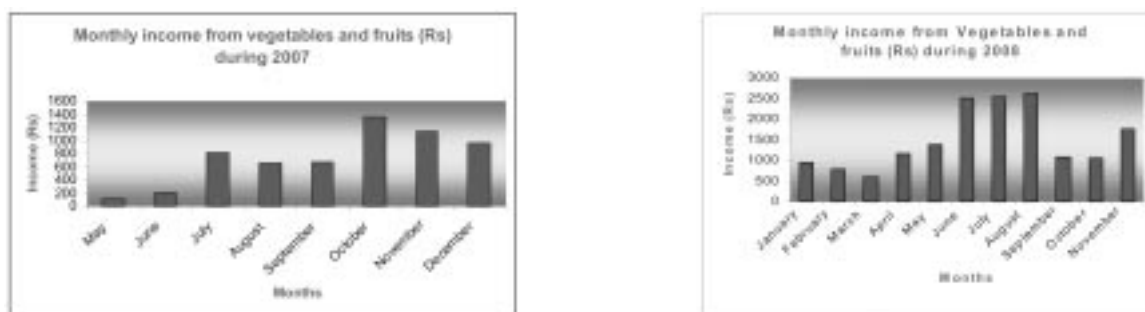
Vegetables and Fruits Production on the Dykes of the Pond

The raised dykes of the pond were effectively utilized for raising vegetables and fruits to meet daily food and nutritional requirement of 5-6 persons and to generate daily income to meet domestic expenditure. The per month income generated throughout the study period varied from Rs. 206 to 2614. The month wise variations in income during 2006-07 and 2007-08 are given in Figure 2. The fruits planted on the dykes started bearing fruits in 2008 (about 2 years after planting). Between August, 2006 and December, 2008, 252 kg of banana, 82.5 kg of guava and

Table 5. Economics of honey production

Particulars	2006-07	2007-08	Overall
Fixed cost	6358	5250	11608
Variable cost	17807	3978	21785
Total cost	24165	9228	33393
Honey production (kg)	343	106	449
Gross income	41160	12660	53820
Net income	16995	3432	20427
B – C ratio	1.70	1.37	1.61

7.5 kg of karaunda was produced. The income from the sale of banana, guava and karaunda planted on the dykes was Rs.2529, 1237 and 105, respectively. The income from these plants is likely to be increased several fold over the years.

**Figure 2.** Monthly income from vegetables and fruits during 2007 and 2008

Poultry Production

The poultry component was introduced in the last week of August, 2008. The chicks numbering 120 of *desi* mixed breed were purchased for Rs.3000/-. In a period of first three months, about 91 chicks died because of some feed related infections confirmed by the poultry doctor. One of the hens out of the remaining birds started laying eggs in last week of December. The other hens are yet to start laying eggs. During this period, about 80 kg litter from the bedding material comprised of rice husk and excreta of poultry birds was added into the compost pit. From August to December, 2008, 264 kg feed costing about Rs.2640/- was given. The tentative sale price of the birds for meat purpose is estimated as Rs.6000/-.

Rearing of Ducks

The component of duckery was introduced from September, 2008. Hundred ducks were imported from Bhubneshwar centre of the Central Avian Research Institute, Mathura. Because of some feed related infections 89 ducks died between September and November, 2008. At present 11 ducks are remaining and are quite healthy but they are yet to start laying eggs. Rs.200/- were spent on the medicines for ducks. Most of the day time, the ducks swim in the fish pond and increase oxygen availability for fish. After the introduction of ducks the mortality of fish in the pond has considerably decreased.

Mushroom Production

The culture for raising mushroom as a part of the multi-enterprize agricultural system was prepared during October-November, 2008 using wheat straw and compost. Ten kg mushroom seed was imported from National Research Centre on Mushroom, Solan and was sown in different trays and was placed in environmental controlled green house made using local materials available from the residues of the crops, bamboo sticks etc. The mushroom production started from November 25, 2008. The per day production varied from 0.2 to 4.4 kg and the total revenue generated per day during the study period varied from Rs. 10 to Rs. 340.

Water Balance in the Pond

The soil water conservation engineering expert is keeping a comprehensive information on the water balance in the pond. The total water added into the fish pond was 6900m³. The water contribution through the rainfall was 1604

m³. The loss of water from the pond due to seepage and evaporation was 3329 m³ and 2554 m³, respectively during the study period. The pumping time for irrigation and input cost of water was also worked out. The discharge of tubewell was 30 lps, depth of water table 12 m, pumping head 18 m and kilowatt required 15. Total pumping hours in one year were 64 and total units of electricity required to pump the water was 9960 units. The total expenditure was worked out Rs.4800. The monthly variations in pH₂, EC and salinity of water in the fish pond were monitored during the study period. The variation in pH₂ ranged from 7.6 to 8.3; EC from 0.6 to 0.8 and total dissolved salts from 380 to 520 meql⁻¹. These values were well within the limits prescribed for fish culture in ponds (Figure 3).

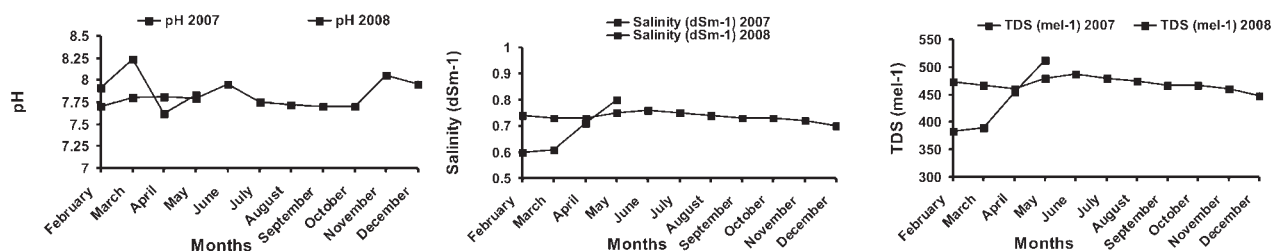


Figure 3. Monthly variations in pH, EC and salinity of the water in fish pond during 2007 and 2008

Per day Returns

Weekly and per day returns were worked out for the month of December, 2008, about 2½ years after establishment of the model. The details of the sales are given in Table 6. During the month, the per day income came from the sale of milk, vegetables grown on the dykes of the pond, fish and mushroom. The revenue generated/day from milk, vegetable and fish was Rs.623/-, 114/- and 397/- respectively. The average total income generated per day during December was Rs.1134/-. In case we take 50% as expenditure per day even then Rs.570/- as net income can be generated from this model. This does not include income from mushroom. This income is likely to increase with the passage of time when other components like fruits, poultry and ducks will also start yielding revenue. In addition, daily requirement of energy for cooking and electricity generation is met without incurring any additional expenditure.

Table 6. Revenue generation details during December, 2008

Commodity	Total sale (Rs.)	Weekly sale (Rs.)	Per day sale (Rs)
Milk	19,316.00	4389.00	623.00
Vegetables on the pond dykes	3,542.00	799.75	114.00
Fish	12,297.00	2776.69	397.00
Gross sale	35,155.00	7,938.00	1134.00

Acknowledgements

A multidisciplinary team of scientists is working on the project. The contribution of each of them is gratefully acknowledged. Special thanks are due to Mrs. Sunita Malhotra and Mr. Sultan Singh for typing and final preparation of this manuscript.

References

- Ganesan, G., Chinnasamy, K.N., Bala Subramanian, A. and Manickasundram, P. 1990. Studies on rice based farming system with duck cum fish culture in deltaic region of Thanjavur district, Tamil Nadu, *Farming Systems Newsletter* 1 (2): 14.
- Jayanthi, C. Rangasamy, A., Mythili, S., Balusamy, M., Chinnusamy, C. and Sankaran, N. 2001. Sustainable productivity and profitability of integrated farming systems in lowland farms. In: *Extended Summaries* (A.K. Singh, B. Gangwar, Pankaj and P.S. Pandey, Eds.), pp 79-81. National Symposium on Farming Systems Research in New Millennium, PDCSR, Modipuram.
- Shanmugasundram, V.S., Balusamy, M. and Rangasamy, A. 1995. Integrated farming system research in Tamil Nadu. *Journal of Farming Systems Research and Development* 1 (1 and 2) : 1-9.
- Shelke, V.B., Kulkarni, S.N., Waghmore, D.B. and Chauvan, A.A. 2001. Study on integrated farming system in Marathwada. In: *Extended Summaries* (A.K. Singh, B. Gangwar, Pankaj and P.S. Pandey, Eds.), pp 99-100. National Symposium on Farming Systems Research, PDCSR, Modipuram.

Session 1.4: Irrigated Systems

Rational and Application of CA for Irrigated Production in Southern Europe and North Africa

Helena Gomez-Macpherson^{1*}, Hakim Boulal^{1,2}, Rachid Mrabet³, Emilio Gonzalez⁴

¹*Instituto de Agricultura Sostenible, CSIC, Apartado 4084, 14080 Córdoba, Spain*

²*Universidad de Córdoba, Spain*

³*National Institute of Agricultural Research (INRA), Tangier, Morocco*

⁴*Asociación Española Agricultura de Conservación Suelos Vivos, Córdoba, Spain*

(*Email: hgomez@cica.es)

The development of sprinkler and drip irrigation has resulted in an extension of the irrigated land in the hilly areas of Southern Europe and North Africa increasing the risk of soil erosion. CA systems may reduce this risk but their adoption is quite limited. Residues and cover crop management, soil compaction and new pests have discouraged many farmers. This work presents the major problems encountered in the CA irrigated production systems in the region and introduces the most promising options.

Key words: conservation agriculture, irrigation, permanent beds system

Water scarcity is the main constraint for crop production in Mediterranean environments. Paradoxically, typical heavy rains in autumn and winter cause the main environmental problem associated to agriculture: the soil erosion. The soil lost in cultivated land has been estimated as 35 tn/ha/y in northern Morocco (Heusch, 1985) and 40 tn/ha/y in Southern Spain (Junta de Andalucía, 2003). Although these are questionable figures, the magnitude of the problem was acknowledged in the Pan-European Soil Erosion Risk Assessment in which risk figures above 10 tn/ha/y are relatively common in the southern European countries (Montanarella, 2005).

The development of powerful machinery last century displaced the less intensive traditional soil management methods. The new methods allowed rapid farm work and were extremely effective controlling weeds but also resulted in a reduction of soil organic matter and a deterioration of soil aggregates, and therefore, an increased risk of water and wind soil erosion. On the other hand, the irrigated agriculture land has increased in the last decades in all countries around the Mediterranean reaching nearly 4 million hectares in Italy and Spain, nearly 3 million ha in France and around 1.5 million ha in Greece and Morocco (FAO, 2008). This irrigation development was mostly associated to sprinkler and drip irrigation systems that, contrary to furrow or flood irrigation, do not require leveled land for an efficient water application allowing the irrigation of hilly fields and further increasing the risk of water soil erosion.

Conservation agriculture (CA) approaches have been proposed to reduce the risk of soil erosion (e.g. Holland, 2004). According to the European Conservation Agriculture Federation (ECAAF), CA refers to several practices which permit the management of soil for agrarian uses, altering its composition, structure and natural biodiversity as little as possible and defending it from erosion and degradation. In particular, for the ECAAF, CA includes direct sowing / no-tillage, reduced tillage / minimum tillage, non or surface- incorporation of crop residues and establishment of cover crops in both annual and perennial crops. The European Union promotes CA systems but leaves to each member country the decision on which approach should be followed for this promotion. In 2006, more than 15 million ha in the EU practiced a type of CA (Gonzalez, per. comm.).

In the Mediterranean basin, CA systems have been widely studied for rainfed conditions (Moreno et al., 1997; López-Bellido et al., 1996, 2000; Mrabet, 2000; Pagliari et al., 1995; Ben-Hammouda et al. 2006). The residues left on the ground help to protect the soil from the wind and the rain drops (López et al., 1998), to improve soil aggregation and fertility (Mrabet et al., 2001; Saber and Mrabet, 2002; González-Fernández and Ordoñez-Fernández, 1997) and to increase water infiltration in the soil and water availability for the crop (Moreno et al., 1997; Cantero-Martínez et al., 2007) although a minimum mulch layer is required (Lampurlanés and Cantero-Martínez, 2005). In most cases yield results unaffected although it may increase (Moreno et al., 1997; Murillo et al., 1998; Ben-Hammouda et al. 2006).

In contrast to the extensive research work in rainfed CA systems, there is a limited research work being carried out under irrigation (Boulal et al., 2008; Casa and Lo Cascio, 2008; Lithourgidis et al., 2005). This is surprising

considering that water use efficiency is a general goal in Mediterranean countries due to insufficient water irrigation allocation for covering full crop requirements, a worsening situation as irrigated land expands as well as the water demand for urban and industrial uses. The limited research on irrigated CA systems probably contributes to their limited adoption in the region. There is no information on CA surface under irrigation but we could assume that it may reach 10% of CA surface, i.e. around 400 ha in France and 125 ha in Spain, being negligible in the rest of countries. These poor figures may change in Southern Europe with new normative recently approved. For example, in Andalusia (Spain), there is a premium of 59 €/ha/y for a commitment of direct sowing during 5 years in hilly lands of 8% average slope. Furthermore, most subsidies are not linked anymore to the production of specific crops leaving farmers more freedom in the selection among available option and increasing their interest in alternatives that may reduce the production costs.

The present study aims at revising the main problems associated to CA under irrigation in Southern Europe and North Africa and at introducing the most promising systems while identifying the research needs for their development and adoption.

Cereals Based Systems

Residues management is a major limitation for no-tillage adoption in irrigated maize-based cropping systems in southern Europe. Average maize yield for the common 700 cycles in the region are higher than 12 t ha⁻¹ (Aguilar *et al.*, 2007). This implies that a similar amount of residues may be left in the field after harvest. Residues are necessary for improving soil quality as well as for limiting soil erosion, particularly in the hilly lands in this region (Boulal *et al.*, 2008). However, there is a drawback to maintaining them as they affect negatively the establishment of the following crop, typically cotton, because of the reduced soil heating during seedling emergence and the increased damages by armadillo bugs and slugs (Griffith *et al.*, 1977). In the past, residues were burnt but nowadays most farmers will incorporate them into the soil unless maize is cultivated for silage (Lithourgidis *et al.*, 2005).

Farmers in Southern Spain also identified soil compaction caused by heavy drills used in the spring sowing, or by heavy cotton harvesters used in autumn, as another major reason for non adopting CA. Indeed, increased compaction and lower yields in CA cotton have been observed elsewhere (Raper *et al.*, 2000) and the need of occasional deep ripping has been argued (Wild *et al.*, 1992).

A permanent beds system has been developed in a commercial farm in Southern Europe to deal with excessive residues and soil compaction of CA irrigated maize-cotton system (Calleja *et al.*, 2008). The crop is cultivated on the top of permanent beds with 95 cm inter-beds distance (given by cotton harvester). Two weeks before sowing, the residues from the top of the beds are shoved to the lower part of the furrow leaving a clean band of 20 cm approximately. A single row of crop is established in this band, 5 cm aside from the top centre, which is the distance at which drill's boots are deviated. The following year, the drill starts sowing at the other side of the field so the row is established 10 cm apart from preceding crop. The beds facilitate the respect of controlled traffic leaving 20 % of furrows with no traffic in any operation (sowing, treatment application, fertilization or harvest). Permanent beds systems have been used in other regions (see Govaerts *et al.*, 2005) usually where excessive residues do not pose a problem. In Mexico, the system allows fitting two crops (wheat and maize) in one campaign (Limón Ortega *et al.*, 2000). In Turkey, the permanent bed system facilitates the mechanic harvest and reduces the costs (Ozpinar and Isik, 2004).

Calleja *et al.* (2008) collected information on maize grain yield and water applied in two neighbor paddocks before and after the previously described permanent bed system was adopted (2001 and 2005 for each of the paddocks). There are a total of 7 seasons before as well as after the adoption. Additionally, some field measurements were taken after 5 years of adoption in one of the paddocks and in a neighbor traditionally tilled system. The measurements included: top residues, soil organic matter and soil water stable aggregates (determined as in Barthes and Roose, 2002) as well as saturated hydraulic conductivity, water infiltration and soil losses using a portable rainfall simulator (Alves *et al.*, 2008; Boulal *et al.*, 2008).

The permanent beds system had 210 g m⁻² of dry residues covering the surface at sowing after 5 years of no tillage whereas the conventional system has none (Calleja *et al.*, 2008). The mulch and the reduction in tillage resulted in an increased soil organic matter from 1.5% to 2.4% in the top 10 cm with no differences in deeper layers. This is a higher increment than the one obtained in rainfed cereal-based agriculture in the same region (Ordoñez-Fernández *et al.*, 2007). The water stable aggregates was also significantly higher (23% for the top 20cm)

when compared to the conventional paddock. Interestingly, there were no differences in soil organic matter or aggregates between the top and bottom of furrows in spite of shoveling the residues to the bottom two weeks before sowing.

When compared with the conventional system, the permanent bed system improved the saturated hydraulic conductivity, the soil infiltration rate and reduced significantly soil losses (Sánchez-Domínguez, 2004; Boulal et al., 2008) and more so in the furrows without traffic (Boulal et al., 2007). High water infiltration is particularly important under pivot irrigation as the intensity of irrigation in the distal part can be much higher than in the central part resulting in more erosive situation similar to a heavy rainfall (Howell et al., 2002). The improved hydraulic conditions resulted in a reduction of applied irrigation without yield penalty in this commercial farm (Figure 1). A water balance model is being adapted to incorporate CA particularities for studying possible impact of CA adoption in terms of water saving and reduction of soil erosion in the region (Boulal, unpublished).

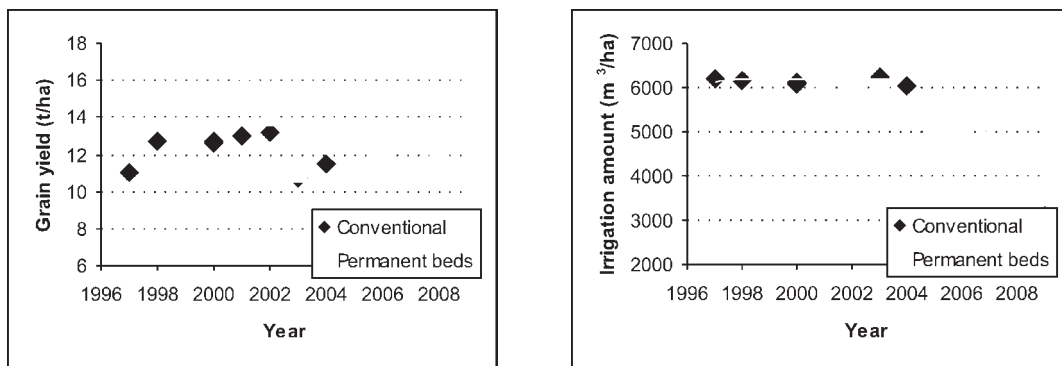


Figure 1. Paddock maize yield and applied irrigation before (conventional) and after the introduction of permanent bed system in Fuente Palmera (Spain)

Soil temperature is lower under a layer of residues because radiation does not reach directly the soil surface and cannot heat it. Lower temperatures slow down emergence and seedling growth of crops like maize (Griffith, 1977). This is particularly important for the maize and cotton crops sown in southern Europe because the cycle is tightly adjusted to the growing period and a late sowing is not desirable. Calleja et al. (2008) found a difference of 7.5 and 5 °C at 2 and 5 cm deep, respectively, in a permanent bed system when compared to uncovered soil in a conventional system, in agreement with Benjamin et al. (1990).

Various maize varieties have been tested in the permanent bed system established in the commercial farm during the last seven years and they appear to respond differently, some having a quicker and better establishment that reduces pest damage at seedling stage (Calleja, pers. comm.). These observations put forward the need to evaluate locally available genotypes in the permanent beds system following standard research.

Contrary to Southern Europe, the development of CA in North Africa is mostly limited by the lack of residues to cover the soil because of large feeding demand or overgrazing. Residues are needed for CA success (Govaerts et al., 2005) and the minimum required should be determined in order to develop strategies of balanced residues management. The conflict though often goes beyond farmers decisions as traditional livestock management includes feeding on cropping rests. In these cases, specific policies from authorities are necessary.

In Morocco, a central issue in irrigated agriculture is how to effectively use growing season precipitation and limited available water for irrigation. A balance between the productivity and the quality of soils must be sought as pressure on the irrigated lands is likely to increase. The balance could be realized through simultaneous use of no-tillage systems, as water conserving and soil restorative technologies, and of supplementary irrigation techniques for more efficient and economic use of limited available water. In fact, the feasibility of no-tillage for irrigated cereals has been systematically assessed since the 1990s in Chaouia region (350 mm average rainfall, Mrabet, 2008) and it continuous up to now in Sais region (450 mm average rainfall, Mrabet, unpublished). In the last, no-tillage irrigated system resulted in higher wheat grain yield compared to more conventional systems (Figure 2). In 2006, three applications of 20, 20 and 40 mm were done at selected stages of wheat while, in 2007, only two applications of 15

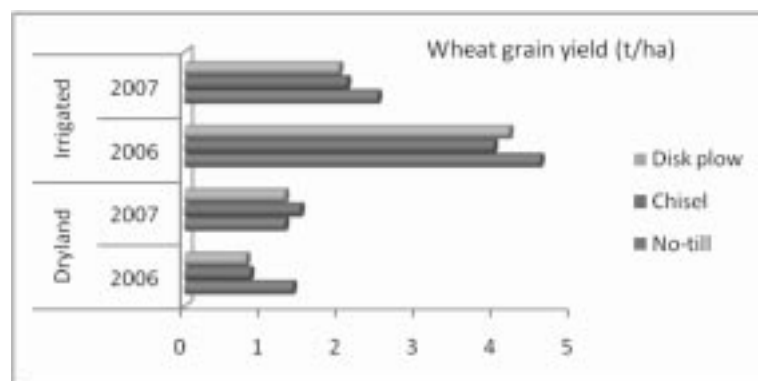


Figure 2. Impact of dryland and irrigated tillage system on wheat grain yields in semiarid Morocco (Mrabet et al., unpublished)

mm were possible. Ten wheat varieties were included in the study and significant interaction with tillage system was observed (data not shown). Further evaluation is needed to identify the best adapted varieties to irrigated CA systems.

Olive Orchards and Vineyards

Olive orchards and vineyards form the most extensive perennial cropping systems in the Mediterranean region. Traditionally they occupy hilly lands with the highest risk of soil erosion due to common mechanical weed control. The use of cover crops reduces this risk (Gómez et al., 2009) but, in rainfed conditions, their management in order to avoid the competition for water is tricky. In the last decades, however, the development of irrigation systems has facilitated the extension of cover crops because of more flexibility in the killing timing without increasing the risk for water competition and yield decrease.

Cover crops may be sown each year or second year or, alternatively, the natural vegetation can be left to re-grow and cover the inter rows space. Some farmers prefer to use arable crop residues or chipped bark as mulch. Any of these options accompanied by chemical weed control appear cost effective compared to tilling the soil (Jones et al. 2006). Furthermore, the use of cover crops in vineyards may also improve wine quality in soils with high water availability as in Portugal (Monteiro and Lopes, 2007) and France (Celette et al., 2008). Cover crops though can result in lower surrounding temperature and increased risk of frost damage and requires special attention to fertilization (Rupp and Fox, 1999).

In irrigated olive orchards, zero or minimum tillage improved water availability compared to conventional tillage, increasing the oil yield production by 9% (Pastor, 2005). Most irrigated olive orchards follow a system of deficit irrigation and special attention is required for a correct irrigation scheduling that avoids damaging droughts and yield penalties. In conventional orchards, Orgaz et al (2006) has proposed the use of a new crop coefficient that is the sum of i) a tree transpiration component, ii) an evaporation from the soil component and iii) an evaporation from the areas wetted by emitters. The calculations obtained with this model can be corrected during the season with current rainfall and ETo values, however, the model has not been adapted to include cover crops. The last will require an increased crop coefficient and its variation associated to herbicides use. The water balance should include higher water infiltration and reduced runoff movement than in the conventional system (Gómez et al., 2009). For citrus orchards of 50% canopies, FAO Monograph 56 (Allen et al., 1998) proposes to increase the crop coefficient from 0.60 to 0.75 if an active ground cover is present.

Research Needs

The following research themes are proposed to develop CA under irrigation on commercial basis:

- Water balance models for adjusting irrigation scheduling to CA conditions and improving water use efficiency and soil protection.
- Water balance models of permanent crop / cover crop system for minimizing competition for water and soil erosion and for improving fruit quality.

- Study the evolution of off-site movement of agrochemicals (particularly herbicides) and sediments.
- Adjust available models of evolution of residues degradation and soil physical and chemical characteristics to CA under irrigation.
- Develop alternatives for residues management in competition with livestock.
- Evaluation of controlled traffic and periodical tillage to avoid or relieve soil compaction.
- Evaluation of genotypes for permanent bed systems and direct seeding.

A participatory research approach as in Rawson et al (2007) should be considered due to the local specificities required for the adaptation of CA systems.

Acknowledgements

The work presented from Southern Spain and Morocco was partially funded through project AGL2005-05767.

References

- Alves Sobrinho, T., Gómez-Macpherson, H. and Gómez, J. A. 2008. A portable integrated rainfall and overland flow simulator. *Soil Use & Management*, 24, 163-170.
- Aguilar, M., Borjas F. and Espinosa M. 2007. Agronomic response of maize to limited levels of water under furrow irrigation in southern Spain. *Spanish Journal of Agricultural Research*, 5, 587-592.
- Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. *FAO Irrigation and Drainage Paper no. 56*, Rome, Italy.
- Barthes, B. and Roose, E. 2002. Aggregate stability as an indicator of soil susceptibility to runoff and erosion: validation at several levels. *Catena* 47, 133-149.
- Ben-Hammouda, M., M'Hedhbi, K., Abidi, L., Rajeh, A., Chourabi, H., El-Faleh J. and Dichiara, C. 2006. Conservation Agriculture Based on Direct Sowing. In: *The Future of Drylands*. p. 647-657. International Scientific Conference on Desertification and Drylands Research Tunis, Tunisia.
- Benjamin, J.G., Blaylock, A.D., Browns, H.J., Cruse, R.M. 1990. Ridge tillage effects on simulated water and heat transport. *Soil & Tillage Research*, 18:167-180.
- Boulal, H., Alves Sobrinho, T., Gómez-Macpherson, H. and Gómez, J.A. 2007. Efecto del tráfico controlado sobre la infiltración del agua y la erosión del suelo en un sistema de cultivos anuales en lomos permanentes en el sur de España. In: *Estudios de la zona no saturada del suelo Vol. VIII*. p. 211. Córdoba (Spain).
- Boulal, H., Gómez-Macpherson, H. and Gómez, J.A. 2008. Water infiltration and soil losses in a permanent bed irrigated system in Southern Spain. *Italian Journal of Agronomy*, 3, 45-46.
- Calleja, R., Boulal, H. and Gómez-Macpherson, H. 2008. An innovative way to handle residues in a no-tillage maize-based system under sprinkler irrigation in southern Spain. *Italian Journal of Agronomy*, 3, 643-644.
- Cantero-Martínez, C., Angás, P. and Lampurlanés, J. 2007. Long-term yield and water use efficiency under various tillage systems in Mediterranean rainfed conditions. *Annals of Applied Biology*, 150, 293-305.
- Casa, R. and Lo Cascio, B. 2008. Soil conservation tillage effects on yield and water use efficiency on irrigated crops in Central Italy. *Journal of Agronomy and Crop Science*, 310-319.
- Celette, F., Gaudinand, R. and Gary, C. 2008. Spatial and temporal changes to the water regime of a Mediterranean vineyard due to the adoption of cover cropping. *European Journal of Agronomy*, 29, 153-162.
- FAO, 2008. FAOSTAT: <http://apps.fao.org/>. FAO, Roma Italy.
- Gomez, J.A., Sobrinho, T.A., Giraldez, J.V. and Fereres E. 2009. Soil management effects on runoff, erosion and soil properties in an olive grove of Southern Spain. *Soil & Tillage Research*, 102, 5-13
- González-Fernández, P. and Ordóñez-Fernández, R. 1997. La fertilización en el laboreo de conservación. In: *Agricultura de Conservación: Fundamentos Agronómicos, medioambientales y Económicos* (L García-Torres and P González-Fernández, eds.), p 75-104. Asociación Española de Agricultura de Conservación/Suelos Vivos, Spain.

- Govaerts, B., Sayre, K.D. & Deckers, J. 2005 Stable high yields and zero tillage and permanent bed planting? *Field Crops Research*, 94, 33–42
- Griffith, D.R., Mannerling, J.V. and Moldenhauer, W.C. 1977. Conservation tillage in the eastern cornbelt. *Journal of Soil Water Conservation*, 32, 20-28.
- Heusch, B.P. 1985. *Conservation in North Africa: Its status and related agricultural production*, SOGREAH, Grenoble, France 37 pp.
- Holland, J.M. 2004. The environmental consequences of adopting conservation tillage in Europe: a review. *Agriculture, Ecosystems and Environment* 103, 1-25.
- Howell, T.A., Schneider, A.D. and Dusek, D.A. 2002. Effects of furrow diking on corn response to limited and full sprinkler irrigation. *Soil Science Society of America Journal*, 66, 222-227.
- Jones, C.A., Basch, G., Baylis, A.D., Bazzoni, D., Biggs, J., Bradbury, R.B., Chaney, K., Deeks, L.K., Field, R., Gomez, J.A., Jones, R.J.A., Jordan, V.W.L., Lane, M.C.G., Leake A., Livermore, M, Owens, P.N., Ritz, K., Sturny, W.G. and Thomas, F. 2006. *Conservation agriculture in Europe: an approach to sustainable crop production by protecting soil and water?* SOWAP, Jealott's Hill, Bracknell, RG42 6EY, UK
- Junta de Andalucía. 2003. *Informe de Medio Ambiente de Andalucía*, Junta de Andalucía, Sevilla, Spain.
- Lampurlanés, J. and Cantero-Martínez, C. 2006. Hydraulic conductivity, residue cover and soil surface roughness under different tillage systems in semiarid conditions. *Soil & Tillage Research*, 85, 13-26.
- Limón-Ortega, A., Sayre, K.D. and Francis, C.A. 2000. Wheat and Maize Yields in Response to Straw Management and Nitrogen under a Bed Planting System. *Agronomy Journal*, 92, 295-302.
- Lithourgidis, A.S., Tsatsarelis, C.A. and Dhima, K.V. 2005. Tillage effects on corn emergence, silage yield, and labor and fuel inputs in double cropping with wheat. *Crop Science*, 45, 2523–2528
- López, M.V., Sabre, M., Gracia, R., Arrúe, J.L. and Gomes, L. 1998. Tillage effects on soil surface conditions and dust emission by wind erosion in semiarid Aragón (NE Spain). *Soil & Tillage Research*, 45, 91–105.
- López-Bellido, L., Fuentes, M., Castillo, J.E., Lopez, F.J. and Fernandez, E.J. 1996. Long-term tillage, crop rotation, and nitrogen fertilizer effects on wheat yield under rainfed Mediterranean conditions. *Agronomy Journal* 88, 783-791
- López-Bellido L., López-Bellido, R.J., Castillo, J.E. and López-Bellido, F.L. 2000. Effects of tillage, crop rotation, and nitrogen fertilization on wheat under rainfed mediterranean conditions. *Agronomy Journal* 92, 1054-1063.
- Montanarella, L. 2005. Emerging issues in soil and water management for vineyard and olive-tree orchard. In: *Integrated soil and water management for orchard development* (Eds. Benites J., Pisante M., Stagbari F.). FAO, Rome, Italy.
- Monteiro, A. and Lopes, C.M. 2007. Influence of cover crop on water use and performance of vineyard in Mediterranean Portugal. *Agriculture, Ecosystems & Environment*, 121, 336-342
- Moreno, F., Pelegrín, F., Fernández, J.E. and Murillo, J.M. 1997. Soil physical properties, water depletion and crop development under traditional and conservation tillage in southern Spain, *Soil & Tillage Research*, 41, 25-42.
- Mrabet, R. 2002. Stratification of soil aggregation and organic matter under conservation tillage systems in Africa. *Soil & Tillage Research*, 66, 119-128.
- Mrabet, R. 2008. *No-Tillage systems for sustainable dryland agriculture in Morocco*. INRA Publication. Fanigraph Edition. 153p.
- Mrabet, R., Saber, N., El-Brahli, A., Lahlou, S. and Bessam, F. 2001. Total, particulate organic matter and structural stability of a Calcixeroll soil under different wheat rotations and tillage systems in a semiarid area of Morocco. *Soil & Tillage Research*, 57, 225-235.
- Murillo J.M., Moreno F., Pelegrín F. and Fernández J.E., 1998. Responses of sunflower to traditional and conservation tillage under rainfed conditions in southern Spain. *Soil & Tillage Research*, 49, 233-241.
- Ordóñez, R., González, P., Giráldez, J.V., Perea, F. 2007. Soil properties and crop yields after 21 years of direct drilling trials in Southern Spain. *Soil & Tillage Research*, 94, 47–54.
- Orgaz, F., Testi, L., Villalobos, F.J. and Fereres, E. 2006. Water requirements of olive orchards—II: determination of crop coefficients for irrigation scheduling. *Irrigation Science*, 24, 77–84.
- Ozpinar, S. and Isik, A. 2004. Effects of tillage, ridging and row spacing on seedling emergence and yield of cotton. *Soil & Tillage Research*, 75, 19-26.
- Pagliai, M., Raglione, M., Panini, T., Maletta, M. and La Marca, M., 1995. The structure of two alluvial soils in Italy after 10 years of conventional and minimum tillage. *Soil & Tillage Research*, 34, 209–223.

- Pastor, M. 2005. Mantenimiento del suelo en olivar de regadío: manejo del suelo y herbicidas. In: *Cultivo del olivo con riego localizado : diseño y manejo del cultivo y las instalaciones, programación de riegos y fertirrigación* (Ed. M. Pastor). Mundiprensa, Spain, pp. 589-623
- Raper, R.L., Reeves, D.W., Burmester, C.H. and Schwab, E.B., 2000. Tillage depth, tillage timing, and cover crop effects on cotton yield, soil strength, and tillage energy. *Applied Engineering in Agriculture*, 16, 379–385
- Rawson, H.M., Gómez-Macpherson, H., Hossain, A.B.S., Saifuzzaman, M., ur-Rashid, H., Sufian, M.A., Samad, M.A., Sarker, A.Z., Ahmed, F., Talukder, Z.I, Rahman, M., Siddique, M.M.A.B., Ammin M. 2007. On-farm wheat trials in Bangladesh: A study to reduce perceived constraints to yield in traditional wheat areas and southern lands that remain fallow during the dry season. *Experimental Agriculture*, 43, 21-40.
- Rupp, D. and Fox, R. 1999. Optimized water and nitrogen supply by adapted soil management in the Württemberg Vineyard region. *Acta Horticulture*, 493, 83–85.
- Saber, N. and Mrabet, R. 2002. Impact of no tillage and crop sequence on selected soil quality attributes of a vertic calcixeroll soil in Morocco. *Agronomie* 22, 451-459.
- Sánchez-Domínguez, M.A. 2004. *Efecto de la cubierta vegetal sobre la escorrentía, pérdida de suelo y fertilidad en la finca La Parrilla, Fuente Palmera (Córdoba)*. Proyecto Final de Carrera, Escuela Técnica Superior de Ingenieros Agrónomos y de Montes, Universidad de Córdoba, 102 pp.
- Wild, M.R., Koppi, A.J., McKenzie, D.C. and McBratney, A.B. 1992. The effect of tillage and gypsum application on the macropore structure of an Australian Vertisol used for irrigated cotton. *Soil & Tillage Research*, 22, 55–71.

Implementing Conservation Agriculture Concepts for Irrigated Wheat Based Systems in Northwest Mexico: A Dynamic Process Towards Sustainable Production

Bram Govaerts^{1*}, Nele Verhulst^{1,2}, Ken D. Sayre¹, Fabian Kienle³, Dagoberto Flores¹ and Agustin Limon-Ortega⁴

¹*International Maize and Wheat Improvement Centre (CIMMYT), Mexico, D.F., Mexico*

²*Department of Earth and Environmental Sciences, Katholieke Universiteit Leuven, Celestijnenlaan 200 E, 3001 Leuven, Belgium*

³*Colegio de Postgraduados, Km 36.5 Carr. México -Texcoco, CP 56230, Montecillo, Mexico*

⁴*INIFAP-CEVAMEX, AP10, Km 17.5 Carr. México-Lechería, CP 56230, Chapingo, Mexico*

**Corresponding author (Email: b.govaerts@cgiar.org)*

In this paper we use the example of the irrigated wheat based systems of North Mexico as a typical example of a step-by-step process to advance the use of Conservation Agriculture based Resource Conserving Technologies towards the final goal of the implementation of Conservation Agriculture. Sonora in northwest Mexico. This region is characterized by a desert climate, mostly sunny and dry with a total rainfall of about 381 mm per year with 253 mm during the summer cycle (May – Oct). The Yaqui Valley is one of the main agricultural production areas encompassing nearly 255,000 ha of irrigated land using primarily gravity irrigation systems fed by canals (over 80% of irrigation water) and deep tube wells (around 20% of irrigation water). Crops planted during the winter cycle are wheat (November-May), safflower (January-June), winter maize (September-February), chickpea (December – April) while during the summer cycle summer maize (May – October), sorghum (March – July), dry beans (March – May) are most common. There have been 3 main shifts in farming system practices during the last decades: (1) In 1981, the majority of the farmers were planting with 'melgas' (crops planted in solid stands on the flat with flood irrigation in basins) with only 6% of farmers in the valley planting on raised beds. However by 1996, 90% of the farmers had shifted to planting on raised beds. The great benefits from bed planting are reduced production costs, reduced irrigation water use, enhanced field access which facilitates control of weeds and other pests, and timely and efficient application of nutrients, reduced tillage, and crop residue management. (2) Another remarkable change in farmer practices has been crop residue management. In the 1992/93 cycle, residues were burned by 95% of the farmers. This practice was deeply entrenched. By 2001, however, 96% of the farmers are no longer burning but incorporating the residue. (3) Recently there is growing interest to take the next logical step in making raised bed planting more sustainable by reducing tillage and manage crop residues on the surface by reusing permanent raised beds with only superficial reshaping in the furrows between the raised beds as needed before planting of each succeeding crop, following even distribution of the previous crop residues. Therefore in 1991 the crop management team at CIMMYT started research on permanent beds to offer farmers opportunities to further reduce production cost and increase sustainability of the system through the positive effects on chemical, physical and biological soil quality.

Keywords: permanent raised bed planting, residue management, irrigated wheat systems, resource conserving technologies

In many parts of world, agricultural practices are determinant in food production. Adoption of new agricultural technologies, intensification of agriculture and improved crop varieties have dramatically increased crop yields in developing countries (Gupta and Seth, 2007). However, modern society demands cropping systems that not only aim at stable and high yields, but also maintain soil fertility, reduce negative effects for the environment and are economically sound (Lal, 1997).

Farmers concerned about the environmental sustainability of their crop production systems combined with ever-increasing production costs have begun to adopt and adapt improved management practices for their cropping systems that lead towards the ultimate vision of sustainable conservation agriculture solutions. Conservation Agriculture combines the following basic principles:

1. **Reduction in tillage:** The objective is the application of zero tillage or controlled tillage seeding systems that normally do not disturb more than 20-25% of the soil surface
2. **Retention of adequate levels of crop residues and surface cover of the soil surface:** The objective is to maintain an adequate soil cover through the retention of sufficient crop/cover crop residues on the soil surface to protect the soil from water/wind erosion, water run-off and evaporation to improve water productivity and to enhance soil physical, chemical and biological properties associated with long term sustainable productivity;

3. **Use of crop rotations:** The objective is to employ economically viable, diversified crop rotations to help moderate/mitigate possible weed, disease and pest problems and offer economically sound cropping alternatives to help minimize farmer risk.

These conservation agriculture principles seem to be applicable to a wide range of crop production systems including low-yielding, dry rain-fed as well as high-yielding irrigated conditions. However, how these principles are applied will depend on the situation and will need a flexible approach as a function of different production systems. Obviously, specific and compatible management components (weed control tactics, nutrient management strategies and appropriately-scaled implements.) will need to be identified through adaptive research with active farmer involvement to facilitate farmer adoption of appropriate CA-based technologies for contrasting agro-climatic/production systems. As such, the movement towards CA-based technologies normally is comprised of a sequence of stepwise changes in cropping system management to improve productivity and sustainability. The principles of marked tillage reductions are initially applied in combination with the retention of sufficient amounts of crop residue on the soil surface, with the assumption that appropriate crop rotations can be included or maintained to achieve an integrated, sustainable production system. Local soil and environmental conditions will determine if zero-tillage, strip tillage, permanent raised bed planting, or any other reduced tillage system is the best alternative. Local market conditions, crop production level, farming system and environment will determine the residue management strategies but with the near certainty that unless adequate residues are not retained, marked reductions in tillage will unlikely be feasible over the long term. In this paper we use the example of the irrigated wheat based systems of North Mexico as a typical case of a step-by-step process that involves the application of CA-based Resource Conserving Technologies towards the final goal of the implementation of Conservation Agriculture.

The Yaqui Valley in Sonora, Mexico

Sonora, located in the northwest of Mexico, is characterized by a desert climate, mostly sunny and dry with total amount of rainfall is about 381 mm per year with 253 mm from June to August during extreme rain events in the summer cycle (1971-2000). Average day-time temperatures during the grain filling stage are moderate (18°C) for wheat and hot (31°C) for summer maize. Sonora has national and international importance for wheat production, especially the Yaqui Valley which forms a part of the North-West Mexican coastal plains and is located 27.33 N, 109.09 W and 38 masl (Figure 1). The valley represents a microcosm of events characterizing the progress in wheat production that has occurred around the world over the past 40 years. This valley was the center of the wheat improvement program that Dr. Norman Borlaug and his colleagues initiated in Mexico in the mid 1940s. From this modest program came the remarkable semi-dwarf wheat germplasm that dramatically increased wheat yields in Mexico, especially in irrigated areas. This material also constituted the initial introductions sent to South Asia (especially India and Pakistan) that stimulated the Green Revolution in wheat production during the mid to late 1960s. Much of the initial seed of the new, semidwarf varieties in south Asia was produced and exported by farmers in the Yaqui Valley (Sayre and Moreno-Ramos, 1997).

This valley encompasses about 255,000 ha of irrigated land using primarily gravity irrigation systems fed by canals (over 80% of irrigation water) and deep tube wells (around 20% of irrigation water). Farming is mechanized but operational farm size can range from less than 10 ha to several hundred hectares or more. Crops planted during the winter cycle are wheat (November-May), safflower (January-June), winter maize (September-February) and chickpea (December – April) while during the summer cycle summer maize (May – October), sorghum (March – July) and dry beans (March – May) are most common. (Aquino, 1998).

Four planting methods are traditionally practiced by wheat farmers in the Yaqui Valley (Aquino, 1998):

1. *Melgas*. This is the traditional system of planting wheat on flat seedbeds. Wheat seed is either broadcast and incorporated (generally with a harrow), or seeded with a small grain drill in rows spaced from 15 to 25 cm. Borders are raised to form the *melgas* (basins), the size and shape of which depend on how well the field has been levelled. The farmer can subdivide the field into straight *melgas* on levelled fields or into *melgas* that follow the contour of the land (*curvas de nivel*) (Figure 2).
2. *Corrugations*. Wheat is seeded as for *melgas*, either broadcast or with a small grain seeder. However, instead of raising borders, farmers make a shallow furrows spaced 70 to 90 cm apart to carry irrigation water.
3. *Planting on beds*. The use of a raised seed bed (60 - 90 cm) with two - four rows on the bed for wheat, one for maize and one or two for sorghum.



Figure 1. Location of the Yaqui Valley, Sonora in Mexico



Figure 2. Traditional planting in the Yaqui Valley of Sonora in melgas

4. *Permanent raised beds*: The use of raised bed planting systems, reshaping the original beds with only superficial soil movement in the furrows between the raised beds as needed before planting of each succeeding crop with no tillage on the surface of the beds, ideally combined with even distribution of the previous crop residues on the soil surface.



Figure 3. Conventionally tilled raised beds planted with wheat (left) and maize (right)

Conventionally Tilled and Permanent Raised Beds

Briefly, this technology consists of seeding 1-4 rows depending on the crop on the raised beds, 70-90 cm wide. Bed height is normally 15-30 cm. Irrigation water is applied to the corrugations between the beds. The system facilitates a pre-seeding irrigation to eliminate the first generation of weeds by doing shallow tillage at the time of seeding into the residual moisture. Currently most farmers use conventional tillage prior to making the beds for wheat planting; incorporating the residues of the previous crop. The system allows mechanical cultivation as an alternative method of weed control during the crop cycle including small grain crops like wheat and barley. It also makes hand weeding an economical option because of the easy field access resulting from row orientation on the beds. Irrigation water management is more efficient and less labor intensive with the use of furrows, compared to the traditional flood irrigation system.

Moreno et al. (1982) provide a brief summary of the research conducted in the Yaqui Valley to establish the basis for the raised bed planting system used on irrigated wheat in Mexico. In the early 1960s, research on the effect of different row spacing on wheat were initiated. The results showed similar yields for a wide range of spacing (from 17 to 70 cm) and demonstrated the feasibility of modifying how wheat can be planted with reduced seed rates by implementing raised bed systems. In the late 1970s a concerted effort was made to introduce and transfer this technology to farmers and the effort was successful. In 1981, only 6% of farmers in the valley were planting on beds; while by 1996 over 90% of farmers were using the system. This adoption has been paralleled by similar increases in the use of pre-seeding irrigation as an efficient part of weed control (which also ensures better stand establishment for the common heavy clay soils) and in the use of mechanical cultivation during the crop cycle for weed control (Sayre and Moreno-Ramos, 1997).

Another remarkable change in farmer practices has been the way crop residues are managed. In the 1992/93 cycle, residues from the wheat harvest were burned by 95% of the farmers and the practice was deeply entrenched. When asked how they would manage the residues from the 1993/94 cycle, 94% of farmers answered that they would continue burning it. Most respondents (75%) stated that they burn residues because of the short time available to prepare land and establish the crop for the spring-summer cycle (Aquino, 1998). In 2001, however, 96% of the farmers were no longer burning but were incorporating the residue. This is a clear example of a first step in the continuum towards sustainable systems. Conventional raised beds, however do not meet the criteria of CA but can be considered as a CA-based Resource Conserving Technology that prepares the terrain for further development to more sustainable systems.

The next step for these irrigated systems to increase sustainability was to apply the CA concepts to reduce tillage and manage crop residues on the surface by reuse of the existing raised beds with only superficial reshaping in the furrows between the raised beds as needed before planting of each succeeding crop, following even distribution of the previous crop residues (Sayre, 2004) (Figure 4). Permanent raised beds permit the implementation of crop residue strategies to maintain a permanent soil cover for greater rainwater capture and conservation.



Figure 4. Permanent raised beds planted with soybeans in remaining wheat stubble (left) and wheat planted in maize straw (right)

The Scientific Base for Permanent Raised Beds

In 1991 CIMMYT and local partners showed interest in the development of permanent raised bed production technologies based on the CA principles. These would have the potential to reduce production costs, improve input-use efficiency, permit more rapid turn-around between crops and provide more sustainable soil management while still allowing the use of the existing, widespread gravity irrigation system. Therefore, a long-term experiment was initiated in 1992 in the Yaqui Valley to compare common farmer practice (based on extensive tillage to destroy the

existing raised beds with the formation of new beds for each succeeding crop), with the permanent raised bed system combined with different crop residue management options. Also several component technology trials to fine-tune different aspects of the permanent bed planting system were implemented. A detailed description of the experiments can be found in the different publications referred to below.

Crop Yields and Economic Performance with Different Long-term Bed Planting Practices

As can be observed in Figure 5, there have been large annual changes in wheat yields. Low wheat yields in 1995 and 2004 were the result of extended warm, cloudy periods during the first half of the crop cycles. However, the key outcome seen in Figure 5 is that yield differences between management treatments clearly diverged after 5 years. There were no significant wheat yield differences between any of the tillage/residue management practices for the first 5 years (10 crop cycles). However, yield differences between management treatments clearly diverged with a dramatic overall reduction in the yield for permanent beds where all residues have been routinely burned from onset of the trial, after the initial 5 years. The effect from management practices in irrigated agriculture systems (at least for tropical, semi-tropical and the warmer, temperate areas), appears to be “hidden or postponed” by the irrigation water applied until a level is reached that no longer can sustain yield even with irrigation. Research to characterize tillage and residue management issues must therefore include a time horizon at least five or more years to insure that potential differences between management practices have adequate time to be expressed. Full retention and partial retention of residues had a similar yield expression, indicating that for irrigated systems with the associated high residue yields, substantial amounts of residue probably can be removed for other economic uses without suffering a yield decline (Sayre et al., 2005).

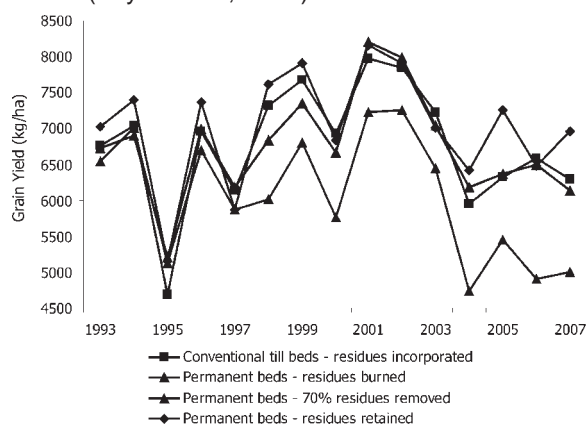


Figure 5. The effect of tillage and residue management on wheat grain yields (kg/ha at 12% H₂O), CIMMYT long-term sustainability trial on irrigated wheat systems, Yaqui Valley, Sonora, Mexico, 1993-2006 (Adapted from Sayre et al., 2005)

Although the yields of properly managed permanent beds are not markedly higher than conventionally tilled beds with residue incorporation, permanent beds production costs are markedly lower. Figure 6 illustrates the clear yield and economic advantage of permanent raised beds over conventionally tilled beds. These results are derived from a large-scale trial/farmer demonstration module where crops are planted when possible for each planting system (usually 7-10 days earlier for wheat in the permanent beds as compared to tilled beds due to faster turn-around between crops).

Similar economical benefits were observed in the summer sorghum crop planted farmer fields (Figure 7). With the conventional planting system, the minimum production of the crop to recover costs was 4.6 ton/ha while for the permanent raised beds system this point is already reached with 3.4 ton/ha. The increased production and reduced costs with permanent raised beds resulted in a cost-benefit ratio of 1.6 as opposed to 1.2 for conventionally tilled raised beds. For the marked economic advantages of the permanent raised-bed planting systems, farmers in the Yaqui Valley are now in the early stages of adopting the system (Figure 7).

A further step in implementing the CA principles is through taking advantage of the reduced turn around time between crops with reduced tillage systems and including emphasis on augmenting cropping diversity offering farmers alternative, economically viable crop rotation options. Sound crop rotations can result in positive yield

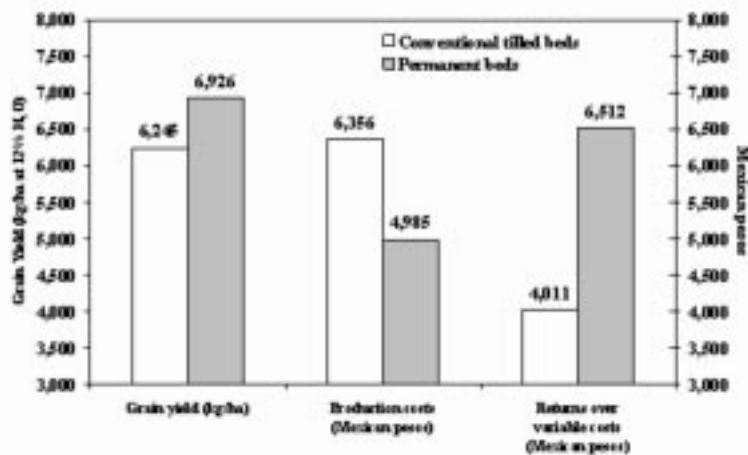


Figure 6. Comparison of average wheat grain yields, variable production costs and returns over variable costs of wheat produced with conventional tilled beds versus permanent raised beds conservation agriculture trial on irrigated wheat systems, Yaqui Valley, Sonora, Mexico, 1993-2006

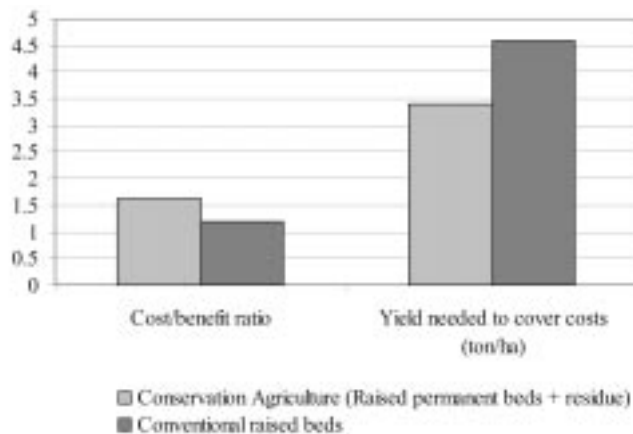
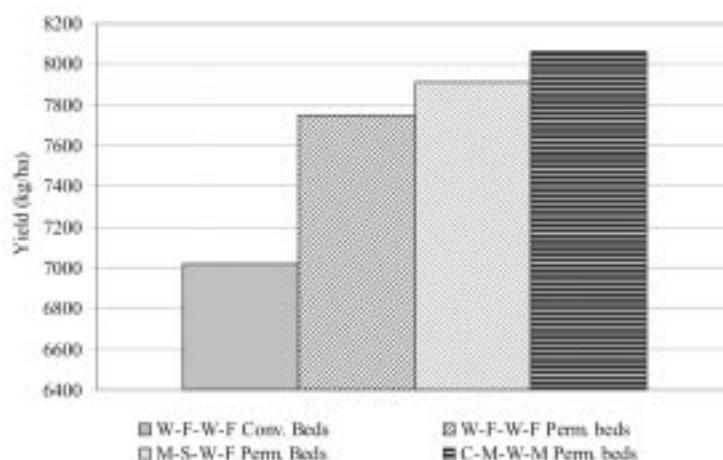


Figure 7. Comparison of cost/benefit ratio and yield required to cover cost for a sorghum summer crop with conventional tilled beds versus permanent raised beds in a farmer field of the Yaqui Valley, Sonora, Mexico

increases for the different crops in a rotation. Figure 8 shows that wheat yields are higher in systems that involve more diverse rotations, as compared to the wheat-fallow system, especially when a legume, in this case chickpeas, is included in the rotation.

Soil Quality and Soil Degradation as Influence by Different Tillage Systems

Several soil related parameters were measured in the long-term raised bed planting trial. A clear increase in stable macroaggregation was observed for permanent raised beds with residue retention compared to conventionally tilled raised beds (Table 1). Burning of residues also had a detrimental effect on soil aggregation although to a lesser extent than tillage. The effect of the decreased aggregate stability is reflected in the soil erosion by irrigation water as well as in the time-to-ponding (a rapid method to determine a soil's potential water infiltration capability). The soil loss for conventionally tilled raised beds was significantly higher compared to permanent raised beds when residues are retained (Figure 9). A longer time-to-ponding indicates that the soil has more potential infiltration ability. The time before ponding occurs is brief and very brief for tilled beds with residue incorporated and for permanent beds with the residues burned, respectively (Figure 10). However, as the level of retained residues increases with the permanent beds, time-to-ponding increases sharply, an indication that water infiltration potential also will dramatically increase. Not only is water infiltration improved, but also the soil moisture conservation in the permanent bed planting system with residue retention is better compared to conventionally tilled beds (Figure 10).



W= Wheat; F= Fallow; S= Sorghum; M= Maize; C= Chickpea; Perm. Beds= Permanent raised beds;
Conv. Beds= Conventionally tilled beds

Figure 8. Effect of tillage and crop rotation on wheat grain yield averaged for 2006 and 2007 at CIMMYT long-term sustainability trial on irrigated wheat systems, Yaqui Valley, Sonora, Mexico

Table 1. Effect of tillage and crop residue management on soil properties (0-7 cm) for the CIMMYT long-term bed planting trial Sonora, Mexico (Adapted from Sayre et al., 2005; Limon-Ortega et al., 2006).

Tillage/Residue Management	% Organic Matter	Na (mg kg _{soil-1})	Aggregate Distribution MWD (mm)	Aggregate Stability MWD (mm)	SMBC (mg kg _{soil-1})	SMBN (mg kg _{soil-1})
Conv. Beds Residue incorporated	1.23	564	1.32	1.262	464	4.88
Permanent Beds Burn Residue	1.32	600	0.97	1.12	465	4.46
Permanent Beds Partial Removal Residue	1.31	474	1.05	1.41	588	6.92
Permanent Beds Retain Residue	1.43	448	1.24	1.96	600	9.06
Mean	1.32	513	1.15	1.434	552	6.40
LSD (P=0.05)	0.15	53	0.22	0.33	133	1.60

MWD= Mean Weight Diameter; SMB N= Soil microbial biomass – C content; SMB N = Soil microbial biomass – N content; Conv. Beds= Conventionally tilled beds

Results of this work also indicate that the long-term use of permanent beds with all crop residues retained increases C and N from the SMB over time (Table 1). The apparent amelioration of Na levels for permanent beds with partial or full residue retention (Table 1) may have great potential for vast areas where soil salinity is an increasing problem associated with gravity-based irrigation systems (Sayre et al., 2005; Limon-Ortega et al., 2006).

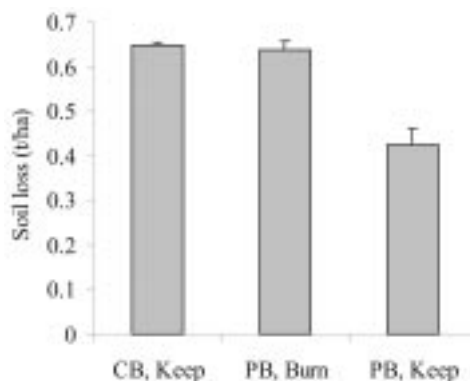


Figure 9. Effect of tillage and crop residue management on soil loss (t/ha) for the CIMMYT long-term sustainability trial on irrigated wheat systems, Yaqui Valley, Sonora, Mexico

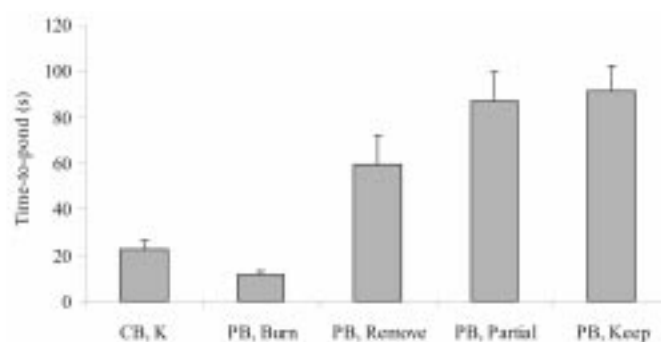


Figure 10. Effect of tillage and crop residue management on time-to-pond for the CIMMYT long-term sustainability trial on irrigated wheat systems, Yaqui Valley, Sonora, Mexico

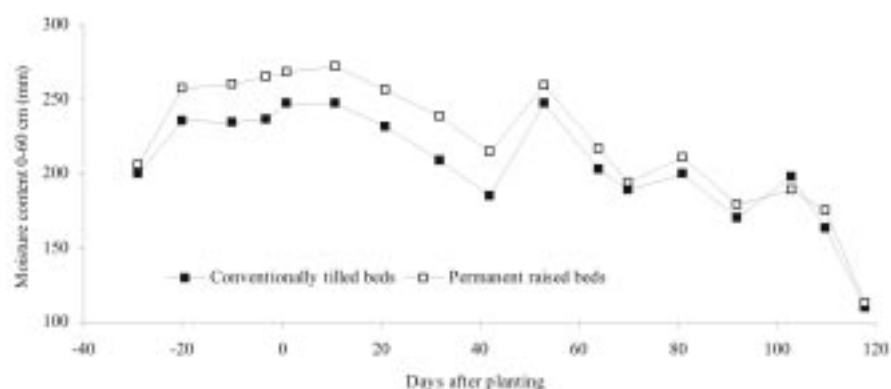


Figure 11. Effect of tillage on soil moisture (mm) through the soil profile (0-60 cm) in the CIMMYT long-term sustainability trial on irrigated wheat systems, Yaqui Valley, Sonora, Mexico

Farmers Applying Permanent Raised Bed Planting in the Yaqui Valley, Sonora, Mexico

Because of the promising results of the above described trials there has been increasing interest by farmers and organizations to adopt the permanent bed technology in the Yaqui Valley of Sonora, Mexico. PIEAES, a local farmer organization, supported actively the development of an on-station farmer training module. The module is now jointly managed by the CIMMYT crop management team and PIEAES and serves as the training platform for recent new initiatives. In 2007 extension projects were started that aim at training farmers, farm managers, technicians, tractor drivers among others, in the permanent raised bed technology. Also in 2007 the Mexican Wheat Chain Organization started a program that supported the purchase by farmer groups of CA planters.

When moving to permanent raised beds farmers have continued to use a similar sized raised beds (70 to 80 cm from furrow to furrow) in line with the bed widths that have routinely been used by farmers for conventional tilled beds. By maintaining the same bed widths that farmers are already using for tilled beds, it has been easier, whenever feasible, to modify existing implements for use with permanent beds as well as to eliminate the need to alter tractor wheel spacing already in use. The goal has been to attempt to utilize the permanent beds continuously for as long as feasible and possible.

The main factor that has limited extension and adoption of permanent raised beds (and essentially most other relevant CA technologies) in the past has been the utter lack of appropriate implements, especially seeding equipment. In many ways the development of prototype implements for seeding on permanent beds with retained residues, for band application of fertilizers on permanent beds and for maintaining the shape of the beds, has been the most important issue to confront. Therefore, the philosophy the Mexico based CIMMYT crop management team has been to develop multi-crop/multi-use implements that can be simply reconfigured to reshape beds, band apply basal or post-emerge fertilizer and seed both small and large seeded crops easily and rapidly (Figure 12).

The prototype developed has fertilizer and seed tanks with appropriate distribution mechanisms that can seed both small and large seeded crops with an acceptable level of precision using a multiple tool bar arrangement to

mount all needed attachments with adjustable clamp systems (fertilizer/seed tanks and their distribution systems, seed openers, fertilizer opens, residue management tools like discs or residue cleaners and shovels or discs for bed reshaping). The goal is to have a single implement capable of being easily and rapidly reconfigured to perform most seeding, fertilizing and bed permanent bed management activities for the crops grown by these farmers to markedly reduce the machinery costs as farmers convert from conventional, flat planting systems to permanent beds.



Figure 12. Left-Multi-crop/multi-use implement configure for reshaping permanent beds and applying basal fertilizer; Right-Same implement configured for bed reshaping, fertilizing and maize planting.

There are now irrigated permanent beds with the farmers using the multi-crop multi-use implement now commercially available in the Yaqui Valley that have supported up to 4 consecutive crops of wheat, maize and safflower but while still in a very initial stage of adoption, the area is growing. It will be of utmost importance that farmers, local organizations and scientists from all disciplines keep working together to support further extension and solve second generation problems where needed.

Conclusions

The system of raised bed planting for irrigated conditions that has been widely adopted by farmers in northwest Mexico and offers an innovative option for diversifying wheat production practices in other, similar areas around the world. Bed planting offers many advantages in irrigated production systems. The great benefit resulting from bed planting is reduced production costs, reduced irrigation water use, and marked, enhanced field access, which facilitates control of weeds and other pests, the timing and placement of nutrients, tillage reductions, and crop residue management.

The next logical step to make raised bed planting more sustainable is to reduce tillage and manage crop residues on the surface by reuse of the existing raised beds with only superficial reshaping in the furrows between the raised beds as needed following even distribution of the previous crop residues before planting each succeeding crop,. Permanent raised beds will further reduce production cost and will increase sustainability of the system through the positive effects on chemical, physical and biological soil quality. Providing farmers with viable management alternatives should be the primary role of agricultural scientists.

Acknowledgements

N.V. received a PhD fellowship of the Research Foundation - Flanders. We thank M. Ruiz Cano, J. Gutierrez Angulo, J. Sanchez Lopez, A. Zermeño, C. Rascon, B. Martínez Ortiz, A. Martinez, M. Martinez, H. González Juárez, J. Garcia Ramirez and M. Perez for technical assistance. The research was funded by the International Maize and Wheat Improvement Center (CIMMYT, Int.) and its strategic partners and donors.

References

- Aquino, P. 1998. The adoption of bed planting of wheat in the Yaqui Valley, Sonora, Mexico. Wheat Special Report No. 17a. CIMMYT, Mexico, D.F.
- Gupta R. and Seth A. 2007. A review of resource conserving technologies for sustainable management of the rice-wheat cropping systems of the Indo-Gangetic plains (IGP). *Crop Protection* **26**, 436-447.
- Lal, R. 1997. Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO₂-enrichment, *Soil Tillage Research* **43**, 81-107.
- Limon-Ortega, A., Govaerts, B., Deckers, J. and Sayre, K.D. 2006. Soil aggregate distribution/stability and microbial biomass in a permanent bed wheat-maize planting system after 12 years. *Field Crops Research* **97**, 302-309
- Moreno R., O., Salazar G., M. and Mendoza M., S. 1982. La siembra de trigo en surcos. Folleto Técnico Num. 2. CIANO-INIFAP. Cd. Obregón, Sonora, México.
- Sayre K.D., Limon-Ortega A. and Govaerts B. 2005. Experiences with permanent bed planting systems CIMMYT, Mexico. In *Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico*. (Roth C.H., Fisher R.A. and Meisner C.A., Eds.) pp. 12-25. Proceedings of a workshop held in Griffith, NSW, Australia; March 1 to 3, 2005. ACIAR Proceedings No. 121
- Sayre, K.D. 2004. Raised-Bed Cultivation. In *Encyclopedia of Soil Science*. (Lal R., Ed.) Marcel Dekker, Inc,
- Sayre, K.D. and Moreno-Ramos, O.H. 1997. Applications of Raised-bed planting systems to wheat. Wheat Special Report No. 31. CIMMYT, Mexico, D.F.

Rationale for Conservation Agriculture under Irrigated Production in Central Asia: Lessons Learned

J.P.A. Lamers¹, A. Akramhanov¹, O. Egamberdiev¹, A. Mossadegh-Manschadi¹, M. Tursunov¹, C. Martius^{1, 2}, R. Gupta^{2, 3}, K. Sayre³, R. Eshchanov⁴ and S. Kienzler⁵

¹Center for Development Research (ZEF), Walter-Flex Str. 3, Bonn, 53113, Germany

²International Center for Agricultural Research in the Dry Areas (ICARDA-CAC),

P.O. Box 4564 Tashkent 100000, Uzbekistan

³International Maize and Wheat Improvement Center (CIMMYT), Mexico

⁴Urgench State University, Khorezm, Uzbekistan

⁵Earth Science Faculty, Free University of Berlin

The irrigated lowlands of Central Asia have been cultivated for at least 5000 years. The large-scale mechanization, introduced during the recent Soviet-time era, provoked slowly but clearly reduced soil fertility. To revert this trend, crop management technologies that conserve natural resources are imperative. Conservation agriculture (CA) technologies, which are practiced worldwide on 95 million hectares, have been proven suitable for a wide variety of agro-ecological situations, yet mostly in rainfed areas. There various arguments to introduce CA practices also in the irrigated lowlands in Central Asia. Following a review of the current status for CA in the irrigated areas of Central Asia it is argued here that the prospects and need for CA in this region are enormous. Yet, the introduction and spread of CA practices needs to be shouldered by an awareness creation of all stakeholders including farmers, researchers, extensionists and policy makers. This necessitates in some countries legal, administrative and economic reforms. Also intensive training and education of farmers needs to be scheduled aside from the planning to ensure that the necessary agricultural equipment such as seeders and planters become available and accessible. There is also a demand for further research efforts particularly on the development of implements as well as on assessing the financial benefits from investments in CA practices. But introducing CA could alleviate the present pressure on existing land and water resources in Central Asia and reduce soil salinity which in turn could increase household income for the rural poor.

Key words: Soil degradation, salinity, water use, tillage, fuel economy, Uzbekistan

At present, already 12% (ca. 1.56 billion ha = Bha) of the global total land area of 13 Bha is used for crop cultivation, of which slightly less than 280 million ha (Mha) or 18% of the total cropland are irrigated (UNESCO-WWAP 2006, pp. 250 ff.). This amounts to a worldwide average of 0.25 ha of cropland per capita (as of 2006). In addition, an estimated 2,300 km³ water is annually used from blue (precipitation turned into freshwater in rivers and lakes) and green (precipitation stored into soil moisture and used for plant production) water sources for irrigation worldwide. While irrigated land areas increased globally from 50 Mha in 1900 to 280 Mha (2003) in about one century, in the Aral Sea Basin in Central Asia (Figure 1) an increase from 2.0 to 7.9 Mha ha irrigated cropland was reached within four decades (FAO 2000), i.e. the relative annual increase of 7.4% in the latter was almost double that of the worldwide increase of 4.6%.

About roughly 60% of the present global food production stems from rainfed cultivation, and thus ca. 40% of all foodstuffs are produced under irrigation (UNESCO-WWAP 2006), nonetheless irrigated agricultural is of paramount importance since it forms the backbone of the livelihoods in arid and semi-arid regions as well as in the humid-tropics in Southeast-Asia. Despite the high need for increasing food production worldwide, the scope for extending irrigated cropping is assessed as restricted by the limited water resources (UNESCO-WWAP 2006). This is exemplified by the situation in the Aral Sea Basin which covers most parts of the five Central Asian Republics (CARs) Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. From the about 33 Mha of land considered suitable for irrigation, only about 3% (ca 11 Mha) are used for irrigated agriculture (Kijne 2005), for which annually 96 km³ of water are used in the basin. This underlines the importance of this relatively small irrigated area for the livelihood of 60 million people living in the CARs (Table 1). Concurrently, the increasing population increases the pressure on the natural resources, and land and water resources suffer from degradation caused by erosion, salinization, water-logging, compaction, overgrazing, and desertification. For instance, the salt-affected irrigated areas in the CARs vary between approx. 11% in the Kyrgyz Republic 50% in Uzbekistan, and up to 96% in Turkmenistan (Saigal 2003), whilst the estimated annual costs associated with desertification and land degradation for all CAR amount annually to \$2.5 billion (ADB 2006). Soil organic matter (SOM) contents such as in Uzbekistan are low (Ergamberdiev, 2007).



Figure 1. Irrigated lowlands of the Aral Sea Basin comprise the regions of Surkhandarya, Kashkadarya, Samarkand, Bukhara, Khorezm and Karakalpakstan in Uzbekistan; the regions Tedjen, Mary and Dashoguz in Turkmenistan, and the downstream regions on the Syr Darya in Kazakhstan. Source: By courtesy of the University of Wuerzburg, Germany

Table 1. Selected indicators by countries

Countries	Total Land, '000 ha	Rainfed, '000 ha (% of total land area)	Irrigated, '000 ha (% of total land area)	% Salinized of irrigated area	Population, million	Agriculture, % of GDP
Kazakhstan	269,970 (100)	18,994 (7.0)	3,556 (1.3)	33.0	15.1	6.5
Kyrgyzstan	19,180 (100)	238 (1.2)	1,072 (5.6)	11.5	5.1	34.1
Tajikistan	13,996 (100)	208 (1.5)	722 (5.2)	16.0	6.9	24.2
Turkmenistan	46,993 (100)	400 (0.9)	1,800 (3.8)	95.9	6.5	26.0
Uzbekistan	42,540 (100)	419 (1.0)	4,281 (10.1)	50.1	26.3	28.1
Total/Average	392,679 (100)	20,259 (5.2)	11,431 (2.9)	41.3	59.9	23.8

Source: FAOSTAT 2003

Due to the critical level of degradation of the key natural resources, there is an urgent need to alter the current soil and crop cultivation practices in favor of conservation agricultural-based practices (CA) to better sustain soil fertility and increase water use efficiency. A balanced management of these key resources should be sought by all CAR governments to better arrest the present over-exploitation of the natural resources. Although CA is known to sustain soil resources and improve their production potential by reduced tillage alone, assessment of the potential application/value of CA-based technologies has in the irrigated areas of the CAR only just begun.

Agriculture in Central Asia

During the Soviet Union (SU) era, agricultural production in the CARs was organized in large, heavily mechanized (in particular for land preparation, seeding and weed control) state (*sovkhoz*) and collective farms (*kolkhoz*). Small-scale, private, and non-mechanized farming was also practiced but mainly for domestic and household use. Agriculture was boosted in a centrally planned economy that designated CARs as suppliers of cotton fibre (especially Uzbekistan), winter wheat (particularly in the rainfed areas of Kazakhstan) and early maturing vegetables, which were exported to, and processed in other SU republics (Morgounov and Shevtsov, 2004). Hence, the state and co-operative farms were usually specialised in the production of specific commodities. For most production units the input supply and commodity marketing was heavily subsidized and centrally organized and the entire chain was oriented towards maximizing production while using high-input monocultures often of poorly adapted crops (Morgounov and Shevtsov, 2004). Important managerial decisions were taken outside the actual production units.

Following the break-up of the SU, agriculture in the CARs remains an important sector, employing over a quarter of the population and contributing, on average, about the same share to GDP (Table 1). It should be noted

that the dependence of the national economies of the CARs on agriculture has generally increased after gaining political independence in 1991, although this was related more to the demise in other sectors of the economy rather than a genuine increase in agriculture production *per se* (Table 2).

Table 2. Crop production in Central Asian countries in 1992 and 2005.

Major crops		Kazakhstan*		Kyrgyzstan		Tajikistan		Turkmenistan		Uzbekistan	
		1992	2005	1992	2005	1992	2005	1992	2005	1992	2005
Cotton	Area (Mha)	0.11	0.19	0.02	0.05	0.29	0.29	0.57	0.60	1.67	1.39
	Yield (tha ⁻¹)	2.10	1.80	1.90	3.20	1.80	1.70	2.10	1.10	2.30	2.70
Wheat	Area (Mha)	13.72	11.50	0.25	0.42	0.18	0.32	0.20	0.90	0.63	1.40
	Yield (tha ⁻¹)	1.30	1.00	2.70	2.20	0.90	2.00	1.90	3.10	1.50	4.10
Rice (paddy)	Area (Mha)	0.12	0.08	0.00	0.01	0.01	0.01	0.03	0.05	0.18	0.05
	Yield (tha ⁻¹)	4.00	4.10	1.50	2.90	2.00	5.20	2.30	2.40	3.00	3.20
Barley	Area (Mha)	5.63	1.50	0.26	0.10	0.06	0.05	0.06	0.07	0.30	0.11
	Yield (tha ⁻¹)	1.50	1.00	2.40	2.10	0.80	1.30	2.10	1.00	0.90	0.90

Source: FAOSTAT 2006. * most yield data are for rainfed wheat and barley

The dominant irrigation method for crop cultivation in the CARs is furrow irrigation, characterized by relative low energy demand but high water consumption, and low efficiency (e.g., surface water irrigation has an average efficiency of 40% only; Kijne 2005; Khorst 1989). Moreover, water managers of different CARs recurrently stressed the fact of general water scarcity and considered water as the limiting factor for further expansion (Kuo et al., 2006). On the other hand, due to their irrigation water usage rates, all five CARs rank high on the list of per-capita water use in the world (WWF 2008). Irrigated crop and pasture production uses about 80% of the available water resources (in Uzbekistan even up to 95%), the remaining being allocated for industrial use and as drinking water (Horinkowa and Duchovny, 2004).

Land reforms following independence of the CARs in 1991 aimed at transforming the former state-owned *kolkhozi* and *sovkhozi* into smaller private farms. These occurred in the different CARs with different pace and intensity and in e.g. Uzbekistan has not even been completed, it resulted in various farm types (Table 3). However, the state-controlled input supply and marketing system have largely disappeared, except in the case for cotton and winter wheat in Uzbekistan and Tajikistan (Kuo et al., 2006; Spoor and Visser 2001).

The newly established private farmers face vast problems (Table 4) such as saline, polluted and degraded soils, inefficiency of irrigation water supply, and soaring machinery and fuel costs (Horinkowa and Duchovny, 2004). The resulting decline in crop yields and agricultural income threaten the farmers' livelihoods to the point that many families only survive on large remittances from family members working abroad. Money transfers from Uzbek labor migrants for instance reached 1.4 billion USD in 2006 (national scale), which was equal to 8.2% of GDP of Uzbekistan (Center for Economic Research, 2007). However, due to the worldwide crisis which also has impacted Russia and the Ukraine, much labor is forced to return and transfers and cash inflow in general is expected to decrease

Why Conservation Agriculture could be Relevant to the Irrigated Areas of Central Asia?

Worldwide evidence has recurrently shown that CA could counterbalance the aspects of soil degradation and water miss-use, help producers to meet the challenge of a more efficient use land and water and derive higher incomes. To cite only one example: long-term field experiments with zero tillage under rainfed conditions in the subtropical highlands of Mexico (Govaerts et al. 2006) demonstrated the positive effects of zero-tillage, crop rotation and crop residues, compared with conventional tillage. On the other hand, there are cases where no clear benefits could be shown from CA, e.g. in Belgium (D'Haene et al., 2008, 2009 in press).

The basic components of CA are reduced tillage and field traffic in general, adequate retention of crop residues on the soil surface and the application of economically feasible and diversified crop rotations. These components are thus not site specific, but instead the most critical objectives of CA allow extending these technologies efficiently across a wide range of production conditions. CA is therefore considered an innovation process with the aim of modifying conventional crop production technologies with the use of appropriate CA implements and suitable crop cultivars and crop rotations (Gupta et al., 2007; Gupta and Seth, 2007). Although this is often referred to as minimum-till or reduced till rather than no-tillage *per se*.

Table 3. Overview of farm types and their characteristics in four central Asian Republics (as from 2008)

Country	Farm type	Ownership	Number of owners	Land area
Kazakhstan	Household plots	Private land ownership with the right of inheritance	1 family	Small plots below 1 ha
	Peasant farms (individual farms)	Private land ownership on a long-term rent base from 5 to 49 years	2-3 families, or the largest up to 7 families	Small from 7 ha and large up to 250 ha
	Agricultural Cooperation	Private land ownership on a long-term rent base from 49 to 99 years. This includes limited liability and joint-stock companies.	Large number up to 200 members	2,000-14,000 ha of total land
Kyrgyzstan	Family farms (Small-Scale individual farms)	Private land ownership	Single family farms. Mainly livestock production	Minimum 1 ha irrigated land in mountainous, and 5 ha in non-mountainous areas
	Peasant farms: Medium scale individual farms	Private land ownership	Several families Importance of crops increases	Land area varying from 5 to 150 ha
	Agricultural cooperatives	Private land ownership	Several households or family farms that are cooperative members	Land size varying from 5,000-87,000 ha
Turkmenistan	Household plots	Private land ownership	1 family	Small plots of about 1/4 ha and around 15 heads of sheep
	Family Farms	Private land ownership	1 family	Variable ranging from 3 ha to 150 ha
	Private (peasant) livestock producers	Mainly sheep and camel producers	2-3 families	No arable land, no land property rights, rely on sandy used as common rangelands
	Agricultural cooperatives	Practically similar to old collective farms	Cooperative membership	Large farming units operating on vertical integration
Uzbekistan	<i>Dehqon</i> farms:	Private ownership with share of cooperative assets	1 family	0,25-1 ha within the irrigated area
	Individual farms for cotton and wheat production	Lease contracts for a maximum of 50 years. They can run their farming business individually or if they are members of the cooperative by taking their share and running their own farming	1 family	Following the land consolidation of November 2008, 80-200 ha
	Orchards and vineyards farms	Private ownership	1 family	Minimum 1 ha
	Livestock farms	Livestock & poultry	1 family	Depending on the animal stock. Rule is a share of 0.33 ha per cattle unit with a minimum of 30 heads of cattle equivalents (thus 10 ha)

In addition to the three basic tenets above, often the adequate adaption of machinery is a must for successfully implementing and adopting CA. This has occurred worldwide in tropical, subtropical and temperate regions to grow rainfed cereals, cereals between rows of perennial crops, irrigated rice-wheat systems, and development of agriculture in hillsides sloping lands. CA has steadily increased and covers nowadays about 7% of the worlds' arable land area amounting to about 95 Mha. In countries such as Paraguay, Brazil and Argentina it is now covering more than 50% of the total agricultural land. In southern Brazil, CA is practiced on nearly 90% of the arable area (Friedrich, 2007, Personal communication).

CA is not commonly practiced Central Asia, except in the rainfed areas of Kazakhstan owing to an intensive promotion from the 1960s onwards. It was meant as one avenue to reduce the massive occurring soil erosion at that

Table 4. Brief overview of agricultural characteristics inherited from the Soviet Union that persist after independence in Central Asian Republics

-
- Large scale area exploitation
 - Monoculture on large scale collective farms with heavily mechanized production systems
 - Excessive water use resulting in increasing salinization in downstream areas
 - Agrarian Reforms since independence in 1991, leading to cooperative and private farming from 1994 onwards, but state production quotas remained in some CARs
 - Weak financing for investments, rehabilitation, operation and maintenance
 - Lack of extension and advice systems in agriculture
 - Agricultural research structures and institutions dysfunctional
 - Deteriorating infrastructure in irrigation and drainage network
 - Inadequate agricultural equipment (as former large farms were privatized)
 - Rising prices for inputs
 - Declining yields, declining income, increasing poverty
-

Source: Adapted from Horinkowa and Duchovny, 2004.

time. The concept of reduced tillage to counterbalance wind erosion had been studied intensively in rainfed areas of Northern Kazakhstan, very likely due to the harsher climate when compared to the irrigated areas in the South¹. But despite the obvious benefits, CA has not spilled over to the irrigated areas of Central Asia and neither has CA figured in many research agendas for irrigated production systems, with perhaps one exception: Direct seeding of wheat into the standing cotton stubble is practiced in over 60% of the cotton-wheat growing areas in Uzbekistan in case of a delay in the cotton harvest, nevertheless showing that farmers adopt new technologies quickly when the benefits are demonstrated.

Recent results from the Indo-Gangetic Plains (IGP), which are under similar agro-ecological conditions as the CARs and where irrigated production systems also dominate, confirmed that CA technologies improve yields, reduce water consumption, and reduce negative impacts on the environmental quality also in these irrigated production systems (Gupta and Seth 2007). CA technologies were initiated in the early 1990s in the IGP but gained momentum since the late 90s when the technology became rapidly adopted by farmers. Current estimates by Gupta and Seth (2007) of winter crops planted using zero-till are as high as about 2 Mha, also caused by a research approach implemented by various international and national organizations, e.g. the Rice-Wheat Consortium. Recent findings in the northwest of Uzbekistan (Ergamberdiev 2007) showed particularly an increase in SOM with corresponding improvements in soil structure with greater soil moisture holding capacities. Most of the other benefits such as changes in soil chemical, biological and physical properties are expected to be further enhanced in the long-run. While no significant effects of reduced tillage on cotton or wheat yields could be observed in Uzbekistan, the initial yield loss that typically occurs when CA is introduced could not be observed here, while clear savings in operational costs were achieved (Tursunov 2009). Cumulative gross margin (GM) analysis showed higher gross margins in all conservation agriculture practices as compared to the control (conventional tillage). Dominance analysis revealed an advantage of the conservation practices over conventional tillage because of the lower total variable cost and higher GM (Tursunov 2009). Most of the other benefits such as changes in soil chemical, biological and physical properties are expected in the long-run.

Thus, adopting CA practices on irrigated soils of Central Asia can improve the sustainability in agricultural production and make it more profitable to farmers.

Hurdles to Master for Introducing Conservation Agriculture to Irrigated Areas in Central Asia

Awareness Creation

Successful farmer adoption of CA principles may mean altering generations of traditional farming practices and implement use (from hoes to the recently introduced large-scale machineries). In Central Asia, an additional challenge is the fact that many new small and medium-scale farmers are often inexperienced former *kolkhoz* workers and have little experience with farming, let alone modern farming technologies. In fact, the needed change in mind set, not only by farmers but also by scientists, extension agents, private sector members and policy makers, has often represented the most difficult aspect associated with the development, transfer and adoption of CA technologies

¹ Wind erosion in the irrigated areas has been combated by the establishment of an extensive network of tree windbreaks (e.g. Molchanova, 1980).

(Pieri et al., 2002a, 2002b). In many cases, it has been difficult to explain to farmers the rationale for adoption of the basic CA tenets beyond the potential to reduce production costs associated with tillage reductions (Knowler et al., 2001). As recently postulated "... *it has been shown to be easier to adapt the no-tillage technology to physical conditions than to human conditions as mindset continues to be one of the biggest barriers to no-till adoption and here farmers, researchers and extensionists are included*" (Derpsch, 2005).

Prior to introducing CA, the land needs to be prepared to avoid the typical initial reduction in yields (Knowler et al., 2001). This foundation can be laid by a specific cropping sequence. A transition period deems necessary to also resolve potential conflicts between the different uses of the crop residues. In many situations in the CARs, crop residues are presently used as livestock feed or burnt for cooking fuel and these uses therefore may be in conflict with field retention to provide effective soil surface mulch (Ergamberdiev 2007). Spatial factors such as available field sizes for a production of sufficient crop residues for both livestock and CA should be considered and in such cases it should also become practice that crop residue production sites must be at close distance to, or at CA areas to minimize transportation costs and that irrigation water availability is adequate.

Machinery and Equipment

Although national policies in CARs focus on agriculture, many administrators underestimate that the accessibility of locally made, appropriate CA implements has a high priority to successfully introduce CA. Farm machinery supply enterprises are mainly serviced by small and medium size private entrepreneurs (SMEs). Unfortunately, in spite of the acknowledged importance of the role of these services in the national economy, this sector is only marginally supported and motivated by governmental programs. Moreover, critical services such as for land levelling and no-till/raised bed planting are providing also employment opportunities to jobless rural youths and employment in small-scale manufacturing and transport related sectors (Gupta and Sayre, 2008). Manufacturers, importers and dealers should be proactive in increasing the demand for CA machinery and take advantage of their knowledge to ensure that they keep abreast of current advances in mechanization for CA systems, particularly in similar agro-ecosystems around the world as occur in CARs.

The key policy issue is that benefits of new technologies must reach the farmer through lower equipment and rental costs. Wherever cost of new agricultural technologies such as land levelling are extremely high, several subsidy schemes could be introduced since this practice in particular benefits the environment, save water, and improve productivity. But also seeders and planters is one of the chief requirements for the introduction of CA as it they are supposed to be suitable for the planting of crops in untilled and mulched soil and in the presence of stubbles and/or a cover crop, which at the same time protect the environment and soil properties. For example, in Uzbekistan, farmers must conduct up to five field operations to seed winter wheat into the standing cotton. First, the soil is loosened, and then the seeds are spread. Next, the seeds are buried and finally, the cotton stems are cut at ground level and removed from the fields (Tursunov 2009). Although many types of seeders are industrially produced in CARs, they have been designed mainly for sowing crops in tilled soils. Seeders for untilled soils are not commercially produced yet. The import or even the development of appropriate, multi-purpose machinery that works under the conditions of the soils in the region, as well as the cropping systems, and that allows to seed and fertilize the land at the same time, is therefore imperative (Tursunov 2009). Worldwide evidence shows that very little will happen to extend CA to farmers, especially small-scale farmers, until suitable implements are locally made and cheaply and readily available (e.g. Knowles et al. 2001).

Financial Feasibility of Conservation Agricultural Practices

The benefits of CA measures are often highlighted but dispersed widely over time. It should not be underestimated that CA also demands long-term investments (e.g. in new machinery such as direct seeders etc.), but it is unrealistic to expect that investments in a more judicious resources use will be accepted readily by farmers and land users simply because the options are better for the environment (Knowler et al., 2001). Given the present high uncertainty of marketing commodities, the general undercapitalization in rural areas, the long distances to the urban centres with potential buyers, the restrictions in input supply, obviously the farming population in the CARs is not in a position to eagerly experiment with new technologies.

Furthermore, farmers use to look for immediate and often economic benefits and are less concerned with longer-term or ecological benefits (Knowler et al., 2001). In this respect, CA like any other novel technique must clearly show economic benefits and options before farmers would consider it for adoption. This is not unique to CA,

but is overlooked often by those who emphasize the ecological side. From the standpoint of innovation, it is to be expected that economics will guide the evolution of suitable CA technologies much more than ecological benefits. Farmers may already recognize ecological problems such as advancing soil degradation or inefficient resources use, but for CA to be their solution by choice, it must provide a direct financial advantage. The recent established class of farmers in all five CARs just cannot afford risking even a temporary plunge in profitability based on recommendations that emphasize long-term economic benefits and ecological sustainability only. At present, CA technologies provide direct and immediate benefits to farmers through (i) cost-reduction incurred by lower expenses of fuel, labour, and time and (ii) yield-enhancing factors such as a reduction in soil erosion and water use effects in the short term, while improving the quality of land, water and the environment in the longer term. It should thus be ascertained that the initially mounting costs of herbicide use does not surpass the costs savings incurred by less labour, fuel and the use of equipment as well as reduced fertilizer use.

Recent financial estimates based on cumulative gross margin (GM) and dominance analyses in Uzbekistan showed higher GM with three CA practices compared to the conventional tillage as practiced by farmers (Tursunov 2009). The values were highest under intermediate tillage with crop residue retention which amounted to UZB 1,288,000 (ca. USD 1075,-) per hectare summed up) over three years. While using the results of three consecutive growing seasons, a dominance analyses showed the potential of CA over conventional practices owing to higher total variable costs and lower GM of the latter. Although these findings are encouraging, such estimates for the situation in CAR are presently too limited in numbers and need to be extended. In a recent overview on the economics of CA as practiced worldwide (Knowler et al., 2001), it was concluded that the financial profitability of CA practices varies, is thus site-specific and hence needs to be researched each time.

Training and Education

It is recurrently emphasized that the application of CA practices demands far greater managerial skills and understanding of agriculture compared to conventional cultivation practices (Knowler et al., 2001). Hence, one of the chief challenges for the introduction of CA in Central Asia is beating this lack of expertise. Organisations such as ICARDA, CIMMYT or the Tashkent Institute for Mechanization (TIM) as well as the ZEF/UNESCO Khorezm project at the University of Urgench have conducted in the past a number of workshops, seminars, conferences, and trainings which was attended by local researchers, which certainly contributed to the dissemination of information about the principles of CA (PFU 2008). However, the total number is still low, and most attendants have been researchers rather than farmers. ICARDA also published a handbook in several languages (Nurbekov 2008).

Analysis of shortcomings in agriculture in CAR emphasized numerous technical aspects, but also underlined the typical lack of managerial skills amongst the producers (Lamers et al, 2000; Lamers et al, 2008). Although land reforms and farm privatisation in the CARs aimed at boosting the agricultural sector, it established a new class of farmers who had never run a farm enterprise before. Many of them had previously been employed on former state farms, machine-tractor parks or other support organizations but not in leading positions and therefore lack the managerial skills and agronomic knowledge to adequately manage day-to-day farm operations. The low level of knowledge of the new farming generation and its governors represents major challenges in the development of the agricultural sector in CARs as to cope with shallow, saline ground water tables in particular causing secondary soil salinisation, whilst the on-going unsustainable agricultural practices enhances further soil erosion and degradation.

As with all research findings, a major challenge of CA research findings is to convert their outcomes into recommendations that fit into the production and livelihood systems. The experimental-based evidence must cope with a high measuring stick: it must be agronomic and financial superior to local practices, fit the socio-economic environment and farming systems, and should be durable. And with particular reference to CA practices, this does not require one single, standardized technology solution, but flexible recommendations, which allow farmers to adopt them according to their means and aims within the diversity and variability of the income generating options they pursue.

Constraints to Introduction

We currently have no information about the situation in all five CARs, but for Uzbekistan the situation is described by Schoeller-Schletter (2008) as follows: “*Since Uzbekistan became independent in 1991, its legal system has been subject to frequent changes. [...] The restructuring of the agricultural sector of Uzbekistan has been accompanied by fundamental reforms in the legal framework regulating agricultural production.*”. Many new

laws and regulations have been introduced since independence that sometimes created conflicts of norms. Nevertheless, the state order system which still prevails in Uzbekistan e.g., is modelled on previous laws, by which the government controls cotton and wheat production. Since this includes very specific recommendations of land use, e.g. also the need for ploughing a legal framework must create an enabling environment for the employ of CA practices. Before such legal obstacles are not carefully investigated and mandated, CA with its emphasis on the reduction of tillage would find a small chance only for implementation as it would clash with legal norms.

Research Needs

Most knowledge about CA within the irrigated areas of CARs stems from very recent and actually on-going research, for which little findings have been published yet. Moreover, much of the present and on-going research has been limited to a few crops only. Despite the limited time span in which the research has been conducted, potential advantages of CA over conventional practices in cotton and wheat production have recently been summarized (see e.g. Ergamberdiev 2007; Tursunov 2009; Pulatov 2002). For instance, experiments conducted in the northwest of Uzbekistan on the dominating cotton-winter wheat rotation, was analysed for seven cropping seasons. ANOVA results showed that crop residues had a positive effect on SOM and Nitrogen contents in the topsoil, whilst soil salinity was unaffected by the soil mulch. SOM amounts were higher under zero tillage practices compared to conventional tillage (0.67 and 0.63 % respectively), whereas soil salinity was lower (0.41 and 0.47 %). Low cotton yields resulted under zero tillage but indicated PB to be the better compromise with respect to soil parameters and yields. Yet, given this recent interest only, many points of CA are still open for further research.

This concerns e.g. the adopting of the general basic tenets of CA to the local and regional conditions, which is certainly a key research challenge for the near future. Obviously, specific and compatible management components such as weed control tactics, nutrient management strategies, appropriately-scaled implements etc., will need to be developed to facilitate farmer adoption of CA in CARs. To appraise the influence of tillage and mulch treatments on soil parameter and yields adequately, the dynamics need to be studied for a longer time span than so far (Tursunov 2009), to achieve more comprehensive findings. Whereas much evidence points at the advantages of mulching and retaining crop residues, recent findings based on simulations with the soil-water model Hydrus-1D indicated that water uptake by cotton or wheat would only marginally benefit from a surface mulch layer, although it would reduce soil evaporation, capillary rise of groundwater and in turn secondary soil salinization (Forkutsa et al., forthcoming). Several aspects related to the most suitable cover crop, the retention of crop residues and in what minimum amounts, the decomposition rate and contribution of a mulch in reducing salinization and crop water demands needs to be examined and quantified.

Since one of the major constraints in the adoption of CA practices in CARs seems to be the competing interest in the use of crop residues, crop combinations have to be identified that provide both residue and fodder. Owing to a lack of adequate machinery such as tractors for plowing, crop stubbles essential for CA, are often burned, or, more commonly, removed from the field as livestock feed. This means that CA practices need to be adapted to the need of the rural population.

Also, since other innovations to enhance water and soil conservation are practiced, it may very well be that CA is perhaps not always the most beneficial option to farmers and this also needs more clarification. Since CA practices usually needs long-term commitments, the use of crop-soil simulations models has to be considered as one tool to assist in estimating the impact of management changes on crop growth and soil nutrient dynamics. For the conditions of western Uzbekistan, the model CropSyst has been parameterized and calibrated for conventional cotton and winter wheat (Sommer et al. 2008). Finally given the growing importance of livestock for household security in CARs (Iñiguez et al. 2005), also crop-livestock interactions under CA need to become subject of future research. Further research should also address incorporating the standard principles of CA to the reality of the small-scale farms and small farmers' financial possibilities and operational skills. Based on the lessons learned from elsewhere, an interaction between agricultural, soil, water and environmental research and the end-users of research findings must be considered in CARs to achieve similar results as outside the CARs.

Summary and Conclusions

The irrigated areas within Central Asia are as large 8-11 Million ha, and irrigated agriculture is key in the economy of most Central Asian Republics (CARs) (Müller 2006). Hence, the agricultural sector forms the basis for any economic progress. The advancing soil degradation and decreasing soil fertility within these irrigated areas

must be arrested within the very near future to allow for sustainable agricultural development, food security and poverty alleviation. Recent research findings demonstrated the prospects for CA in CARs. Immediate benefits include decreased soil erosion, increased water use efficiency and reduced costs for fuel and labor, whereas long-term benefits may include increased soil organic matter (SOM) and biological activity, reduced pesticide use and greenhouse gas emissions. These characteristics underline indeed the challenging potential of CA practices in CARs, but since these experiments have been few in numbers, it necessitates a cautious extrapolation of the findings to irrigated regions with similar characteristics.

The introduction and spread of CA practices needs however to be flanked by an awareness creation of farmers, researchers, extensionists and policy makers alike. The necessary change of the present resource use practices must commence, but they need to be backed up by legal, administrative and economic reform. Also training and education of farmers is compulsory in the future planning. Additional research is needed on improving implements as well as assessing the financial benefits from investments in CA practices.

Introducing CA could provide the one major avenue for bringing about important environmental and social benefits in land use systems prevailing in the CARs. By alleviating pressure on existing land and water resources and reduce soil salinity on marginal lands this could increase household income for the rural poor at the same time.

References

- ADB 2006. CACILM Multicountry partnership framework. Project document.
- Center for Economic Research, 2007. The impact of money transfers on the economy of Uzbekistan, *Uzbek Journal of Economic Review*, vol.4, pp. 20-24 (In Russian).
- Derpsch, R. 2005. The extent of Conservation Agriculture adoption worldwide: Implications and impact. III World Congress on Conservation Agriculture, Nairobi, Kenya, October 4-8, 2005.
- D'Haene, K., J. Vandenbruwane, S. De Neve, D. Gabriels, J. Salomez and G. Hofman (2008) The effect of reduced tillage on nitrogen dynamics in silt loam soils. *European Journal of Agronomy* 28, 449-460
- D'Haene, K., S. Sleutel, S. De Neve, D. Gabriels and G. Hofman (2009 in press): The effect of reduced tillage agriculture on carbon dynamics in silt loam soils. *Nutrient Cycling in Agroecosystems*.
- Dukhovny, V. A., L. S. Pereira. 2005. Future trends in water management for Central Asia. In: L.S.Pereira, V.A. Dukhovny, and M.G. Khorst (Eds.), *Irrigation management for combating desertification in the Aral Sea basin. Assessment and tools*. Vita Color, Tashkent.
- Egamberdiev O., 2007. Dynamics of irrigated meadow alluvial soil properties under the influence of resource saving and soil protective technologies in the Khorezm region, Uzbekistan. Ph.D. thesis. National University of Uzbekistan (in Uzbek).
- FAO 2000. Crops and Drops. Land and Water Division of the food and agriculture organization. FAO, Rome, Italy.
- Gangwar K.S., K.K. Singh, S.K. Sharma and O.K. Tomar. 2006. Alternative tillage and crop residue management in wheat after rice in sandy loam soils of Indo-Gangetic plains. *Soil and Tillage Research*. 88 (1-2): 242-252.
- Govaerts B, K.D. Sayre, J. M. Ceballos-Ramirez, M. L. Luna-Guido, A. Limon-Ortega, J. Deckers and L. Dendooven (2006): Conventionally tilled and permanent raised beds with different crop residue management: effects on soil C and N dynamics. *Biomedical and Life Sciences and Earth and Environmental Science*, 280 (1-2): 143-155.
- Gupta, R., A. Seth. 2007. A review of resource conserving technologies for sustainable management of the rice-wheat cropping systems of the Indo-Gangetic plains (IGP). *Crop protection* 26: 436-447.
- Gupta R., Hobbs P.R., Sayer K., 2007. The role of conservation agriculture in sustainable agriculture. *The Royal Society*. 1-13.
- Gupta R. and K. Sayre, 2008. Conservation Agriculture in South Asia - Some Lessons Learnt. *Professional Alliance for Conservation Agriculture, (PACA), News Letter*, 3: 1-3. New Delhi
- Iñiguez L, Suleymanov M, Yusupov S, Ajibekov A, Kineev M, Kheremov S, Abdusattarov A, Thomas D, Musaeva M (2005) Livestock production in Central Asia - Constraints and opportunities.
- Forkutsa, I., R. Sommer, R., Y. Shirokova, J.P.A. Lamers, K. Kienzler, B. Tischbein, C. Martius, P.L.G. Vlek (2008 subm.): Modeling irrigated cotton with shallow groundwater in the Aral Sea Basin of Uzbekistan: I. Water dynamics.
- Horinkowa, V. M. and V.A. Duchovny, 2004. Water resources in Central Asia. Current constraints and development potential. pp. 44-55. In: Ryan J., Vlek P. and Paroda R. (eds). *Agriculture in Central Asia: Research for Development*. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria.

- Khorst, M.G. 1989. Efficiency of different irrigation systems. pp. 44-55. in SANIIRI. Transactions of the central Asian Research Institute of irrigation. SANIIRI Tashkent.
- Kienzler, S. 2007. Effects of soil conserving cultivation technologies on soil parameters as well as on cotton and wheat production in Khorezm, Uzbekistan. B.Sc. thesis of the Geographic Faculty of the Free University of Berlin.
- Kijne, J. W. 2005. Synthesis report. Towards a strategy for feasible investment in drainage for the Aral Sea Basin. Aral Sea Basin Initiative. IPTRIDFAO.
- Knowler, D., Bradshaw, B. and Gordon, D. 2001. The economics of conservation agriculture. Land and Water Division of the food and agriculture organization. FAO, Rome, Italy.
- Kuo, C.G., R.F. Mavlyanova, and T.J. Kalb. 2006. Increasing market-oriented vegetable production in Central Asia and the Caucasus through collaborative research and development. AVRDC publication number 06-679. AVRDC – The World Vegetable Center, Shanhua, Taiwan. 1-250 pp.
- Lamers, J.P.A, G. Dürr and P.R. Feil, 2000. Developing a client-oriented, agricultural advisory system in Azerbaijan. Human Resources in Agricultural and Rural Development, pages 104-117. FAO. Rome.
- Lamers J.P.A, Feil, P.R., Bayverdiyeva N, Guliyeva Y. and Djafarov F., 2008. From Kolchoz systems to fee-based private agricultural extension: Achievements with a client-oriented training and advisory concept as support for private farming in Azerbaijan. Journal of Applied Biosciences 8 (1): 262 - 271.
- Molchanova A., 1980. History of shelterbelt plantings on irrigated and rain-fed lands in Central Asia. pp.11-22. In: Afforestation Recommendations No.20. Central Asian Forest Research Institute (in Russian)
- Müller M. 2006. A General Equilibrium Approach to Modelling Water and Land Use Reforms in Uzbekistan. Bonn: ZEF, Bonn University.
- Morgounov, A. I. and Shevtsov V.M., 2004. Improvement of crop productivity in Central Asia through germplasm enhancement. pp. 212-228 In: Ryan J., Vlek P. and Paroda R. (eds). Agriculture in Central Asia: Research for Development. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria.
- Nurbekov A.I., (2008). Manual on conservation agriculture practices in Uzbekistan. ICARDA, Tashkent. Available in English, Russian, Uzbek and Karakalpak languages.
- Pieri, C., Evers, G., Landers, J., O'Connell., P., Terry, E., 2002a. A road map from Conventional to no-till farming. Agriculture and Rural Development Working Paper. The International Bank for Reconstruction and Development. Washington D.C., World Bank. pp. 20.
- Pieri, C., Evers, G., Landers, J., O'Connell., P., Terry, E., 2002b. No-till farming for sustainable rural development. Agriculture and Rural Development Working Paper. The International Bank for Reconstruction and Development. Washington D.C., World Bank. pp. 32.
- Program Facilitation Unit (PFU), 2008. A Decade of Partnership for Sustainable Agricultural Development in Central Asia and the Caucasus. CGIAR PFU CAC, Tashkent, Uzbekistan. January, 2008. Fourth Edition. 32 pages. http://www.icarda.org/cac/decade_brochure.pdf
- Pulatov, A., 2002. Results of zero tillage in wheat production in Uzbekistan. International workshop on conservation agriculture for sustainable wheat production in rotation with cotton in water resource areas, 14-18 October 2002, Tashkent, Uzbekistan
- Saigal S. 2003. Uzbekistan: issues and approaches to combat desertification. Asian Development Bank, Tashkent, pp. 51
- Schoeller-Schletter, A. (2008): Organizing Agricultural Production – Law and Legal Reforms in Uzbekistan's Transition Process In: P. Wehrheim, A. Schoeller-Schletter, C. Martius (Eds.): Continuity and Change: Land and Water Use Reforms in Rural Uzbekistan. Socio-economic and Legal Analyses for the Re-gion Khorezm. Halle/Saale: IAMO. 17-40.
- Spoor, M., and Visser, O., 2001. The State of Agrarian Reform in the Former Soviet Union, Europe Asia Studies 53/6, 885 -901
- Sommer, R., Kienzler, K., Conrad, C., Ibragimov, N., Lamers, J.P.A., Martius C., Vlek, P., 2008. Evaluation of the CropSyst model for simulating the potential yield of cotton. Agron. Sustain. Dev.:1-10 Available online at www.agronomy-journal.org or at DOI: 10.1051/agro:2008008.
- Tursunov, M. (2009): Potential of Conservation Agriculture for Irrigated Cotton and Winter Wheat Production in Khorezm, Aral Sea Basin. Ph.D thesis, University of Bonn 108 pp.
- UNESCO-WWAP 2006. Water a shared responsibility. The United Nations world water development report 2. <http://unesdoc.unesco.org/images/0014/001454/145405E.pdf>. 584 pp.
- WWF 2008: Living Planet Report 2008. http://assets.panda.org/downloads/living_planet_report_2008.pdf

Session 1.5: Mechanization and Energy Management

Energy Balance in Conservation Agriculture and Conventional Farming: a Comparison

S.K. Tandon^{1*} and Surendra Singh²

¹Assistant Director General (Engg.), Indian Council of Agricultural Research, KAB-II, New Delhi, 110 012, India

²Project Coordinator (FIM), Central Institute of Agricultural Engineering, Bhopal, 462 038, Madhya Pradesh, India

(*Email: sktandon@icar.org.in/skt4339@yahoo.com)

Paddy-Wheat is the major crop rotation adopted in Northern India and covers 12 m. ha. The mechanization of rice-wheat cropping system has provided various machines and options for tackling the challenges under different field conditions. The energy crisis of early seventies forced scientists to conserve energy in all sectors including agriculture and look for alternate source of energy. The energy use in agriculture has also increased and about 8 % of the energy is used in agriculture. Energy is used for doing various farm operations on the farm. Tillage, irrigation, harvesting, and threshing consume a large amount of energy. Hence, efforts were made to determine energy used for various farm operations and to conserve/reduce energy use on the farm by following Conservation Agriculture using no-till drills and by adoption of efficient methods of cultivation. After harvesting of paddy there is very little turn around time available for sowing wheat hence, no-till drill, strip till drill, rota till drill have been developed and were used for direct drilling of wheat in fields where paddy had been grown earlier. In conventional method, pre-sowing irrigation is applied before preparing the field using disc harrow, cultivator and planker and seed-drill is used for sowing of wheat. In minimum tillage technology, pre-sowing irrigation is avoided and no-till drill or strip-till drill or roto till drill can be used for sowing of wheat in unprepared field. Four different tillage systems were selected for the study, vis-à-vis System I (Pre-sowing irrigation + loose straw removed + disc harrow (2) + Cultivator (2) + Planker (2) + Seed-drill); System II (Pre-sowing irrigation + loose straw removed + mould board plough + disc harrow + cultivator + planker + seed-drill); System III (Loose straw removed + No-till drill) and System IV (Loose straw removed + Strip-till drill). The total energy input upto sowing including seeds and fertilizers was 11104, 10491, 8892 and 9057 MJ per hectare for systems I, II, III and IV, respectively. The total energy input was the least for system III (no-till drill), followed by system IV (strip-till drill), system I and system II. The yield was higher in systems III (5.35 t/ha) and IV (5.44 t/ha) as compared to conventional methods. System III with no-till drill and system IV with strip-till drill offered advantages over system I in terms of saving in time and fuel (65-80%). The saving in cost of operation was 70-80% with No-till drill and 60-70% with Strip-till drill. In the paper the energy used for weeding, irrigation, harvesting, threshing and straw management for raising wheat have also been reported and discussed.

Keywords: Minimum tillage, zero-tillage, no-tillage, strip-till-drill, roto till drill, energy input, straw management, conservation agriculture, direct drilling

Energy consumption per unit area in agriculture is directly related with the development of technological level and production. The inputs, such as fuel, electricity, machinery, seed, fertilizer and chemical take significant share of the energy supplies to the production system in modern agriculture due to intensive cropping. Increasing demand on energy from agricultural sources has resulted in large-scale deforestation, soil erosion and loss of fertility on one hand and manifold increase in the requirement of commercial energy in the farm sector on the other. With increased uses of agriculture inputs and mechanization, the energy use in production agriculture has also increased from 5440 MJ/t in 1970 to 11391 MJ/t in 2003. The role of direct commercial energy from electricity and diesel for performing various field operations has been most prominent with 43 times increase during the period as compared to 4 times rise in indirect energy use. The fuel crisis of early seventies and increase in its price forced all countries to look for alternate sources of energy and conservation of energy in all walks of life including agriculture. Anticipating a major upward shift in the energy demand and energy use pattern in the agriculture sector, the Indian Council of Agriculture also during 1971 launched an All India Coordinated Project on "Energy Requirement in Agricultural Sector" to determine the energy use in production agriculture for raising different crops throughout the different regions of the country and to identify and suggest energy conservation techniques. The energy use for performing various operations starting from tillage, sowing, interculture, harvesting and threshing were determined and based on the study improved implements and practices were recommended. Useful information has been generated on energy use patterns for major crops in different farm categories. The results have provided a bench mark of spatial and temporal variations in the energy use patterns in Indian Agriculture. The project helped in generation of national perspective on research on energy use and management aspects of the country. The results have provided a benchmark of spatial and temporal variations in the energy use patterns in Indian agriculture.

In India, the extensive cultivation of crops to obtain higher yields has resulted in intensive resource degradation problems. For example, there is the declining water tables in the high productivity northwest irrigated region which

seriously constrain productivity and ecology. High level of fertilizer use and decreasing use efficiency are increasingly contributing to groundwater pollution and increased emission of green house gases (GHGs). High level of pesticides use in many areas has become a major health hazard. Thus, with the continuously deteriorating resources, widespread problem of water contamination and eroding ecological foundation, agriculture has become highly unsustainable and many farmers have committed suicide due to crop failure and debt. Hence, efforts have been made to conserve resources by practicing Conservation Agriculture (CA) and promoting no-tillage.

Tillage, interculture, irrigation, harvesting and threshing operations consume maximum energy. As tillage consumes maximum energy, hence, efforts were started world over in the 1970s to reduce energy use on the farm by efficiently applying different inputs and by reducing the number of tillage operations to bare minimum for seed bed preparation to get higher or equivalent yield. This led to the development of zero-till drills and gave rise to the concept of Conservation Tillage (CT) or Conservation Agriculture(CA). CA aims to achieve sustainable and profitable agriculture through the application of three CA principles; minimal soil disturbance, permanent soil cover, and crop rotation. A good number of equipment such as rotavator, laser land leveller, zero-till drill, roto-drill, strip till drill, one pass equipment, happy seeders and raised bed planter have been developed and are being propagated for CA.

Paddy and wheat are the major cereal crops of India. The well-known rice-wheat rotation covers about 37% of total area and contributes 52 percent of the country's food production. Practicing rice-wheat systems for the past several decades have however fatigued the natural resources base resulting in declining factor productivity in many areas. This cropping system is extensively adopted in Northern India. The national production of rice and wheat was 84.9 and 68.7 million tones, respectively during the year 2006-07. The mechanization of rice-wheat cropping system may provide various machines such as laser land leveler, no-till drill/strip till drill, rota-till drill, happy combo seeder, raised bed seeder, sprinklers, straw cutter cum spreader, straw baler, straw combine for conserving energy for doing various farm operations. The paper compares and discusses the energy use for doing various farm operations for rice-wheat crop rotation including farm residue management.

Energy Use in Different Farm Operations- A Comparison

Energy-use pattern in production of various crops vary due to different agronomic practices, intensity of input requirement, crop life and complexity in farm operations involved. Quantum of energy-use is also dependent on type of soil and environment made available to the plants.

Apart from technological improvement to increase energy-use efficiency, energy can also be conserved through proper application of energy-efficient implement and techniques. Energy conservation through use of agricultural machinery can be effected by employing following methods:

- Right choice of tool/implement for any operation under specific conditions
- Right combination of tools/implements
- Operating tools/implement at proper moisture
- Operating tools/implement at proper speeds
- Proper sharpening, oiling, greasing, adjustment and replacement of worn out components

Operation-wise salient energy-efficient implement/techniques suitable for cultivation of wheat crop are discussed below:

Tillage, Sowing and Planting

Tillage is one of the major farm operations and is an important contributor to the total cost of production. Excessive tillage is energy and time consuming and costly operation. Excessive tillage is considered harmful to the soil structure and it also contributes to wind and water erosion of the soil. The rising cost of hydrocarbon fuels which are bound to be exhausted sooner or later, availability of herbicides coupled with the motive of timely sowing and reducing the cost of production has provided enough incentive to the researchers all over the world to investigate tillage operations more closely. Seedbed preparatory operations are energy intensive and time consuming, exposing the cultivators to the risk of delayed sowing of crops with consequent lower yield. A one day delay in sowing wheat after optimum time results in 1 % decrease in the yield. Seedbed preparation takes about 10-30 per cent of the energy used in field operations. A number of tillage machinery (animal as well as tractor-drawn) have been developed and found to be energy-efficient for use as compared to traditional implements.

Animal-drawn Tillage Implements

Traditionally, soil stirring and mould board ploughs are used by farmers having animals as power source. The field capacity of the traditional implements is about 0.3 - 0.4 ha/day and thus work output is low. Animal-drawn disc harrows are also used for land preparation. These harrows have either four or six discs depending upon the size of draft animal available. For puddling in the rice fields, the design of disc harrow was further modified and a drum was introduced in between two discs instead of spool and known as harrow puddler. The drum limits sinkage of the discs up to 125 mm during puddling operation and thus even medium sized draught animals can pull the implement. During dry seedbed operation, the drums simultaneously break soil clods and consequently reduce the number of tillage operations. These functional advantages make the implement energy-efficient. Comparison of energy required in tillage operation using traditional animal drawn implement vis-à-vis animal drawn disc harrow-cum-puddler is indicated in Table 1. Energy required in tillage operation ranged between 328 - 362 MJ/ha by bullock-drawn disc harrow-cum-puddler for paddy and wheat crops and was about 46 to 48 per cent less than traditional implements. The difference in yield was statistically insignificant.

Table 1. Energy consumption in tillage operation on bullock farms

Crop	Parameter	Tillage Treatment		Per cent saving over traditional method
		Bullock-drawn moldboard & soil stirring plough	Bullock-drawn disc harrow-cum-puddler	
Paddy	Labour, h/ha	49.4	23.5	52.4
	Pair of bullocks, h/ha	49.4	23.5	52.4
	Energy in tillage, MJ/ha	611	328	46.3
Wheat	Labour, h/ha	54.5	25.6	53.0
	Pair of bullocks, h/ha	54.5	25.6	53.0
	Energy in tillage, MJ/ha	692	362	47.7

Source: Singh et al, 1999

Tractor-drawn Tillage Implements

Tractor-drawn tyne type cultivator was widely used by the farmers for seedbed preparation and intercultural operations. Later on, tractor-drawn offset-disc harrow also became popular for better mixing of straw with soil after harvesting with combine harvester. Farmers prefer to give one or two passes of disc harrow to cut the crop residue and bury them into the soil before pre-sowing irrigation. Introduction of the above mentioned implements slowly replaced use of animal operated implements.

Promotion of use of energy efficient equipment such as rotavator, disc harrow and cultivator with pulverizing roller attachment for seedbed preparation result in fuel as well as time saving. Two to three operations of disc harrow, 3-4 operations of pulverizing roller with cultivator and 2-3 operations of planker were found optimum combination for seedbed preparation of wheat after paddy both from energy and economic return point of view. Tractor-drawn cultivators are the common tillage implements for dry and wet seedbed preparation. Every tractor owner presently has a cultivator. Farmers prefer to use offset-disc harrow after harvesting of paddy and wheat, particularly after harvesting by combine. More and more areas are coming under combine harvest. Seedbed preparation for kharif and rabi crops is becoming time consuming and consequently sowing is delayed. To reduce the number of tillage operations, save time and energy, tractor-drawn rotavator has been introduced. The use of rotavator in lieu of disc harrow for seed bed preparation saves 30-35 per cent of energy in heavier soils. Results of studies conducted on energy used in tillage for paddy and wheat crop using conventional implements (tractor-drawn disc harrow, and cultivator and improved equipment (rotavator) is indicated in Table 2. For paddy, use of rotavator required 5 per cent lower energy and 26.5 per cent less time than the conventional implement. The difference in yield under two tillage treatments was statistically insignificant. Although saving in energy with use of tractor-drawn rotavator is not significant, the amount of saving in critical operational time provides a distinct advantage.

Seedbed preparation for wheat crop by tractor-down rotavator requires 8.2 h/ha of tractor use, which is 46.7 per cent less than that required by using conventional tillage equipment. Diesel consumption by rotavator was 42.6 l/ha, which was 31.8 per cent less than that required by tractor-drawn disc harrow and cultivator. Energy required for rotavator use was 32.4 per cent less, significantly lower compared to that required while using tractor-drawn disc

Table 2. Energy use in tillage on tractor farm

Crop	Parameter	Tillage Treatment		Per cent saving over traditional method
		Tractor-drawn disc harrow & cultivator	Tractor-drawn rotavator	
Paddy	Labour, h/ha	11.7	8.6	26.5
	Tractor, h/ha	11.7	8.6	26.5
	Energy in tillage, MJ/ha	3275	3106	5.2
	Diesel, l/ha	54.2	51.6	4.8
Wheat	Labour, h/ha	15.4	8.2	46.7
	Tractor, h/ha	15.4	8.2	46.7
	Energy in tillage, MJ/ha	3828	2586	32.4
	Diesel, l/ha	62.5	42.6	31.8

Source: Singh et al, 1999

harrow and cultivator. No significant difference in crop yield was noticed under the two tillage treatments. Tractor-drawn rotavator is certainly a better option over combination of cultivator and disc harrow for seedbed preparation in heavier soil for wheat crop as it saves 46.7 per cent time and 31.8 per cent fuel.

Minimizing the number of tillage operations or by combining the tillage and sowing operations may also save energy in seedbed preparation and sowing. The no-till drill and strip-till drill are the machines, which does both the operations together thereby saving time and energy. Research has been conducted under the titles of minimum-tillage, no-tillage or zero tillage, optimum tillage, soil compaction, etc. Results have shown that with the development and use of appropriate herbicides, the technique of zero tillage/minimum tillage/direct drilling has shown considerable potential for some crops under certain conditions. Research conducted in the Department of Agronomy at Punjab Agricultural University, Ludhiana showed that wheat crop could be grown under minimum /no-tillage conditions without any loss in yield. However, the major handicap in the adoption of this technology was the non-availability of a suitable planting machine.

The first approach to the development of a suitable minimum till drill was to develop an appropriate attachment to an existing drill for adoption of the technology. With this end in view, five different types of commercially available seed-cum-fertilizer drills were tried for direct drilling of wheat in manually harvested paddy fields. This was intended to assess the problems arising from the use of commercially available drills under no-tillage regime. The major problems encountered were:

- Accumulation of straw and stubble in front of the tynes.
- Formation of clods
- Poor coverage of seed and fertilizer leading to bird-damage to the seeds
- Excessive slippage and lack of contact of ground wheel due to uneven fields leading to skips in the placement of seed and fertilizer
- Higher power requirement for the operation.

To overcome the above-mentioned problems, it was decided to develop a disc coulter attachment in front of furrow openers of the existing seed drill. A 9-disc coulter attachment to the existing commercial 9-row seed-cum fertilizer drill for direct drilling of wheat after paddy was designed and developed by Shukla, Tandon and Verma(1980). The performance of the zero till drill was found to be satisfactory and comparable yields were obtained under conventional tillage. The reversible furrow openers provided behind disc coulters of the no-till drill resulted in formation of clods and did not allow the seed to emerge above the surface. Hence, Tandon and Powar(1984) replaced these reversible shovel furrow openers by boot type furrow openers with coulters fixed in front of the furrow openers for opening the slit in the soil to enable the seed and fertilizer to be placed in the soil. The modified drill was used for sowing wheat in fields where paddy had been grown earlier and in fallow land. There was not much difference in yield between zero till drilled fields and fields where one disking was done. The fallow-wheat rotation gave lowest yield. In the zero till drilled plots the incidence of weeds was less, mostly broad leaf weeds were observed and there was no incidence of *phalaris minor* a weed which is difficult to control. Later the boot type furrow openers were replaced by inverted T-type furrow openers.

Strip-till Seed-cum-fertilizer Drill/Zero-till Drill

The drill is essentially a 9-row seed-cum-fertilizer drill with a rotary blade attachment for minimum soil manipulation running ahead of the normal furrow openers. A tractor of 35 or higher horsepower (26.11 kW) can pull it. The rotary attachment consists of a frame with a rotor having '9' flanges. Each flange has 6 C-type tines (blades). The spacing between the flanges is the same as the row spacing for the crop to be planted. Power to the rotor shaft is provided from the tractor PTO through a speed reduction gearbox and chain and sprocket drive. The rotor revolves at a speed of 300-rpm corresponding to the rated PTO speed of 540 rpm. The rotary attachment is provided with an MS sheet cover to protect the power transmission system. It also helps to reduce the soil cover over the seed. An 11-row machine is also available. Machine in double drive version is also available.

In the first phase the drill was used for planting wheat crop in heavy texture soils under paddy-wheat crop rotation (Shukla et al, 1996). Wheat variety WL-711 was sown. The experiments were conducted for four years continuously, i.e., 1985 through 1988-89 in the same field using randomized block design with three treatments (including control) and four replications. In each plot 18 rows of wheat crop were planted. The control treatment consisted of adopting standard field preparation as per recommendations of Punjab Agricultural University for raising wheat crop in heavy textured soils. These included two operations by a disk harrow, two operations by a field cultivator and three operations by a plunger in manually harvested paddy field. Post emergence weed control was done mechanically with a manually operated wheel-hoe type weeder.

In treatment T1 direct sowing of wheat with strip-till seed drill without any preparatory tillage was performed. Post emergence weed control was done chemically. However, in treatment T2 Post emergence weed control was done mechanically. Experimental data regarding soil moisture content at the time of sowing, fuel consumption, labour requirement, germination count and yield were taken. The field data was analyzed and found quite encouraging.

Energy input of wheat under paddy-wheat rotation in heavy soil for conventional tillage and strip-tillage was also studied from 1985-86 to 1988-89. Under the minimum tillage system, the diesel fuel consumption in planting operation only (no separate seedbed preparation required) was 18 l/ha while diesel fuel used for seedbed preparation and sowing under conventional tillage system was 60 l/ha. Thus, there was a saving of diesel to the extent of 42 l/ha. The total energy input for minimum tillage system with mechanical weed control was 17264 MJ/ha and that with chemical weed control was 17328 MJ/ha. In conventional tillage, under similar soil conditions, the energy input varied between 19659 MJ/ha and 19723 MJ/ha. Hence, under the strip tillage system, energy saving under heavy soil condition was 2395 MJ/ha.

In the experimental results, no significant difference in the yield was observed when the crop was planted on the same day for both the conventional and strip tillage systems. However, with the strip-tillage system, a time saving of 65 to 70% in comparison with the conventional tillage planting was obtained. Thus, by adopting the strip tillage planting technology for wheat, the timeliness of operation improved significantly resulting in an increase in the total yield of wheat.

Dhaliwal (2000) conducted a study on no-till drill with inverted T-type furrow opener, no-till drill with hoe-type furrow opener, strip-till drill with shovel type furrow opener and no-till drill with double disc type furrow opener under different height of paddy stubbles for sowing of wheat crop. The suitable seeding technology for sowing wheat after paddy was strip-till drill followed by no-till drill with inverted T-type furrow opener. By using direct seeding technology, wheat sowing can also be done in time by which more area can be brought under cultivation.

Bansal (2002) conducted a study on different sowing technologies such as no-till drill with inverted T-type furrow opener and disc coulter attachment and strip-till drill under different conditions of paddy straw. The strip-till drill was found to be most suitable technology followed by no-till drill with coulter attachment and no-till drill with T-type furrow opener. Yield of wheat was significantly higher for strip-till drill under loose straw spread conditions as compared to other seeding technologies including control. The work suggests that minimum sowing technologies such as no-till drill and strip-till drill gives better results as seeds are placed at proper depth and gave better germination. Experiments were conducted in silt-clay loam soil for both the successive years 2000-01 and 2001-02. All the experiments were conducted after combine harvesting of paddy crop. Loose straw was manually removed from the fields. In conventional method, pre-sowing irrigation was applied before preparing the field using disc harrow x 2, cultivator x 2 and plunger x 2 and seed-drill was used for sowing of the wheat. In minimum tillage technology experiments, no-till drill and strip-till drill were used for sowing of wheat crop.

Four treatments were selected during the field experiment in the successive years 2000-01 and 2001-02. The treatment are as follows:

- Treatment I : Pre-sowing irrigation + loose straw removed + disc harrow (2) + Cultivator (2) + Planker (2) + Seed-drill.
- Treatment II : Pre-sowing irrigation + loose straw removed + mould board plough + disc harrow + cultivator + planker + seed-drill.
- Treatment III : Loose straw removed + No-till drill.
- Treatment IV : Loose straw removed + Strip-till drill.

Fuel consumption for seedbed preparations was 41.05 and 30.16 l/ha in Treatment I and II respectively (Table 3). Total fuel consumption was 50.35, 39.46, 11.06 and 14.01 l/ha in Treatment I, II, III and IV respectively. Total fuel consumption was lowest in Treatment III (11.06 l/ha) followed by Treatment IV (14.01 l/ha). The saving in fuel consumption was 70-80% in Treatments III and IV over Treatment I and 60-70% over Treatment II. The sowing was done in second week of November. In case of Treatment I and II the field preparations before sowing of wheat took 10-15 days. No prior field preparations were required for Treatment III and IV. The total time required for field preparation was 13.9, 10.6, 2.7 and 3.9 h/ha respectively for Treatments I, II, III and IV.

The total energy input up to sowing including seeds and fertilizers with different systems was 11104, 10491, 8892 and 9057 MJ per hectare for Treatments I, II, III and IV respectively (Table 3). The total energy input was lower for Treatment III (no-till drill), followed by Treatment IV (strip-till drill), Treatment I and Treatment II. In the trials during successive years 2000-01 and 2001-02, the yield of wheat was maximum in case of Treatment IV (5.44 t/ha), followed by Treatment III (5.35 t/ha), Treatment I (5.16 t/ha) and Treatment II (5.04 t/ha). There was no significant difference within the replicates but the difference was significant in the yields obtained from Treatments (Table 3). Statistically the results of grain yield were found to be significant at 5% level of confidence in all treatments. The yield was significantly higher in case of Treatments III and IV as compared to system I (5.04 t/ha). Emergence of seed was better as these were placed at proper depth and soil disturbance was less in both these minimum tillage technologies. There is 33.3% saving in labour requirement, 62% saving in fuel consumption and 13.7% saving in energy requirement in field operations by use of tractor operated zero-till drill over conventional practices (Table 4).

Table 3. Details of sowing parameters and subsequent observations in the field during the year 2000-01 and 2001-02

S. No.	Parameters	Treatment I	Treatment II	Treatment III	Treatment IV
1	Seed rate, kg/ha	120.7	121.4	116.0	121.3
2	Fertilizer dose, kg/ha				
	Urea	250	250	250	250
	DAP	134.3	133	132.5	130.5
3	Depth of sowing, cm	6.7	6.6	5.3	5.7
4	Speed of operation, km/h	2.86	2.95	3.10	2.93
5	Effective field capacity, ha/h	0.41	0.38	0.38	0.27
6	Field efficiency, %	67.40	66.80	66.90	66.80
7	Fuel consumption, l/ha				
	a) Total tillage operations	41.05	30.16	-	-
	b) For sowing	9.30	9.30	11.06	14.01
	c) Total system	50.35	39.46	11.06	14.01
8	Crop Yield, t/ha	5.04	5.16	5.35	5.44
9	Total energy input till sowing, MJ/ha	11104	10491	8892	9057

Source: Bansal, 2002

Table 4. Energy saving through use of no-till drill in wheat crop

Parameter	Conventional practice	No-till drill	% saving
Labour requirement, man-h/ha	12	8	33.3
Fuel consumption, l/ha	31.6	12	62
Total operational energy, MJ/ha	6687	5777	13.7

A Rice-Wheat Consortium for Indo-Gangetic plain by CIMMYT, a CGIAR eco-regional initiative involving several CG Centers and National Agriculture Research System of India, Pakistan, Bangladesh and Nepal was formulated to promote resource conserving technologies such as, laser land leveller, zero-tillage, furrow irrigated bed planting system (FIRBS), surface seeding, nutrient and water management, residue management, alternative to rice-wheat cropping system in relation to CA technologies. Zero-tilled drills, strip till drills, roto till drill were used for direct drilling of wheat after paddy and their performance was compared with conventional tillage (Table 5). In these drills, the furrow openers were replaced by inverted “T- type” furrow openers. In No-till plots, fuel consumption was found to be 11.30 l/ha as compared to 34.62 l/ha by conventional method resulting in fuel saving of 23.32 l/ha. There was 67 % saving in fuel and 70 % saving in time due to no-tillage as compared to conventional method.

In other study conducted by Rautray(2003), CT as compared to conventional practice showed higher performance in terms of increased benefit cost ratio (2.47 per cent) and lower operational energy (7176 MJ/ha). The reduced tillage system lowered the cost of cultivation due to reduced energy requirement and yield returns were similar to the conventional practice as seen in Table 6. In zero tillage, the specific energy and operational energy were found to be the least (1.93 MJ/kg) as compared to other three treatments.

Table 5. Comparison of different tillage equipment used for sowing wheat after paddy

Particular	No-tillage seeding	Strip tillage seeding	Seeding with roto –till-drill	Conventional tillage (3 passes + levelling)
Time required(h/ha)	3.23 (70.15)	4.17(61.46)	3.45(68.1)	10.82
Fuel used (l/ha)	11.30(67.36)	17.80(49.45)	13.80(60.14)	34.62
Operational energy (MJ/ha)	648.96(67.16)	1001.76(49.31)	783.60(60.34)	1976.11
Cost of operation Rs/ha	639.54(66.39)	979.95(48.50)	807.30(57.58)	1903.04

Figures in brackets show % of saving over conventional practice. Source: S. K. Rautray(2003)

Table 6. Comparative Performance of Zero Till Drill, Strip Till Drill, Roto Till Drill and Conventional Tillage

S.No.	Particulars*	Zero till drilled wheat	Strip till drilled wheat	Rota till drilled wheat	Conventional tillage seedling
1	Grain yield (t/ha)	3.71	3.66	3.70	3.80
2	Cost of production (Rs./ha)	9746	10328	11064	11825
3	Benefit cost ratio	2.47	2.30	2.17	2.09
4	Operational energy (MJ/ha)	7176	8604	9216	9708
5	Specific operational energy (MJ/kg)	1.93	2.35	2.49	2.55
6	Specific cost of production (Rs. /kg)	2.63	2.82	2.99	3.11

Sale price of wheat Rs.6.50/ kg. Source: S. K. Rautray (2003)

The experience of zero tillage /direct drilling showed that there are many benefits in keeping the soil undisturbed for long periods as nature intended. It was found that due to zero tillage, the soil drainage improves with draught cracks - worm channels - old root systems and soil pores all linking together to help to remove rain water quickly and therefore avoiding the sponge effect created by normal cultivation. Researchers found that worm population are higher and that root systems are stronger and deeper in direct drilling system. Soil structure is also improved with the organic matter being retained near the surface. This helps to improve and build up a natural surface tilth which requires little preparation for cereal sowing in addition the crumb stability or increase in soil strength.

Weeding and Interculture

Weeding is a very important operation in crop cultivation. If not done in time, the yield of the crop is reduced drastically. The average energy consumed in weeding operation for various crops is about 3 per cent. Presently weeding is practiced in four ways: i) by *khurpa* (a short handle tool used in squatting posture), ii) by *kasola* (a long handle tool used in standing posture, iii) by wheel hand hoe, and iv) by chemical weeding. It is seen that weeding by *khurpa*, *kasola* and wheel hand hoe requires 105, 75 and 24 man-h/ha respectively (Table 7). Weeding by wheel hand hoe can save 72, 61 and 67 per cent of energy over weeding by *khurpa*, *kasola* and chemical respectively without significant effect on yield. There is also a saving of 28 to 86 per cent of operational time in weeding by *kasola*, wheel hand hoe and chemical as compared to *khurpa*.

Table 7. Energy required under different weed control treatments for wheat crop

Weed control method	Labour requirement (h/ha)	Energy in weeding (MJ/ha)	Saving over use of khurpa (%)	
			Time	Energy
Khurpa	105	215	-	-
Kasola	75	154	28.6	28.4
Wheel hand hoe	24	60	77.1	72.1
Chemical	14	183	86.7	14.9

Source: Singh et al, 1999

Irrigation

Irrigation, consumes a significant portion of total energy input for crop production, and is dependent on commercial energy sources, and energy conservation in the operation would be an effective contribution. Generally three types of irrigation methods are used:

- Flood irrigation
- Border irrigation
- Check basin irrigation

Check basin irrigation requires about 12-40 per cent lower energy as compared to other methods of irrigation without affecting the yield. Using efficient pump sets operated by electric motor and diesel engines can save considerable amount of energy. Some of the easy-to-incorporate energy-saving techniques are

- minimizing the height of delivery pipe from ground level
- use of efficient reflux valve
- use of low friction pipes
- use of large-radius bends
- proper maintenance

Irrigation is the most energy consuming operation requiring 31 % (1892 MJ/ha) of the operational energy. In High Yielding Zones(Punjab, Uttaranchal, Western Uttar Pradesh) areas , 23 % of the tractor farms use canal water for irrigating wheat and rest use(Medium Yielding Zones- Eastern Uttar Pradesh, Maharashtra and Madhya Pradesh)ground water pumped by diesel engine/electric motor. The farms using engine used highest total energy (16311 MJ/ha) for irrigation while farms using motor used minimum energy (15096 MJ/ha)indicating variation of 8 % in energy use. Electric motor being more energy efficient than diesel, hence, farm using motor would operate with higher energy efficiency.

Studies conducted in Punjab showed that irrigation by canal saves about 100-200 % energy as compared to tubewells. Even the use of existing tubewells with proper maintenance and use of energy-efficient valves, bends etc. save about 10-15 % energy. However, irrigation energy use on zero till fields and conventional tilled fields using canal, and tubewell operated by engine and electric motor operated pumps needs to be conducted.

Harvesting and Threshing

Harvesting and threshing operation usually consumes about 25-30 per cent of operational energy used. The share varies with crop being grown. It also indicates that mechanization of the critical operations for paddy and wheat crops has increased the quantum of energy use as compared to crops like maize and cotton, which are mostly handled manually. Before introduction of high yielding varieties of paddy and wheat, harvesting and threshing were mostly done manually. After introduction of high yielding varieties of wheat, threshing operation became partly mechanized in early seventies for timely handling of large volume of crop. However, harvesting continued to be done manually. Later on animal drawn reaper was used for harvesting of paddy and wheat crops, but could not become popular because of its own limitations. Subsequently, tractor-drawn and self-propelled reapers were also developed. In mid seventies, few combines were imported and introduced in Punjab, Haryana and Western UP. Since early eighties, indigenous manufacturing of combine harvester was initiated and from mid-eighties their adoption in

Punjab started picking up for harvesting of paddy and wheat. Use of the machine has been mostly on custom hiring basis.

Harvesting by combine requires 931 MJ of energy per hectare and saves about 40 to 55 per cent of energy in harvesting over other methods of (a) manual harvesting followed by threshing by power thresher (1436 MJ/ha) and (b) using tractor-drawn reaper followed by mechanical threshing (1300 MJ/ha). Farmers commonly use a 35 hp tractor for operating mechanical thresher, which even otherwise can be operated by 7.5 to 15.0 hp diesel engine or 5 to 10 hp electric motor depending upon the capacity of thresher. Tractor engines are therefore operated on part-load with decreased fuel efficiency. There is a lot of wastage of energy only because of not using matching power source, which otherwise can be saved.

Comparison of Different Harvesting and Threshing Systems

Comparison of different harvesting and threshing systems (System I- Manual Harvesting & Manual Threshing; System II- Tractor drawn /self propelled combine; System III - Manual Harvesting & Mechanical Threshing and System IV - Reaper Harvesting & Mechanical Threshing) showed that the labour requirement was minimum in the case of self-propelled combine (4.5 man-h/ha) followed by tractor drawn combine (9.5 man-h/ha). The maximum labour requirement was for system 1 (230-260 man-h/ha). The grain loss in the case of system 1 was the lowest (2.15 %). The losses with combines are 4.56% for tractor drawn combine and 3.08% for self-propelled combine. These losses in combines can possibly be reduced with better adjustment and correct forward speed. The greatest advantage of combine is that the time requirement for harvesting and threshing is considerably low. Time required for tillage operation after combining is the highest as stubbles left in the field are quite large. The total operating cost was highest (Rs 3255/ha) for manual harvesting and mechanical threshing (system III) followed by reaper harvesting and mechanical threshing (system IV) Rs 2835/ha. The lowest system operating cost is for self propelled combines (system II) Rs 2545 for per ha and total system operating cost of tractor drawn combines was Rs 2775 per ha. Total system cost for manual harvesting and manual threshing (system 1) was Rs 2750/ha, if cost of grain losses is also taken into account. The total system cost was lowest in case of system II with combines if the problem of straw handling and removal is taken care of. Also, in this system labour requirement and dependence on labour was very less (<10 man-h/ha).

Straw Management

Rice-Wheat crop rotation is mostly adopted in Northern India. In India, total area under paddy and wheat cultivation was 44.3 and 25.1 million ha respectively and total production 85 million tonne and 70 million tone, respectively. This huge amount of straw is wasted annually either by burning in the fields or due to poor utilization which otherwise could contribute to the income of farmers. So there is a need to manage the paddy straw in an economically and environmentally safe way. There are three options for managing the paddy straw, these are:

- Burning the straw in the field
- Baling the straw
- Incorporation of straw in the field

Burning in Paddy Straw in Field

Burning cause loss of significant quantities of valuable biomass and also cause environmental pollution and cause many diseases. Burning of paddy straw causes a loss of about 79.38 kg/ha of nitrogen, 108.86 kg/ha of potassium and 183.71 kg/ha of phosphorus. This option is not a suitable though it is simple and adopted throughout the Northern states of India.

Baling the Paddy Straw

In recent years, some farmers have tried to remove the straw from the field either manually or mechanically. If rice straw is not burnt then baling may provide an attractive economic environmentally safe option. Manual collection of paddy straw is a laborious job and also storing the large volume of straw is another problem. The straw can be used as dry fodder for animals. It can be used for producing electricity, in paper industry, card board industry etc. Therefore, the need of time is to find the way for manipulation of paddy straw in the field itself.

Incorporation of Paddy Straw

Paddy straw incorporation has many advantages over wheat sowing after conventional tillage. Some of them are listed as follows

- Sustain the productivity of soil as it can hold and supply the nutrients
- Environmentally safe and efficient use of natural resources
- Reduce soil erosion from water and wind
- Act as mulch and modify soil temperature
- Improve physical condition of soil

To avail the advantages there are many ways to incorporate the paddy straw in the soil. So, experiments were carried out using different technologies for paddy straw incorporation and sowing of wheat crop.

Different technologies for Straw Incorporation

Different technologies (Fig. 1) were adopted for incorporation of the paddy straw left in the field after combine harvesting. Total fuel consumption was highest in the field where straw chopper and roto-till drill (Technology V) were operated (63.51 l/ha) followed by straw chopper and strip-till drill (55.11 l/ha), Mould board plough and seed drill (49.40 l/ha), straw chopper and no-till drill (48.81 l/ha) and was lowest in the case of disc harrow and seed drill (42.88 l/ha), Table 9. The cost of total system was higher for straw chopper and roto-till drill (Rs. 3054.3/ha) followed by disc harrow and seed drill (Rs.2906.10/ha), straw chopper and strip-till drill (Rs.2652.00/ha), mould board plough and seed drill (Rs.2601.85/ha) and was lowest in case of straw chopper and no-till drill (Rs.2465.15/ha). In case of all straw incorporation treatments, germination was late than that of generally observed in non-straw incorporated fields. The weed population/m² was higher in case of no-till drill (73.8) than other treatments. Because in sowing with no-till drill comparatively less soil was disturbed.



Figure 1. Different technologies used for incorporation of paddy straw

There was significant difference in grain yield between different treatments. The average grain yield for technology I, technology II, technology III (no-till drill), technology IV (strip-till drill) and technology V (roto-till drill) was 5.05, 5.04, 4.83, 5.04 and 4.78 t/ha, respectively. Among different technologies used for straw incorporation and sowing of wheat in paddy harvested fields, technology I, technology II and technology III (strip-till drill) showed significantly higher grain yield as compared to technology III (no-till drill) and technology IV (roto-till drill). The technology I, technology II and technology III were at par with each other. The lower yield in case of no-till drill and roto-till drill technologies was due to repeated blockages of the machine with the chopped paddy straw during sowing of wheat. This resulted in non-uniform placement of seeds and formed patches of straw accumulation in the field, which affected the germination and thereby lowered number of tillers/m².

Energy Requirements in Field Operations for Cultivation of Rice and Wheat in India

Under the AICRP on ERAS efforts were made to determine the energy use for rice- wheat crop rotation in different states. The energy requirement for the cultivation of rice crop in different states varied widely from 3370 MJ/ha in Madhya Pradesh to 95758 MJ/ha in Tamil Nadu. The variation in energy requirement in different states could be attributed mainly to irrigation, which is highest in Tamil Nadu and in most cases maximum as compared to other field operations. There was wide variation in energy requirement in seedbed preparation. It was lowest in Madhya Pradesh and highest in Tamil Nadu. Similar situation exists for wheat cultivation also. Seedbed preparation, irrigation and harvesting & threshing are the three operations consuming more than 70% of energy requirements in operations. Energy requirements in seedbed preparation were lowest in Madhya Pradesh (738 MJ/ha) and highest in West Bengal (1789 MJ/ha). Energy requirements in harvesting and threshing were more in Punjab and Uttar Pradesh due to use of threshers, which are mostly operated by tractor available with the farmers.

Conclusions

From the different studies conducted by various researchers with respect to the energy use under no tillage and conventional tillage especially with respect to sowing operation have shown that no tillage results in saving in energy as compared to conventional tilled plots. Use of no tillage also results in saving in 30-40 % labour, fuel and time as compared to conventional tilled wheat. But, the energy use varies from state to state depending upon the methods, equipment and technologies used. Some states are using more energy than required. Laser land leveler have been introduced and have been found to save 30-40 % saving in water. Hence, studies w.r.t laser leveled fields and conventional leveled fields need to be conducted. Studies by various researchers have been conducted to determine the energy use on the farm for growing wheat under different tillage systems. However, there is need to take up a large scale comprehensive study to determine the energy use in no tillage and conventional tillage for performing different farm operations by using efficient methods/equipment such as, laser land leveler for leveling the land, no till drills with self depth adjusting tynes, mechanical and chemical weed control, irrigation by canal and tubewells using motor/engine operated pumps, harvesting by reaper, combine and conventional method, threshing by motor, engine and tractor and straw management. As straw incorporation into the soil requires large amount of energy hence, most of the paddy straw is burnt causing atmospheric pollution. Studies with respect to energy use for growing wheat and other crop rotations on fields harvested by manual method, reaper, combine and different heights of the standing stubbles needs to be conducted so as to arrive at actual energy use on no till and conventional tilled fields.

References

- Bansal S K (2002) Studies on the effect of direct seeding technologies on wheat crop under different paddy residue conditions. Unpublished M.Tech. Thesis, Deptt. of Farm Power and Machinery, Punjab Agricultural University, Ludhiana.
- Dhaliwal I. S. (2000) Study of different seeding technologies on wheat crop under standing paddy stubble conditions. Unpublished Ph. D. Thesis, Deptt. Of Farm Power and Machinery, Punjab Agricultural University, Ludhiana.
- Shukla, L.N., Tandon, S.K. & S.R. Verma. 1984. "Development and Field valuation of a Coulter Attachment for Direct Drilling". AMA, Japan, Vol.XV No.3.
- Shukla L N, Chauhan A M, Dhaliwal I S and Verma S R (1996) Development of minimum till planting machinery. *Agricultural Mechanization in Asia, Africa and Latin America*. Vol.27 pp.15-18.
- Singh Surendra, Mittal J P and Verma S R (1997) Energy requirements for production of major crops in India. *Agricultural Mechanization in Asia, Africa and Latin America*. Vol.28 No. 4 pp.13-17.
- Singh Surendra, De Dipanker and Pannu C J S (1999) Energy Conservation Technology for farm Operations in Punjab. Technical Bulletin no. CIAE/99/73. *Central Institute of Agricultural Engineering, Bhopal* Singh Surendra (2002) Annual report of Project, Mechanization of rice wheat cropping system for increasing the productivity" 2001-02, Deptt. of Farm Power and Machinery, Punjab Agricultural University, Ludhiana.
- Tandon, S.K. & J.S. Panwar. 1985. "Studies on Reduced Tillage System for Irrigated Wheat". Proceeding of Silver Jubilee Convention, ISAE 29 31, Vol. I Farm Power & Machinery.
- Tandon, S.K. and J.S. Panwar. 1987. "Potential of Energy Economy through Reduced Tillage System for Wheat (*Triticum aestivum*)". Paper published in the Proceedings of National Conference on Energy in Agriculture and Food Processing. Indian Society of Agricultural Engineers and School of Energy Studies, Punjab Agricultural University, 30 31st October, Ludhiana.

Actual Challenges : Developing a Low Cost No-till Wheat Seeding Technologies for Heavy Residues; The Happy Seeder

H.S. Sidhu¹, Yadvinder Singh¹, Manpreet Singh¹, J. Blackwell², Harmanjit Singh¹, Rajinder Pal Singh³ and H.S. Dhaliwal¹ and Ajaib Singh¹

¹Punjab Agricultural University, Ludhiana 141 004, Punjab, India

²International Centre of WATER for Food Security, Charles Sturt University, Wagga Wagga, Australia

³Department of Primary Industries, NSW, Australia

Rice-wheat (RW) is the most popular cropping system followed on around 13.5 million ha area in the South Asia extending across the Indo-Gangetic alluvial plain. In north-western India combine harvesting of rice and wheat is now a common practice leaving large amount of crop residues in the fields. Rice straw has no economic uses and remains unutilized. To vacate fields for the timely sowing of wheat, majority of the rice straw is burnt in situ by the farmers causing environmental pollution and loss of plant nutrients and organic matter. Recently, Punjab Agricultural University, Ludhiana in collaboration with Australian Centre for International Agricultural Research has developed a new machine called 'Happy Seeder'. The Happy Seeder which needs 45 hp tractor for its working cuts, lifts and manages the standing stubble & loose straw, retaining it as surface mulch and sows wheat in a single operational pass of the field.

It is encouraging to note that about 80 ha area each in India and Pakistan have been successfully sown wheat using Happy Seeder during 2007-08 producing 5-10% more yield (with 50-60% less operational costs) compared to conventional sown wheat. Additional advantages like less weed growth, water saving, improved soil health & environment quality were also noted under the use of 'Happy Seeder' technology. Machine weight, load on the tractor and choking of machine under heavy stubble load were the major constraints in machine operation. Our objective was to develop new prototype of Happy Seeder which will work efficiently with 35hp tractors mostly available with farmers in the region. To achieve the above objective several modifications/improvements in machine design were made and tested under field conditions. These modifications included: increasing row spacing, blade geometry, blade tip speed, machine weight and rotor size/curvature to reduce the power requirement of the present machine. A light weight prototype of Happy Seeder with 30% more tip speed of modified rotor blades, 40% more window opening for easy loose straw movement and 19% less weight has been developed having row to row spacing 25.7 cm. Replicated field experiments conducted at three locations during 2007-08 showed that row to row spacing of 30 cm out yielded the conventional 20 cm row spacing by 10%. The detailed field evaluation of the prototype is in progress for analysing the interactive effect of variety, date of sowing and row spacing on wheat yield during 2008-09. A very dedicated and committed extension efforts & government support is required to popularize this eco-friendly technology for sustainable agriculture.

Keywords: Happy Seeder, Rice Residues, Management, Surface Mulching, Direct Drilling

Rice wheat (RW) is the major cropping system in the Indo-Gangetic Plains of South Asia grown on about 13.5 million ha each year (Timsina and Connor 2001). About 2.6 million ha are under RW system in the small state of Punjab, India alone where more than 90% of the area under rice is machine harvested leaving behind enormous quantity of residues. Rice straw is considered (excepting that from basmati variety) as of inferior feeding quality and has very limited alternative uses. Thus the majority of rice straw (about 18 million tons) is burnt in the field in Punjab, India, as this is a rapid and cheap management option, allowing for quick a turn around between crops. In addition to huge loss of plant nutrients (particularly nitrogen and sulphur) and organic matter, burning causes severe air pollution with deleterious effects on human and animal health (Bijay Singh et al. 2007, Dobermann and Fairhurst 2002). Crop residues are a renewable resource for improving soil health and are important for the sustainability of the RW eco system.

In-situ rice straw incorporation has been previously recommended as an alternate to burning but it is practised by less than 1% of the farmers only as it is costly and energy & time intensive. Moreover, loose residues interfere with tillage and seeding operations for wheat. Developing a cost-effective technology for efficient in-situ management of this vast resource was a challenging task for the farm engineers. Minimum and zero-till technologies for wheat have been demonstrated beneficial in terms of economics, irrigation water saving and timeliness of sowing in comparison with conventional tillage (Malik et al. 2004; Humphreys et al. 2007; Singh et al. 2008). However, there are problems with direct drilling of wheat into combine harvested rice fields as loose straw accumulates in the seed drill furrow openers, seed metering drive wheel traction is poor due to the presence of loose straw and the depth of seed placement is non-uniform due to frequent lifting of the implement under heavy trash conditions.

Happy Seeder describes a new approach in solving the problems of direct drilling of wheat into heavy rice residues in a single operational pass while retaining the residues as surface mulch. Happy Seeder consists of a straw managing unit and a sowing unit in one composite machine. The hinged flails mounted on the rotating shaft cuts the standing stubbles and loose straw coming in front of the furrow opener with simultaneous tyne cleaning (for proper seed placement) and places the residue in between the sowing tynes. This PTO operated machine can be operated with 45 hp double clutch tractors and can cover 0.3 – 0.4 ha/hr. The Happy Seeder technology (HST) provided an alternative to burning and thus Govt of Punjab, India is encouraging adoption of this technique. The HST during 2007-08 produced 5-10% more yield (with 50-60% less operational costs) compared to conventional sown wheat. Financial analysis showed that the Happy Seeder is more profitable than the conventional alternatives, full stubble incorporation or direct drilling or rotary seeding both of which require at least partial burning whereas the Happy seeders does not require any burning of the rice residue. The study has also identified important health, community and environmental benefits from the widespread adoption of the Happy Seeder (Singh et al 2008). Additional advantages like 60-70% less weed growth, water saving (particularly pre-sowing irrigation), improved soil health (through improvements in nutrient supply capacity and soil structure) and environment quality improvement were noted for the technology (Sidhu et al 2007).

Loose straw spreading, machine weight, load on the tractor (requiring 45 hp tractor for operation) and choking of machine under heavy stubble load were the major constraints in the early machine operation. The existing machine is more expensive which is a key barrier to adoption for the poorer segment of farmers in North West India. The objective of the present study was to develop a new prototype of Happy Seeder which will work efficiently in heavy straw load with 35hp tractors mostly available with farmers in the region.

Materials and Methods

Machinery Development: Initially the furrow openers and rotor were positioned according to the normal row to row spacing of 20 cm with nine furrow openers in the machine. In 2007-08 row to row spacing was adjusted to 20-40-20 cm and 30-30 cm with the hypothesis that the wider row to row spacing in wheat will compensate for low plant population with high tiller density thereby no adverse effects on yield. In order to achieve the 20-40-20 cm row geometry, alternate furrow openers and rotor blades were removed and there were only six furrow openers along the width of machine. But to achieve the 30-30 cm line spacing geometry the furrow openers and rotor was modified and adjusted in such a way that distance between the two openings was 30 cm and there were only six furrow openers along the width of machine. The power requirement of Happy Seeder was reduced by modifying the rotor and position & shape of blades (C type and Gamma type) as well as furrow openers. Fuel consumption was also monitored for two blade shapes.

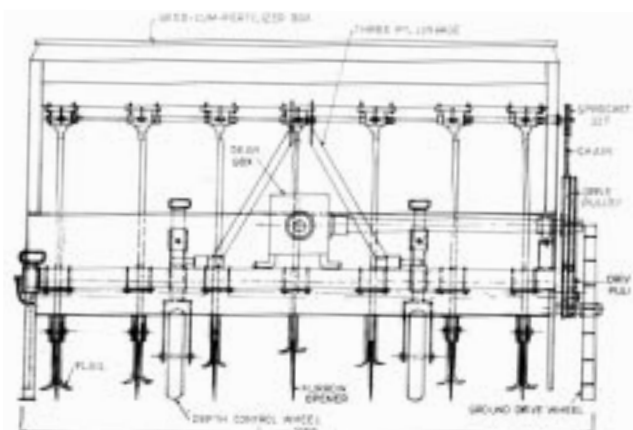
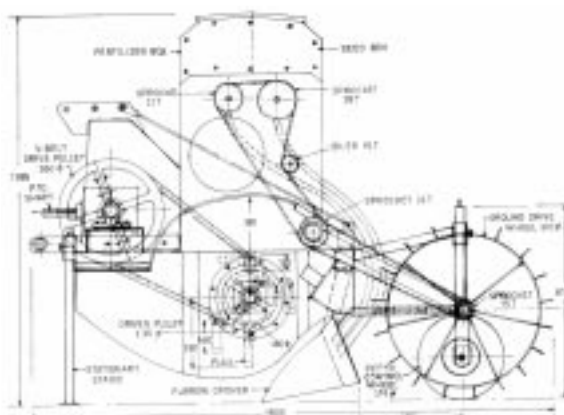
Field Experiments: Three replicated field trials were conducted at PAU Ludhiana (loamy sand and sandy loam soils) and KVK, Sangrur (sandy loam), Punjab, India to evaluate the effect of row spacing on the wheat yield during 2007-08. Wheat was sown with Happy Seeder using three row spacings/geometries of 20-20 cm, 20-40-20 cm and 30-30 cm using a seed rate of 100 kg/ha. Fertilizer, weed and irrigation management practices were followed as per recommended package of practice of Punjab Agricultural University, Ludhiana (Anonymous 2008) . At sowing 60 kg/ha P_2O_5 ha⁻¹ as DAP was drilled along with the seed and 35 kg N/ha as urea was broadcast before sowing. Additional 60 kg N/ha urea was top dressed 21-25 days after sowing prior to 1st irrigation. Grain yield was recorded at the time of maturity from 6 m² area with in the each plot.

Results and Discussion

Wheat sown with a 30-30 cm row spacing yielded 10 % more compared to other row spacings/geometries (Table 1). The increase in grain yield with 30-30 cm spacing compared to the 20-20 cm and 20-40-20 cm spacing was possibly due to increase in the tillering density, grain weight and no. of grains per ear head. Based on the encouraging results from study, a light weight prototype (Figs. 1, 2 & 3) of Happy Seeder with 30% more tip speed of modified rotor blades, 40% more window opening for easy loose straw movement and 19 % less weight has been developed having row to row spacing 25.7 cm (Table 2). It was also observed that the new Gamma type blades consumed 34 % less fuel as compared to the L-type blades.

Table 1. Grain Yield (t/ha) of different row to row spacing experimental trials

Sites	Soil type	Straw Load (t/ha)	Sowing date	Yield (t/ha)		
				Row spacing (20 cm)	Row spacing (20-40-20 cm)	Row spacing (20-40-20 cm)
1	Loamy sand	8.25	28.10.07	4.22±0.12	4.68±0.27	4.93±0.56
2	Sandy loam	8.94	6.11.07	4.89±0.30	4.47±0.24	5.21±0.14
3	Sandy loam	8.30	7.11.07	3.285±0.28	3.47±0.21	3.98±0.30

**Figure 1.** Front view of Happy Seeder**Figure 2.** Side view of Happy Seeder**Figure 3.** New prototype of Happy Seeder in operation with 35 HP tractor**Table 2.** Comparison of modified prototype of HS with the existing machine

Sr. No.	Specifications	Happy Seeder	
		Happy Seeder (45 hp)	New prototype (35 hp)
1	Machine function	Direct drilling of wheat/ mungbean into residues.	Direct drilling of wheat/ mungbean into residues.
2	Horse power required, hp	45	35
3	Flails tip speed (m/sec) at 1000 tractor engine rpm	26.98	35.07
4	Capacity, ha/h	0.26 – 0.3	0.26 – 0.3
5	Window area, m ²	561	786
6	Weight, kg	625	506
7	Fuel Consumption, l/ha	16.22	11.63
8	Rotor drum diameter, mm	290	381
9	Cost, US \$	2062	1753

It is encouraging to note that area under Happy Seeder Technology has increased from 80 ha in 2007-08 to 280 ha in 2008-09 in Punjab, India. Approximately 30 machines have been sold to Government departments and Industry by three different manufacturers in the Indian Punjab. Ten field research trials for evaluating the newly developed Happy Seeder (35 hp model, 25.7 cm row to row spacing) are in progress at different locations in Punjab, India during the 2008-09 wheat season. Three replicated trials to study the interaction effect of date of sowing, wheat variety and row to row spacing are also in progress during current wheat sowing season.

Constraints and Challenges

The constraint and challenges related to HST which include uniform spreading of loose rice straw in the combine harvested fields before using the machine, damage of germinating wheat seedlings by rodents and the difficulty of forming bunds in uncultivated fields in the presence of rice residue, are being addressed. A mechanical device attached to the combine harvester has been developed and tested under field conditions for uniform spreading of rice straw in combine harvested fields. Use of the spreader attached with the combine harvester will enable harvesting of rice and sowing of wheat using HST on the same day in the residual soil moisture thus saving the use of precious water for pre-sowing irrigation. A simple and cost effective technology is already in place to control rodents in the wheat fields (Anonymous 2008). Similarly, a tractor-drawn disc bund maker is available to prepare bunds in wheat fields with heavy straw loads. Training of contractors and technical staff is essential for proper operation and maintenance of machine. The involvement of contractors is also important to enable farmers with small holdings to be able to have access to the technology without having to buy the costly Happy Seeder planters (US \$ 1753) of their own. A highly dedicated and committed extension effort along with sincere government support are required to popularize this eco-friendly technology for sustainable agriculture on large areas under RW system.

References

- Anonymous (2008) Package of practice for Rabi crops of Punjab. Punjab Agricultural University, Ludhiana, India
- Dobermann A and Fairhurst T H (2002) Rice straw management. Better Crops International Vol. 16, May Special Supplement.
- Humphreys E., Masih I., Kukal S.S., Turrall H. and Sikka A. (2007). Increasing field scale water productivity of rice-wheat systems in the Indo-gangetic Basin. In "Proceedings of the International Rice Congress", New Delhi, 9-13 October 2006.
- Malik R.K. and Yadav A., Gill G.S., Sardana P., Gupta R.K. and Piggin C. (2004). Evolution and acceleration of no-till farming in rice-wheat cropping system of the Indo-Gangetic Plains. In 'New directions for a diverse planet', Proceedings of the 4th International Crop Science Congress, Brisbane, 29 September-3 October 2004. At <[http://www.cropscience.org.au/icsc2004/symposia/2/2/459_malikrk.htm](http://www.cropsscience.org.au/icsc2004/symposia/2/2/459_malikrk.htm)>. Accessed 9 May 2006.
- Sidhu H.S., Manpreet Singh, Humphreys E., Yadvinder Singh and Sarbjeet Singh Sidhu (2007). The Happy Seeder enables direct drilling of wheat into rice stubble *Australian Journal of Experimental Agriculture*, 2007, 47, 844–854
- Singh Bijay, Shan Y. H., Johnson-Beebout S. E., Singh Yadvinder, and Buresh R. J. (2007) Crop Residue Management for Lowland Rice-Based Cropping Systems in Asia, *Advances in Agronomy*, Volume 98; 118-186.
- Singh R.P., Dhaliwal H.S., Tejpal Singh, Sidhu H S, Yadvinder Singh and Humphreys E. (2008). A financial assessment of the Happy Seeder technology for rice-wheat systems in Punjab, India pp-182-190. In "Permanent beds and rice residue management for rice-wheat systems in the Indo-Gangetic Plain" ed. by E. Humphreys and C. Roth, ACIAR proceedings No. 127.
- Timsina J. and Connor D.J. 2001. Productivity and management of rice-wheat cropping systems; issues and challenges. *Field Crops Research* 69, 93-132.

Actual Challenges: Developing Low Cost No-Till Seeding Technologies for Heavy Residues; Small-Scale No-Till Seeders for Two Wheel Tractors

Israil Hossain¹; R. Jeff Esdaile², Richard Bell³; Chris Holland⁴; Enamul Haque⁵,
Ken Sayre⁶ and M Alam⁷

¹Senior Scientific Officer (Ag Engineer), Wheat Research Centre, Dinajpur, Bangladesh, email:
<mdisrail@gmail.com>

²Agricultural Consultant, ACIAR Project Australia email: rjesdaile@bigpond.com

³Professor, Murdoch University, W. Australia, rbell@murdoch.edu.au

⁴Principal, Spring Ridge Engineering, Spring Ridge 2343 NSW Australia

^{5,6&7}Senior Program Manager and Agronomists, CIMMYT Bangladesh, CIMMYT Mexico and IRRIBangladesh, respectively

Small farmers from South Asia and other parts of the world use two wheel tractors as the main means of land preparation and other farm operations due to small farm and field size combined with an affordable price. These units have become very popular, and over 500,000 are manufactured annually worldwide. There are over 350,000 operating in Bangladesh alone. Two low cost and robust no-till seeders to suit two wheel tractors (12HP) have been developed at the Wheat Research Centre (WRC), Dinajpur, Bangladesh (with support from the Australian Centre for International Agricultural Research). This follows initial research and development work assisted by CIMMYT and Bangladesh Agricultural Research Institute from 1995 to 2004.

A. No till seed drill

This drill is structurally improved, lighter and more versatile than the original prototype. A fertiliser attachment has now been fitted, residue clearance is improved, and the seed drill is easily adjustable for tine layout, row spacing, and depth of seeding. Seed and fertiliser rates are easily adjusted and the machine can conveniently meter all seed sizes from maize to mustard. Press wheels have also been fitted. Attachment hitches for both Chinese made, as well as Thai made two wheel tractors are available.

B. Modified rotary tillage seed drill

This standard rotary tillage drill has been modified by the provision of a fertiliser attachment and an improved seed metering system. Seed placement has been enhanced by the incorporation of superior tine openers. Press wheels have also been fitted. It can be used as a 100% tillage implement, or as a strip tillage seed drill.

The no till seed drill has been intensively tested in farmer's fields in NW Bangladesh for wheat, maize, pulses and rice planting through moderate densities of cereal residues without plugging. Two wheel tractors can pull 4 tines in light soils and 3 tines in heavy soils. It has generally performed well. However, it has done a mediocre job in some hard setting clay soils.

The rotary tillage drill in either strip or full tillage mode has proved to be successful under practically all conditions in Bangladesh. This seed drill generally produces a satisfactory environment for crop establishment, with good seed placement and a fine tilth of soil, except under very wet conditions, when slot smearing by the tractor blades still occurs. Both implements are suitable for traditional or conservation farming systems. Seed placement and depth control in both machines is greatly improved, by the provision of superior tines and press wheels. Plant establishment has improved by 17-25% compared to zero press wheel treatments. The seeders are simple, light in weight, and could be fabricated by local farm machinery manufacturers. Costs are expected to be < US\$500 once production scales up.

Key words: Two wheel tractor, zero tillage, strip tillage, seed drill, rotary seed drill

Small farmers from South Asia, and other parts of the world use the power tiller (two wheel tractor) as the main means of traction for tillage and other farm operations. These units have become very popular, and over 500,000 are manufactured annually worldwide. There are over 350,000 operating in Bangladesh alone (Alam et al., 2007).

Many small farmers in South Asia are aware of the benefits of conservation farming systems including minimum and zero tillage. However they lack the means to put into action these farming systems due to the unavailability of a suitable seed drill.

The benefits of conservation farming systems are well known, and this system of farming has reached an advanced stage in many parts of the world. However the equipment to put this into practice has been principally designed for traditional four wheeled tractors and there are no commercially available conservation farming implements

(principally seed drills) for two wheel tractor. Late planting is one of the main constraints to successful crop production in this region. Saunders (1988) reported that a linear decline in yield of 1-1.5% per day was observed when wheat was planted after the end of November irrespective of short or medium duration varieties. In this case increased nitrogen applications can not compensate for the decline in yield from late planting. Zero tillage option increases the water and nutrient use efficiency by allowing timely planting and producing high yields (Hobbs, 2003).

Haque *et al* (2004) reported on the fabrication and testing of a power tiller operated zero tillage seed drill in Bangladesh. The development and testing of a prototype was conducted between 1999 and 2004. Results indicated a cost saving of 83-89% over the traditional tillage system, and a time saving of 10-15 days, when planting *rabi* crops into *aman* rice residue in October/November. The research was funded by USAID, FAO and carried out by WRC, CIMMYT Bangladesh. However funding ceased in 2004, and no commercially available implement has been produced.

Justice *et al* (2004) also reported on an associated project in Bangladesh where a commercially available Chinese Power Tiller Operated Seeder (PTOS) was modified for strip tillage. This also was used to plant *rabi* crops into *aman* rice residue in October/November. One pass full tillage was compared to strip tillage. In the strip tillage treatment, half of the tiller blades were removed and the seeds placed into the tilled strips. Field capacity of the seed drill was increased by 25%, fuel consumption was reduced by 20% and planting cost reduced by 8% compared to the full tillage treatment. Adoption of the power tiller operated rotary tillage seed drill has been more successful and 400 units were sold in Bangladesh between 2005 and 2007. However ongoing research into this planting system also ceased in 2004.

In 2006 the authors realised that the ongoing research and development of seed drills for two wheel tractor was effectively at a standstill. Also we realised that this technology, although developed for Bangladesh, could also be applied to other South Asian countries where two wheel tractors is the main farm traction unit (East India, Cambodia, Laos PDR, Vietnam, Indonesia, and Mainland China).

Materials and Methods

In mid 2007, application was made to the Australian Centre for International Agricultural Research (ACIAR) who agreed to fund a continuation of this research work. An original Wheat Research Centre (WRC) made zero till (ZT) drill, and a standard rotary drill were modified in Bangladesh in late 2007 at WRC, Dinajpur and field work with these units commenced in November 2007. In addition, A Chinese made (Dong Feng brand, 12Hp) two wheel tractor was imported into Australia in early 2008, along with a rotary drill. This tractor and seed drill was used as the test modules for further prototype seed drill fabrication. Improved examples of the two seed drill types were fabricated at Spring Ridge Engineering using local expertise. This experience has been acquired in the manufacture of larger zero tillage seed drills in Australia. They are as follows:

Tined Type Zero Till Drill. (Tool bar mounted)

This implement is essentially an improved model of the original tined type ZT drill as described by Haque *et al* (2004). A much improved three bar tool bar frame that is 1000mm. wide has been made up from 50mm x 4mm thick square tube. There are two side rails, of 75mm wide x 10mm thick x 825 mm long flat steel. Holes have been drilled in the side rails every 90mm. The tool bars can be fitted at various points to allow adjustable bar spacing. The resultant frame can be set up as a one bar, two bar, or three bar implement at bar spacings of up to 700mm.

Up to four tines can be fitted to the tool bar. The tines are made of 50mm x 12mm high tensile steel. Each tine is 700mm long, and is fitted with a non-detachable point (which is tungsten tipped) and a seed tube. Each tine is in a holding bracket and is clamped to the bar by 50mm square “U” bolts. Tines can be adjusted both vertically and laterally along the bars. Mounted 250mm diameter x 50mm wide press wheels are fitted to a 25mm axle at the rear of the implement. Press wheel spacing is adjustable, and the number of press wheels can be varied to suit the number of tines being used for sowing.

Dual two row bi-compartment boxes are fitted, with the front compartments for seed, and the rears for fertiliser. In order to ensure good seed drop, and allow good clearance for the tines and tool bar, the boxes are mounted either side of the handlebars of the tractor. Box position is adjustable vertically and laterally to allow for suitable fitting to different types of two wheel tractor. Fig.1 shows the two wheel tractor zero till drill.

The front box is fitted with Asian made dual system fluted roller seed meters. These meters can measure out seed of all sizes from maize to mustard at variable rates. A second set of fluted roller meters in the rear box. These meters deliver fertiliser also at variable rate as required. Toolbar frame also facilitated fixing different type of seed metering devices and other implements.

Drive to the seed and fertiliser boxes is by a chain drive, from the main drive wheel of the tractor intermediate shaft above the front bar and hitch. A clutch is fitted to the intermediate shaft. External chains then drive to the metering shafts.

Modification to Rotary Tillage Seed Drill

In the standard commercially available arrangement this Asian made seed drill is set up for one pass seeding with 100% rotary tillage. The seed box is set up above the tillage unit, and the seed delivered by tubes and lightweight soil openers to the soil immediately behind the tilled zone. A steel long roller then lightly firms the soil behind the seed drill. No fertiliser box is available.

The authors noted that seed positioning into the tilled soil behind the unit was poor. Some seeds were on the soil surface, some at intermediate positions in the tilled zone, and some were at the bottom of the tilled layer. Seed pressing was also poor. This setup may be satisfactory in optimum moist soils, or where the new crop is to be 'watered up' by irrigation, or where follow up rain to germinate the seeds is assured. However in dry soils, or *rabi* crop planting with no follow-up rain, seed placement is unsatisfactory.

Fertiliser application is by a separate operation, and fertiliser cannot be positioned in the seed row with the seed. The seed box was removed and an add-on tool bar, the width of the tiller (1200 mm.) was made up. This tool bar is also of 50mm x 50mm x 4mm square bar, with similar tines to the tined unit described earlier. The bar is positioned immediately above and behind the tiller. It is attached to the main frame of the tiller. Tine type openers are positioned so that all the seeds can be delivered to the bottom of the tilled layer, and into the untilled subsoil if required. Fig. 2 shows the rotary till drill. The steel roller was removed, and replaced by a 25mm axle with press wheels similar to the tined unit.



Figure 1. Two wheel tractor zero till drill



Figure 2. Two wheel tractor driven strip till drill

Seed and fertiliser boxes similar to the boxes used on the no till drill are fitted. Drive from the two wheel tractor axle, through an intermediate shaft is similar to the no till drill.

General Field Performance

A prototype of each of the Australian made ZT drill and the rotary drill modification were sent to Bangladesh in mid 2008. They are currently undergoing exhaustive evaluation behind a Chinese made (Dong Feng) two wheel tractor.

The ZT drill generally has excellent penetration when used for *rabi* planting in Bangladesh. The 12HP two wheel tractors will pull three tines in the sandy loam soils of NW Bangladesh under most conditions. It will also operate three tines in the clay soils of the Barind High Tract under ideal conditions. However in clay soils when the topsoil is dry and the moist soil layer is at 8-10cm. a 12HP tractor could not operate three tines, and there was excessive wheel slip and vibration.

Many of the clay soils of the Barind High Tract are poorly structured, and when the tined seed drill is operated, the topsoil breaks into large dry clods. Seed cover and pressing under these conditions is poor. There has also been some slot smearing in clay soils under wetter than ideal conditions.

The modified rotary drill has proved to be successful under practically all conditions in Bangladesh. This seed drill generally produces a satisfactory environment for crop establishment, with good seed placement at the bottom of the slots and a fine tilth of soil over the seeds, except under very wet conditions, when slot smearing by the tractor blades still occurs. It has been evaluated as a 100% tillage unit, or as a strip tillage machine. In strip tillage mode, strip widths from 20-50mm. have been tried, with the narrow strip system disturbing less soil. However depending on tractor blade shape and slot width, some disturbed soil from the strips is thrown into the inter-row spaces, and this sometimes results in insufficient cover for the sown seeds in the seed rows.

With both drills the addition of press wheels has been very positive. Loose disturbed soil is considerably compacted over the seeds in the planted rows. Increases in crop establishment rates have been observed. The two wheel tractor driven zero till drill has been evaluated by stress analysis and computer simulation and found to be structurally adequate for the tasks for which it was designed (Fraser, 2008).

Results and Discussion

Data from the last three years using the old version zero till drill, and earlier versions of the modified rotary tillage drill as well as the latest models have been summarised and are presented below. Field performance of the ZT drill for wheat, maize, mungbean establishment and comparisons with the standard tillage system in several farmers fields indicate that wheat can be established immediately after rice using the ZT planter. Data is shown in Table 1. Soil moisture content is the key factor for utilization of ZT machine. It is very difficult to operate drill over soil moisture 35% due to excessive tiller wheel slippage. Effective field capacity of the drill for wheat, maize and mungbean planting is shown. The effective field capacity for maize planting was higher than wheat planting due to wider sowing width in maize planting of 1.30 m (2 lines spacing 65 cm) but in wheat seeding it was 80cm. Fuel consumption figures are also shown. Field efficiency during maize planting 75% which was comparatively lower than wheat and mungbean planting due to more time loss with adjustments.

Table 1. Field performance of power tiller operated ZT planter

Sl.No.	Parameters	Wheat	Maize	Mungbean
1	Fuel consumption, lit./hr	1.20	1.2	1.2
2	Speed of operation, km/hr	2.50	2.5	2.5
3	Soil moisture content, %	24	27	25
4	Effective field capacity, ha/hr	0.15	0.20	0.20
5	Field efficiency, %	75	75	75

Crop performance of the ZT planter is shown in Table 2. Originally the persian wheel type seed metering device was used, but this has now been replaced with the dual system fluted roller meters of Chinese origin. The average widths of opening slots are shown. It was found that slower speed is comparatively better for seed placement into the slots. The adjustment of row spacing between two successive passes depends on operator skill and experiences. The width of slot during maize sowing was bigger due to the slightly deeper position of the opener. No till seed drill minimized turn around time 10-12 days between the two crops. Farmer can establish crops utilizing the residual soil moisture without extra land preparation. As no need pre irrigation, that means water, electricity, diesel fuel and valuable time to be saved.

Table 2. Crop performance on zero tillage

SlNo	Parameter	Wheat	Maize	Mungbean
1	Variety	Prodipl	NK 40	BARI Mug-6
2	Seed rate, kg/ha	120	20	20
3	Row to row spacing, cm	20	65	30
4	Depth of planting, cm	3-4	4-5	3-4
5	Width of opening slots, cm	2-3	2.5-3.5	2-3

Table 3 shows the variations of seeding depth and plant population with and without press wheels. Press wheels cover the seeding line which ensures superior seed/soil contact. In the zero press wheel seeded plot direct sunlight and bird damage also contributed to lower establishment. Similarly, in maize and mungbean plots, plant populations in press wheel plot were higher than without press wheel plots.

Table 3. Effect of press wheels on plant stand

Sl No.	Name of crop	Seed germination, %	Seeding depth, mm		Plant population/m ² (CV %)		
			(+) Press wheel	(-) Press wheel	(+) Press wheel	(-) Press wheel	% Increase
1	Wheat	95	30	20-25	265 (8)	206 (10)	22
2	Maize	90	40	25-40	12(7)	10 (11)	17
3	Mungbean	93	30	30	32(12)	24 (12)	25

The yield of wheat, mungbean and rice in ZT system and conventional method is presented in Table 4. The yield of wheat in zero till method varies from place to place due to land type, soil moisture and weed management. The average wheat yield was found 3.8 t/ha which was 21% higher than conventional method. Mungbean and maize yield were 0.9 t/ha and 8.4t/ha respectively. Maize yield was statistically similar with conventional method. Immediate after T. aman harvest, there was less weed burden and the land was suitable for zero till wheat cultivation. Mungbean was planted immediate after wheat harvest (April 1st week). Planting date should be within March for better crop yield and management. Generally farmers in this area do not grow mungbean conventionally, but plenty of wheat land remains fallow up to T. aman planting June –July and a mungbean cop can conveniently be planted by ZT methods. It was found that BARI mung-6 performed well within this fallow period. It can be harvested within 60-63 days. Last three years demonstration, farmers reported that yield of Aman rice increased average 10-15% over non mungbean planted field. There was a great potential to fit mungeban in rice-wheat cropping system reducing the turn around time. It was also critically observed that zero till wheat was less lodge compare to conventional planted wheat. It was due to not much loose soil as conventional till soil. Three crops can be fitted within a year utilizing the efficient performance of the drill.

Table 4. Comparison of yield between zero tillage and conventional method

Sl No.	Planting system	Yield (t/ha) (CV%)		
		Wheat	Mungbean	Maize
1	Zero tillage system	3.8 (12)	0.90 (13)	8.4(10)
2	Conventional method	3.0 (14)	0.55 (11)	7.6 (14)

Planting cost of wheat, mungbean and maize in zero till with conventional method were presented in Table 5. Planting cost of wheat, mungbean and maize in zero till system were Tk. 1951.27, Tk.1576 and Tk.1576.0/ha, respectively. Similarly wheat and maize planting costs were Tk.3740.0 and Tk.7250.0/ha respectively. The planting cost of wheat and maize in zero tillage planters were 48% and 78% less than that of conventional planting method. The cause of variation of planting cost in different crops was different effective field capacity during operation.

Table 5. Comparison of cost (1US\$=Tk.69.0) of planting by zero tillage and conventional system

Sl No.	Planting system	Cost of planting (Tk./ha)		
		Wheat	Mungbean	Maize
1	Zero tillage system	1951.0	1576.0	1576.0
2	Conventional method	3740.0	3740.0	7250.0

Farmers are getting more interest using no till drill considering less cost involvement and less effort on seed sowing.

Break-even use of the zero till drill was shown in Fig.3 and it was calculated on the basis of fixed cost and variable cost of the drill considering purchase price, interest on investment, and machine life according to Hunt (1995). It was observed that cost per hectare decreased with the increasing of land area use annually. Break even use of zero till drill was found 6.5 ha which indicated that it was the point where no loss no profit. An owner must plan for profitable use of the drill over 6.5 ha land annually.

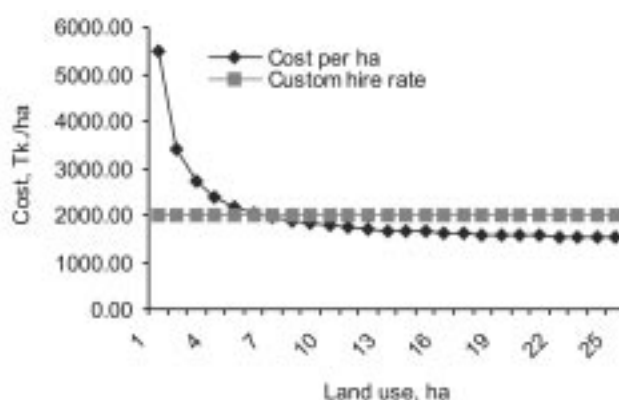


Figure 3. Break even point of zero till drill

Conclusions

The authors consider that these two seed drills have considerable potential to greatly increase productivity in South Asia, and other countries of the world where the two wheel tractor is the main traction unit in farming.

The main task now is to promote this technology and have these drills readily available to farmers at an affordable price. The zero till drill can be readily made from local components in most workshops. Most of the steel for fabrication is simple in design, and tines can be made from old automotive leaf springs. The only specialised items required are the seed meters, which sourced at an inexpensive price from a Chinese manufacturer or local promoter.

The modification to the rotary tillage drill is one which we believe should be seriously considered by the Asian manufacturers of this unit.

Further Work

Zero Till Drill

Although the power tiller ZT seed drill generally operates well, there are avenues for further research that could be contemplated. These include:

- Varying press wheel materials, weight, and profiles to suit different soil types and conditions.
- Different point types on the tines to suit different soil types and cultural operations. (This implement can also be set up as an inter-row cultivator)
- Design and fabrication of a mounted boom spray for power tiller using the seed drill frame.
- The design and fabrication of a small land leveller/road grader for two wheel tractor.

Strip Till Drill

This drill, both in 100% tillage and strip tillage modes is more suited to clay soils which are hard and dry on the surface. The action of the rotary blades pulverises the soil and clods, and there are more small aggregates available in the seed zone for better seed cover and pressing.

- However depending on tractor blade shape and position, some soil is thrown out of the tilled slots and into the inter-row spaces and this can result in insufficient soil being available for adequate seed cover. Further work on the development of shielding to alleviate this problem has commenced.
- Tractor blade shape and seed position can also affect vibration throughout the whole machine as well as the overall quality of the seeding operation. Re-arrangement of blade position and number as described by Lee *et al* (2003) could be a fruitful area of further development of this seed drill.
- In the author's opinion, both seed drills also have potential for direct seeding of rice at the beginning of the monsoon (*kharif*) season. This could be the subject of further work.

- Both seed drills, with little modification, can be used in bed planting systems.
- The disc opener options have not yet been tested in Asia. (However they may be unaffordable to most small farmers).
- One each of the tined drill prototype has also been sent to Cambodia and Lao PDR. These are being evaluated behind a Thai built (Siam Kubota) two wheel tractor. A rotary tillage option is not readily available for Thai built two wheel tractor and thus the strip tillage unit is not being considered in these countries.

Acknowledgements

The authors gratefully acknowledge the support of the Australian Centre for International Agricultural Research (ACIAR) who has funded the work.. The authors also acknowledge the contribution of Dr. Craig Meisner, Dr. Peter Hobbs, Mr. Scott Justice and R.Gupta who devised the original concepts and did the original development work.

References

- Alam, M.M.; M.A.Satter; M.O. Faruque; M.S.Hasan and Chowdhury M.G.R..2007. Manufacturing of agricultural machinery: It's problems, prospects and quality assurance. Proceedings of the national workshop on strengthening agricultural mechanization: policies and implementation strategies in Bangladesh held at Dhaka on 11 June 2007.
- Fraser M.J. 2008. Development of a No-till toolbar for a two wheeled power tiller. Bachelor of Engineering project thesis. Univ. of Southern Qld. Toowoomba, Australia.
- Haque E.M., Meisner C.A., Hossain I., Justice C., Sayre K. 2004. Two-Wheel Tractor Operated Seed Drill: A Viable Crop Establishment and Resource Conservation Option. *Proc.Int. Conf. Beijing Sponsored by CIGR, CSAM and CSAE Beijing, China 11- 14 October 2004.*
- Hobbs,P. 2003. Problems addressed by reduced and zero-tillage and bed planting. Addressing resource conservation issues in Rice-Wheat systems of South Asia. A resource book.pp113-114.
- Hunt, D. 1995.Farm Power and Machinery Management . Cost Determination. 9th Edition, Iowa State University Press, America..
- Justice, S., Haque E.M., Meisner C.A., Hossain I., Ganesh Sah, Tripathi, J, Rashid, M.H. Amin, M.R.. 2004.Giving South Asia Farmers a Choice: A Single Drill for Reduced and Strip Till Crops for 2-Wheel Tractors", *Proc.Int. Conf. Beijing Sponsored by CIGR, CSAM and CSAE Beijing, China 11- 14 October 2004.*
- Lee, K. S., Park S. H., Park W.Y., and Lee C. S. 2003. Strip tillage characteristics of rotary tiller blades for use in a dry land direct rice seeder *Soil and Tillage Research 71 (1)* pp 25-32.
- Saunders, D.A.1988. Crop management research: Summery of results, Monograph No.5: Wheat Research Centre, Dinajpur, Bangladesh.

Research and Development of Light No-till Seeders in China

Li Hongwen, Wang Qingjie, Wang Xiaoyan, He Jin, Gao Huanwen, Li Wenying

China Agricultural University, Beijing, 100083, China

(Email: lhwen@cau.edu.cn)

The adoption of conservation tillage in China, particularly in dry-land farming areas of Northern China, has significant resource, environmental and economic benefits. However, no-tillage seeding in heavy residue cover field is the main limiting factor for the application and extension of conservation tillage in China. Some foreign no-till seeders have strong anti-blockage ability, but they are heavy (765-1130kg/m) and expensive. From 1992, we started the research on lighter and cheaper no-till seeder. These no-tillage seeders with 316-500kg/m of unit weight (50% of foreign seeders) are suitable for Chinese small and middle size tractor (500-650kg/m), while the prices are only 10-15% of foreign no-tillage wheat seeders.

Key words: No-till Seeders, Light-size, Active Anti-blockage, Passive Anti-blockage

Wheat and corn no-till seeders play an important role in the application and extension of conservation tillage. However, due to the unsound implements, especially undeveloped no-till seeders, although we've started conservation tillage research since 1960s, it hasn't yet been widely applied till 1990s. Admittedly, oversea no-till seeders are qualified enough and backed with complete development and large application, but they could only match with large-sized tractors and travel on massive fields. Besides, heavy weight and high price can also lead to the incompatibility with restrictions of mini-sized fields, small tractors and impoverished farmers in China. Therefore, we have to self-develop light no-till seeders particularly suitable to Chinese requirements [1].

The main task of designing no-till seeders is to handle crop straw, namely anti-blockage. Actually, compared with heavy seeders, light seeders are less likely to pass through residues, so when compounded with the significantly increased residues and large noticeable straw which commonly happen in China, the demanding level of anti-blockage of light seeders has been consequently further heightened [2].

Our research team-Conservation Tillage Research Centre (CTRC), Ministry of Agriculture (MOA) first attempted to design light no-till seeder in 1992, with two distinct options: active anti-blockage and passive anti-blockage. Generally, the passive anti-blockage method is used on the field of single-crop a year with relatively small yield and less coverage. By referring to the foreign advanced passive anti-blocking techniques, multi-beams structure and anti-blocking components have been specially developed and strengthened in order to get high trash flow. As a result, more than 10 years efforts have brought out a series of light no-till seeders with passive anti-blocking techniques, possessing advantages of 60% weight lighter, 90% price lower and reasonable anti-blockage ability and thus popularly adopted in single-crop one year regions. While in the double-crop one year fields, due to its strong capability of handling corn stubble, active anti-blocking was chosen. After 16 years research, apart from the strip rotary hoe mini-till seeder and strip chop no-till seeder, we've also achieved with leading technology on wheat no-till seeder through heavy corn residues, which is superior in weight of 50% lighter and expense of 80% cheaper and thereby has formed the series of light no-till seeder in Chinese context.

1. Why to Develop Light No-till Seeder in China?

According to oversea machinery patterns that huge equipment couple with powerful tractors and massive fields, generally in that case blockage is solved by strong cutting forces from heavy weight or lessened by plenty space between openers. Usually, foreign no-till seeders at least weigh about 800-1100 kg/m (Table 1).

Meanwhile, as listed in Table2, light tractor (300-600 kg/m) and small- field in China could only allow middle-sized implements to match with and practice on. So it's impossible for China-produced tractor to lift up such heavy seeder as 800-1100 kg/m even if it is adapted to that tractor's width. The only solution appears to lighten no-till seeder and independently develop small-size no-till seeder with equivalent weight of 300-600 kg/m.

Resulting from 20 years exertion, as illustrated in Table 3, an array of passive and active anti-blocking no-till seeders have been developed, weighing 150-250 kg/m and 300-500 kg/m, respectively, and could be well matched with domestic middle to small-sized tractors.

Table 1. Unit Weight of Foreign No-till Seeders

Country	Type/Opener	Overall Weight/kg	Rows and Spacing/cm	Weight per Meter/ kg.m ⁻¹
USA	Great Plains1500/ Disc	3577	22 19	852
	John Deere 750/ Disc	2917	16 19	958
	John Deere 1590/ Disc	2917	16 19	959
Canada	Morris 7000/ Shovel	11191	52 19	1131
	Morris 7300/ Shovel	13409	64 19	1100
Italy	GASPARDO/ Disc	4090	22 18	1032

Table 2. Unit Left Force of Domestic middle /Small Tractors

Tractor Type	Power/ kw	Lifting Force/kg	Width/mm	Lifting Force per Meter/ kg.m ⁻¹
X700	51.5	1570	1930	814
600	44	1071	1798	595
550	40.5	918	1715	535
450	33.1	816	1730	471
350	25.7	734	1634	449
250	18.4	408	1205	338
180	13.24	336	1205	279

Table 3. The Unit Weight of Chinese Light No-till Seeders

Manufactory	Type / Opener	Overall Weight / kg	Rows and Spacing/cm	Weight per Meter/kg.m ⁻¹	Demanded Power/kw
Nonghaha, Hebei	*2BMFS-5/10 / Shovel	630	10*19	331	44.1
	2BMF-6C / Shovel	210	6*20	175	13.2
Xinjiang, Shanxi	2BMF-11 / Shovel	450	11*20	205	44.1
	2BMF-2 / Disc	175	2*60	146	11
Wafangdian, Liaoning	2BQM-6 / Disc	900	6*60	250	44.1
Haofeng, Henan	*2BMTF-12 / Disc	1200	12*20	500	48
Agro-machinery Station, Liaoning	*2BML-2 / Shovel	276	2*60	137	22.3
Nonghaha, Hebei	*2BMXP-12 / Shovel	710	12*18	328	44.1

Note: * refers to active anti-blocking no-till seeder

2. Light Passive Anti-blocking No-till Seeders

As mentioned above, because of the relatively small yield and low coverage of residues, passive anti-blocking no-till seeder is applicable to single-crop a year region, but owing to its light weight, stubbles are unlikely to be effectively cut off only by discs, so alternative anti-blocking methods have to be attempted and developed.

2.1 Light Passive Anti-blocking Wheat No-till Seeder

As shown in Fig. 1, light passive anti-blocking wheat no-till seeder normally enhances trash flow by saving an opener with seeder-fertilizer-combined but vertically separated openers, eliminating press-wheels with self-cover opening shovel to enlarge space, and adopting multi-beams structure and front-rear arranged openers to maximize trash flowing clearance and avoid stubbles blockage.

2.2 Light Passive Anti-blocking Corn No-till Seeder

Dual dentate disks and front-mounted removers, which will be described in following text, are yet the two major passive anti-blocking manners in China.

2.2.1 Light Passive Anti-blocking Corn No-till Seeder with Dual Dentate Disks

With the accordance of Fig. 2, the main anti-blocking device of this machine is the disk coulter combined with dual dentate disks. When working, firstly, disk coulter will cut the residue, and then the following dual dentate disks



Figure 1. Multi-beams structure and maximized trash flowing clearance

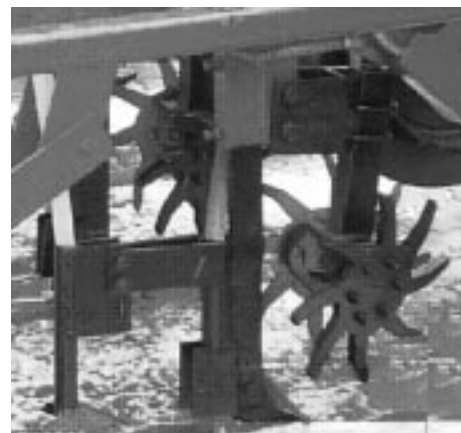


Figure 2. Light passive anti-blocking corn no-till seeder with dual dentate disks

will remove residues from seeding rows, so the narrow-point opener can easily complete no-till seeding. This dual dentate disk method is especially applicable to no-till corn seeding in single-crop one year region.

2.2.2 Light Passive Anti-blocking Corn No-till Seeder with Front-mounted Removers

Those front-mounted and vertical-set removers (see Fig. 3) are capable of correspondingly moving via bearings when encountering with residues or stubbles and self-propelled rotating along with the off-set force coming from the friction between residues and stubbles, in that sense, checking trashes by conducting them to move off removers and thus deviate from opening area.

3. Light Active Anti-blocking No-till Seeder

The main idea of light active anti-blocking wheat no-till seeder is to avoid blockage by cutting straws with actively powered cutting device. Since 2000, China Agricultural University joined with Linfen Agricultural Machinery Bureau, Shanxi Province^[3], North-western Agricultural and Forest University^[4], Hebei Agricultural University^[5] has researched and developed several active anti-blocking no-till seeders, which could not only meet the strict requirement of high yield and also appreciably improve seeding quality.

3.1 Light Active Anti-blocking Wheat No-till Seeder

3.1.1 Strip Rotary Hoe Wheat Mini-till^[3] [6]

The strip rotary hoe wheat mini-till seeder mainly use power-driven rotary blades to loose seedbed, cut off stalks and break roots only in the sector of seeding area, so that the openers can pass through easily. As an example cited with Fig. 4, 2BMFS-5/10 strip rotary hoe wheat mini-till seeder, produced by Nonghaha Manufactory, Hebei Province, its main parameters are: rotary width 12 cm, no-till depth 10cm, 2 rows of wheat, 1 row of fertilizer, non-soil-disturbed width 26 cm and disturbance rate 32%. This type of seeder could practice fairly well under different amounts or levels of coverage with 5-10% increase in emergence rate and yield. But its deficiency in productivity and slightly immoderate soil disturbance can form a constraint on its extension progressing.

3.1.2 Strip Chop Wheat No-till^[7] [8]

To reduce soil disturbance and power consumption, a strip chop no-till seeder named 2BMDF-12 strip chop wheat no-till seeder, has been developed. As shown in Fig. 5, the power driven chop blades beside the opener cut off or push away the stalks hanging on the opener and crush the roots. Disk opener, following the tine opener, pushes away chopped stalks or grass to the sides, and then evenly puts seeds into the soil. Moreover, because the driven blades do not touch the ground, reduced soil disturbance and power consumption and increased seed depths uniformity could be achieved. This seeder is proved to have mild soil disturbance rate, even seeding quality and satisfactory emergence rate, and suitable to those areas where economy has been developed or environment is highly respected.

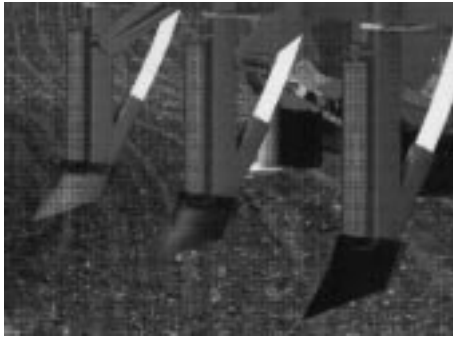


Figure 3. Light passive anti-blocking corn no-till seeder with front-mounted removers



Figure 4. 2BMFS-5/10 strip rotary hoe wheat mini-till seeder



Figure 5. 2BMDF-12 strip chop wheat no-till seeder



Figure 6. oblique driven disc wheat no-till

3.1.3 Oblique Driven Disc Wheat No-till^[9]

The key part in this oblique driven disc wheat no-till seeder (Fig.7) is that the disc is not set vertical to the shaft, but at a 5 degree angle. By using disk swaying to push away 80% stalks on the seedbed, the disc only need to cut off the remained 20%. In that way, blockage and energy consumption are considerably decreased. Furthermore, though the vertical disk can only open a 1cm wide furrow, the following oblique opener could extrude this furrow to 45 or 6 cm -wide, hence- let the 4 cm--diameter seed tube pass through.

In order to control the problems of obvious vibration, high resistance force and heavy disk wear, appropriate rotating speeds are selected so as to work properly well under different yield or covering conditions. Indicated by the results tested from the field of Shenze County in Hebei Province which was covered with chopped corn residues, when the stalks on the seedbed were 3.06kg/m², 0.58kg/m² before and after planting, 80% stalks were pushed away to the seedbed sides and the roots cut-off rate could reach 98%. In this case, anti-blockage could be significantly achieved.

Advantaged with its simplified light and cheap configuration, this oblique driven disc wheat no-till seeder has promising potential of being widespread extended in China. However, the disc is vulnerably being partially worn over time, so it should be reversible to use the other side if needed. Besides, exceeding amount of fertilizer sometimes tend to cause the consequence of burning seeds.

3.2 Light Active Anti-blocking Corn Rigid-till Seeders

3.2.1 Powered Disc Corn Rigid-till Seeder^[10]

Powered disc corn rigid-till seeder (Fig. 7) is mainly designed for ridge tillage in northeast China, to actively anti-block via components consisted of serrated disc, driving shaft and depth-control wheels. Specifically, the serrated disc is firmly fixed with driving shaft and rotating correspondingly with it, vertically to the ground and



Figure 7. Powered disc corn rigid-till seeder



Figure 8. Powered coulters corn rigid-till seeder

paralleled with heading direction. At the same time, by bearings depth-control wheels are semi-connected with driving shaft and are able to every possible spatial rotation. During operation, serrated disc, driven by tractor, cuts corn roots and residues, and open furrows, and then the following narrow-point opener can further open the furrows and produce a comfortable seedbed for the seeds without the occurrence of residue blocking.

Commonly, depth-control wheels travel on the rigids, and, with the help of ground resistance, they could rotate accordingly and uniformly guarantee the cutting strength of serrated discs and seeding depth of openers. In addition, the uneven suburbs of depth-control wheels could interact with rigid side-face and help to prevent machinery from slipping into rigid furrows.

3.2.2 Powered Coulters Corn Rigid-till Seeder^[11]

With the objective of merely cutting soil not turning over soil in the consideration of preserving soil sustainability, a powered coulters corn rigid-till seeder has been developed by mutual efforts of China Agricultural University and Fuxin Agricultural Machinery Bureau, Liaoning Province. As presented in Fig. 8, driving power is originally output from tractor to gearing box, and then transferred to roller chain which finally propels the rotating coulters that is set right on the front of opener. Opener and coulters are supposed to be so closely installed that rotating coulters is possible to swing away disturbing stalks and clear blockage as long as they are stocked on the opener handle. Under the help of this front-mounted and powered coulters which could pre-open a 5-6 cm wide furrow before the arrival of seeding openers, the real opening conditions are significantly improved, thereby press-wheel slippage and seeding depth variability could also be reduced.

3.2.3 Cutting and Digging Corn No-till Seeder^[12]

Briefly, the principles of cutting and digging corn no-till seeder (Fig. 9) are to motivate cutting and digging devices which are fixed on the front of opener. Because these devices only need to cut corn root and dig it out individually with no chopping, lower rotating rates demand less energy and thus conserve more. The cutting device previously slices the bed and breaks corn roots beneath it, and then keeping acting to the curved surface, digging device will follow the crack to unearth the roots so that the seeds could be comfortably planted in soft bed soils. Additionally, stalk eliminating, seeding and fertilizing are designed to be completed over a single bout.

4. Experimental Tests Results and Discussions of Wheat No-till Seeders

During the years from 2004 to 2006, comparative experimental tests of 2BMDF-12 strip chop wheat no-till seeder; 2BMFS-5/10 strip rotary hoe wheat mini-till seeder and John Deere-1590 disc no-till seeder were carried out in Daxing District, Beijing, with outcomes elaborated as follows^[13]:

1. Trash flow: 2BMDF-12 strip chop wheat no-till seeder and 2BMFS-5/10 strip rotary hoe wheat mini-till seeder performed less pleasantly than John Deere-1590 disc no-till seeder in terms of soil disturbance rate and residue retaining rate. However, in the double-crop a year region which is featured with massive residues and where wheat seedless are usually able to shortly catch up, foregoing slight unsatisfactory performance could hardly affect the process of soil and water conservation.



Figure 9. Cutting and digging corn no-till seeder

2. Seedbed and emergence: 2BMDF-12 strip chop wheat no-till seeder and 2BMFS-5/10 strip rotary hoe wheat mini-till seeder demonstrated encouragingly performance relative to John Deere-1590 disc no-till seeder, with higher emergence rate of 9% and 6%, respectively, heavier wheatears of 2% and 6%, and greater output of 3% and 5% as well. It's reasonable to attribute these satisfactory outcomes to the less coverage of seedbed and promising emergence rate in the treatment of active anti-blocking devices which will develop a soft and favorable under-earth environment for crop roots.
3. Fuel consumption: on the aspect of fuel consumption, 2BMDF-12 strip chop wheat no-till seeder and 2BMFS-5/10 strip rotary hoe wheat mini-till seeder individually demand 15% and 35% more than John Deere-1590 disc no-till seeder, resulting in 10 yuan·ha⁻¹ and 15 yuan 10 yuan·ha⁻¹ extra fuel cost to the later treatment. But considering the 160 yuan·ha⁻¹ and 180 yuan·ha⁻¹ less depreciation and 180 yuan·ha⁻¹ and 300 yuan·ha⁻¹ higher income, light active anti-blocking no-till seeders contributed more financial benefits than John Deere-1590 disc no-till seeder, though on the respect of resource and environment, their advantages tended to the opposite direction. Therefore, economically, non-soil-disturbance anti-blocking device or oblique driven disc appeared to be the leading pattern in the future.

5. Experimental tests results and discussions of corn rigid-till seeders

Different treatments of powered disc corn rigid-till seeder and BAFFOLA corn rigid-till seeder were layout in Sujiatun District of Liaoning Province, producing results as below:

1. Trash flow: as to trash flow ability, powered disc corn rigid-till seeder performed better than BAFFOLA corn rigid-till seeder, but with regard to soil disturbance rate and residues retaining rate, the two treatments displayed no significant differences.
2. Fuel consumption: powered disc corn rigid-till seeder consumed 1.5% less fuel than BAFFOLA corn rigid-till seeder, which could be possibly caused from the evidently distinguishing weights.
3. Seedbed and emergence: powered disc corn rigid-till seeder represented roughly similar emergence rate with BAFFOLA corn rigid-till seeder, albeit producing 4.5% more grain. Less soil disturbance could be a likely causal factor to the effects of rigid-form maintaining and soil water reservation.

6. Conclusion

Rather than following the steps of foreign heavy-sized no-till seeders, China has developed a series of light no-till seeders in its own domestic context and they have been proved, based on a great many practices, to be of vital importance in widespread extension. Regarding to the key technique of anti-blocking, let passive anti-blocking device thoroughly exert their advantages in middle or low productivity regions; while when coming up with the confliction between light weight and pressing demand of anti-blocking ability in high producing area, active anti-blocking technique has been creatively explored. In that, two levels of no-till seeders which are respectively light series of 100-250 kg/m weight, middle or small tractor powered and 2000-7000 yuan/m cost and the other series of

316-500 kg/m, large tractor and 4000-10000 yuan/m, cope with two levels of grain producing capabilities. Thanks to the proper anti-blocking solutions, seeding qualities, crop yield and operation input all have been improved, which will also be much helpful to widen popularity no-till seeders and facilitate their extension progress. Till 2007, throughout the whole country there have been over 80 thousand sets of no-till seeders and 2 million more hectore area setting out to apply conservation tillage, among which active anti-blocking no-till seeders were more than 20 sets and the area of double-crop a year and conservation tillage a whole year occupied more than 600 thousand hectore. China is the first country in the world who leads her conservation tillage extension progress onto all-round stage with light implements.

References

1. Gao Huanwen, Li Wenying, Li Hongwen. Conservation tillage technology with Chinese characteristics [J]. Transactions of the Chinese Society of Agricultural Engineering, 2003,19(3),1-4;
2. Zhou Xingxiang, Gao Huanwen, Li Xiaofeng. Experimental Study on Conservation Tillage System in Areas of Two Crops a Year in North China Plain[J]. Transactions of the Chinese Society of Agricultural Engineering, 2001,17(6),81-84;
3. Chai Yuejin. Test and Research on Cingulum Zero Tillage Covering Seeding-machine[J]. Chinese Agriculture Mechanization, 2004,(2),39-40;
4. Xue Huilan; Xue Shaoping; Yang Qing; Yao Wansheng; Lei Shuwu Implementation of combined work of straw crushed for mulching and seeding with fertilizer and design of the machine[J]. Transactions of The Chinese Society of Agricultural Engineering, 2003,19(3),104-107;
5. Zheng Dong xu, Jiang Hai yong, Li Bing, Li Hong wen, Zhang Jin guo. Study on the no-tillage mulch planter for wheat under the bestrow of the whole mealie straw[J]. Journal of Agricultural University of Hebei, 2003,S1,285-287;
6. Jiang Jinlin,Gao Huanwen. Corn rootstalk and residue cutting mechanism of no-tillage planter[J]. Transactions of The Chinese Society of Agricultural Engineering, 2004,20(2),129-131;
7. Wu Ziyue, Gao Huanwen, Zhang Jinguo. Study on Cutting Velocity and Power Requirement in a Maize Stalk Chopping Process[J]. Transactions of The Chinese Society of Agricultural Machinery2001,32(2),38-41;
8. Yao Zonglu, Li Hongwen, Gao Huanwen, Wang Xiaoyan, Zhang Xuemin. Experiment on No-till Wheat Planter under the Bestrow of the Maize Stubble in Double Cropping Area [J]. Transactions of the Chinese Society for Agricultural Machinery, 2007(8),57-61;
9. Ma Hongliang, Gao Huanwen, Li Hongwen, Wei Shuyan. Design and Experiment of No-till Planter with Oblique Driven Disc[J]. Transactions of the Chinese Society for Agricultural Machinery, 2006,37(5) ,45-47;
10. Wang Qingjie, He Jin, Yao Zonglu, Li Hongwen, Li Wenying, Zhang Xuemin. Design and Experiment on Powered Disc No-tillage Planter for Ridge-tillage[J]. Transactions of the Chinese Society for Agricultural Machinery, 2008,39(6) ,68-72;
11. Xu Dijuan, Li Wenying, Wang Qingjie. Development of 2BML-2(Z) type no-till maize seeder in ridge-field [J.] Journal of China Agricultural University, 2006, 11 (3),75 -78;
12. Jiang Jinlin, Gao Huanwen. Corn rootstalk and residue cutting mechanism of no-tillage planter [J]. Transactions of The Chinese Society of Agricultural Engineering, 2004.20(2),129-131.
13. Wei Yanfu, Gao Huanwen, Li Hongwen. Experiment and analyses of the adaptabilities of three wheat no-tillage drills on corn stubble in the areas with two ripe crops a year [J]. Transactions of The Chinese Society of Agricultural Engineering, 2005, 21(1), 97-101.

Avoiding Soil Compaction in CA: Controlled Traffic Systems for Mechanized CA and their Effect on Green House Gas Balances

J.N. Tullberg and CTF Solutions
Brisbane, Australia
(Email: jeff@ctfsolutions.com.au)

Wheel and tyre combinations used on cropping land cannot function without compacting soil to increase its strength. If we spread this impact randomly over fields it is highly visible, damaging, and an ongoing incentive to tillage. Alternatively, we can use controlled traffic and confine damage to permanent traffic lanes, where it will improve trafficability and traction. This requires accurate guidance, and compatible machine track, tyre and operating widths.

Guidance can be provided at low cost by furrows in more intensive Permanent Raised Bed (PRB), or at moderate cost by RTK-GPS in more extensive Controlled Traffic Farming (CTF). Research on both systems has demonstrated major productivity/sustainability benefits, and farmer adoption has shown that these occur on-farm, in practice. Research and adoption of CTF occurred primarily in extensive farming in Australia, in contrast to PRB which was focused largely on more intensive environments, often in low-resource areas.

PRB and CTF are really variants of the same fundamental CA ideas. With controlled traffic:

- Energy requirements of field operations are reduced by ~ 50%.
- Greater infiltration and plant available water capacity increase water use efficiency.
- Hard, compacted permanent wheel lanes improve the timeliness of all operations.
- Material and time input per unit production is reduced.
- Crop yields are greater and cropping frequency increases in some environments.
- Soil erosion and waterway pollution is reduced.
- Soil carbon and greenhouse gas balances can be significantly improved.

The paper will provide evidence of each of these, with greater detail on greenhouse gas impacts, particularly fossil energy use (tractor fuel and equipment manufacture; herbicide and fertiliser manufacture) and soil emissions (soil structure/hydrology impacts on nitrous oxide and methane production, soil organic matter).

The paper will demonstrate that significant improvements are relatively easy to achieve when traffic is controlled, but a number of cropping system changes are crucial to this process. Overwhelmingly, the measures required to improve environmental outcomes are identical to those required for improved productivity and economics. Anecdotal data suggests a positive social impact.

The underlying idea of Conservation Agriculture is care for the soil resource. Controlling traffic is a fundamental part of this care for all soils known to the author

For most practical purposes, mechanised agriculture depends on wheels — usually pneumatic tyred. Wheels supporting relatively small loads (<1t) cause significant structural damage and compromise productivity and sustainability in most of soil types. Controlling traffic, whether by the use of permanent raised beds or “on the flat” avoids this damage and provides a range of benefits, direct and indirect.

To date, the major focus of conservation agriculture research and extension has been on the reducing or eliminating tillage. In Australia this has often involved the replacement of tillage with herbicide weed control, with other system changes occurring only slowly. More recently many farmers have found that zero tillage works much better with controlled traffic, and controlled traffic farming provides more options for system change by improving timeliness and increasing water use efficiency.

This paper attempts to provide a concise comparison and evaluation of the impact of these systems on greenhouse gas emissions from cropping. The objective is to compare systems with and without soil disturbance, and systems with and without compaction and disturbance. Real systems are considered here where, (for instance) “zero tillage” is compromised by occasional requirements to till out harvester ruts, and “zero compaction” is compromised by the need to maintain 10 — 20% of field area as permanent traffic lanes.

Data given here is relevant to three typical systems (defined below) used in extensive semi-arid dryland grain production in Australia, with appropriate equipment and herbicide data. Despite the large differences in scale and level of technology, much of this approach would apply equally well to dryland grain production in northern China. Permanent raised beds (PRB) are a very different situation, but most of the same ideas apply. The systems are:

Stubble mulching, where traditional tillage has been reduced to 1-3 minimum-inversion tine or sweep operations, with 1-3 herbicide operations. Soil is tilled and wheeled, with some residue retained. (probably most common system in Australia).

Zero tillage, with no regular soil disturbance except at planting and full herbicide weed control. Occasional chisel tillage or subsoiling is required to relieve soil compaction, or deal with surface ruts after wet harvests. Soil is wheeled but not tilled, most residue retained. (probably less common than stubble mulching).

Controlled traffic farming, (CTF or PRB) with all heavy wheels restricted to permanent lanes and oriented to provide drainage and safe disposal of surface water. CTF overcomes the problems of wheel traffic in the cropping area, but requires accurate guidance and equipment systems with compatible working, track and tyre widths. No tillage, maximum residue, but 10-20% area is wheeled (this is the least common practice, but growing rapidly in Australia).

The relative impact of stubble mulch (tilled wheeled), zero tillage wheeled and CTF (non-tilled non-wheeled) on infiltration rates, plant available water capacity and earthworm numbers in a clay vertosol is illustrated in figure 1, a), b), and c). Figure 1 d) illustrates the effect of controlling traffic on the tractor power required for planting, where the lower section of the bars illustrates the draft effect of disturbing soil compacted by random traffic (v. non-compacted soil), and the upper section the tractive efficiency improvement when operating on permanent traffic lanes. The centre bar (tractor only) represents the situation where the grain harvester is not included in the controlled traffic system.

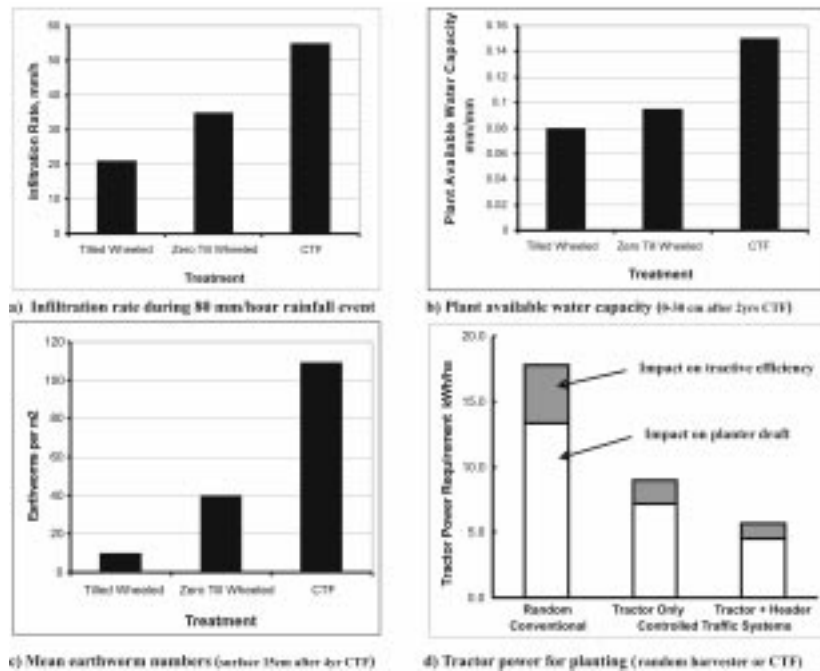


Figure 1. Tillage and wheeling effects on Infiltration, PAWC, Soil Health and Tractor Power

This data — discussed in more detail in Tullberg et al. (2007) — explains why greater water use efficiency, and greater crop yields can be achieved in controlled traffic zero tillage systems (CTF or PRB), while simultaneously reducing fuel and tractor power requirements. For most practical purposes, CTF systems don't waste power compacting soil under tractor tyres, and also avoid the additional power wasted by non-CTF systems in re-loosening soil, (achieving only partial soil amelioration over a limited depth range)

Grain yields from these long-term, side-by-side plot trials precisely reflected the increase in water available to the crop. In side-by-side comparisons, all treatments have to operate at the timescale of the slowest treatment (i.e. stubble mulch), so on-farm yield improvements have been much greater than the 15% effect demonstrated in these trials.

Environmental Effects — Soil, Water

The beneficial environmental effects of CTF or PRB are well accepted and have been quantified in a number of environments (e.g. Wang et al. 2008). Greater infiltration and plant available water capacity reduces runoff and erosion while supporting greater cropping frequency. Reduced runoff obviously reduces soil erosion and waterway pollution by soil, fertiliser and agricultural chemicals. Reduced tractor power requirement and fuel use is also a significant environmental benefit.

The system impact of CTF can be extremely important. Harvesting grain crops high, so minimal residue can be well spread, with no harvester traffic to obstruct re-planting, has allowed cropping frequency to increase. With precision (2 cm) autosteer it is also not difficult to plant interrow. This has allowed unsophisticated planters to operate effectively in heavy residue, placing seeds in a precise relationship with the previous crop, avoiding disturbance of the standing stubble and achieving additional disease control benefits.

Timeliness and damage-free access to growing crops (with system layout for proper drainage) is the other major system impact, allowing efficient in-crop application of fertiliser or agricultural chemicals. CTF has allowed some Australian farmers to claim “doubled production with reduced costs”, including fertiliser and herbicide costs (e.g. Ruwolt 2008). These claims have not been examined in detail, but a large-scale survey of CTF farmers has demonstrated an average ~70% improvement in gross margin, with farmers attributing the effect equally to improved soil conditions and CTF system effects.

As with all forms of conservation agriculture, uptake of CTF has been relatively slow. No precise information is available but it has been estimated that less than 5% of Australian farmers are using full CTF (all heavy wheels on permanent traffic lanes). Another 20% are probably in some partial controlled traffic system, and another 30% might be in zero tillage.,

Environmental Effects — Greenhouse Gases

A simple Excel spreadsheet approach has been used to compare greenhouse gas (GHG) emissions from the different farming systems, and a copy of this spreadsheet appears here as Figure 2 — a numbered series of tables. The tables follow a rational order, dealing first with those emissions that are easily quantified and converted to CO₂ equivalent.

Input-Related Emissions

Fuel emissions obviously relate to the operations involved in the cropping system, and the energy requirement of these operations. Operations typical of the each system are set out in Table 1, where zero tillage has been assumed to need one tillage operation every three years, and CTF requires less spraying, but additional in-crop liquid N application. Fuel requirements are given in Table 2, (based on DPIF 2008 and Tullberg 2000). The total field fuel requirement for each system appear in the right-hand columns of Table 2.

Herbicides emissions, related to the energy embodied the materials, manufacture and transport etc., are large. Zentner (2004) has tabulated the energy data quoted for commonly used herbicide in Table 3. This table also includes an estimate of the frequency with which each herbicide is used, to allow calculation of a “mean spray impact” — the CO₂ equivalent of the average herbicide spray operation, set out below Table 3.

Fertiliser nitrogen is usually represents the largest single energy input to cropping. Nitrogen efficiency of cereal production is generally very poor, with a mean value often around 40%. Fertiliser application typically occurs at seeding, and large nitrogen losses are associated with subsequent rainfall events. Loss mechanisms include leaching and denitrification associated with high water-filled porosity, which occurs in situations of soil compaction and waterlogging. These occur more often in zero tillage when seed and fertiliser are placed in narrow slots cut into a compact surface soil where random traffic has reduced infiltration, exacerbating the problem, particularly in some soils (Rochette 2008).

Cropping System Inputs & Emissions

System Data (with default values for Australian Dryland Grain)

Constants **Outputs** See description below

1. Operations per crop

System	Chisel	Cultivate	Spray	Seed	Fertilise	Harvest
Subble Mulch	1	2	1	1	0	1
Zero Tillage	0.33	0	4	1	0	1
CTF	0	0	3	1	1	1

Constants

	Energy MJ	CO ₂ -e kg
Diesel/L	40	2.9
Gas	CO ₂ -e/MJ	0.06
Nitrogen/kg	MJ/kg	75.6
Phosphate/kg	MJ/kg	9.5
Potassium/kg	MJ/kg	9.9
Nitrous Oxide	CO ₂ -e/factor	310
Methane	CO ₂ -e/factor	23

2. Fuel requirements, L/ha

Operation	Chisel	Cultivate	Spray	Seed	Fertilise	Harvest
Subble Mulch	9.8	6	1.4	5	0	8
Zero Till	9.8	0	1.4	5	0	8
CTF	0	0	0.7	3	1	6

System

Fuel L/ha	CO ₂ kg/ha
36.2	105
21.834	63
12.1	35

3. Herbicides

Commercial Product	Herbicide	Relative Frequency	Label kg/ha	Energy	
				MJ/kg	MJ/ha
2,4-D Amine	2,4-D	1	0.5	98	49
Atrazine	Atrazine	0.5	0.5	190	95
Spray/Seed	D/Paraquat	2	0.25	430	107.5
Roundup CT	Glyphosate	3	0.45	511	229.95

Fuel L/ha	CO ₂ kg/ha
1.23	4
2.38	7
2.69	8
5.75	17

	Average MJ/Spray	equiv/ha	Fuel L/ha	CO ₂ -e/kg	Herbicide CO ₂ kg/ha
So mean spray impact =	15405		3.85	11.2	SubbleMulch 11.2
					Zero Till 44.7
					CTF 33.5

4. Fertiliser

System	Nitrogen 75.6 MJ/kg		Phosphate 9.5 MJ/kg		Potassium 9.9 MJ/kg		Total Energy (from gas)	CO ₂ kg/ha	NFert Ratio v. SMulch
	kg/ha	MJ/ha	kg/ha	MJ/ha	kg/ha	MJ/ha			
Subble Mulch	60	4536	5	47.5	8	79.2	4662.7	279.8	100
Zero Till	63	4762.8	5	47.5	8	79.2	4889.5	283.4	106
CTF	48	3628.8	5	47.5	8	79.2	3755.5	225.3	80

5. Soil Emissions (Measured in organic veg cropping Netherlands)

System	NO ₂ during early growth - kg/ha/day		CO ₂ Equivalent - kg/ha/day		Same as Random Traffic	System	NO ₂ day	Methane day
	Nitrous oxide	Methane	Nitrous oxide	Methane				
Random Traffic	0.068	0.00075	21.08	0.01725		CO ₂ -e kg/ha	CO ₂ -e kg/ha	
Seasonal CTF	0.047	-0.0049	14.57	-0.1127	Same as Seasonal CTF	21.08	0.01725	
						24.242	0.1472	
						14.57	-0.1127	

Emissions/Crop - Australian dryland grain - Speculative

System	NO ₂ Production		Methane Production		Total
	Days	CO ₂ -e kg/ha	Days	CO ₂ -e kg/ha	
Same as Random Traffic	30	632.4	150	2.59	635
Same as Seasonal CTF	30	727.26	150	22.08	749
CTF	25	364.25	150	-36.91	347

CTF Emissions = Rx SMulch Emissions

R Value = 1.15

Emission Period-days	Nitrous Oxide	Methane
30		150

1kg/ha NO₂ = 470 kg CO₂-e = 129 kg C

*This simple spreadsheet has been prepared in an attempt to present a simplified summation of greenhouse gas emissions from cropping. It considers only three common cropping systems, which are broadly representative of those applied in Australian grain production.

Default values are highlighted in green, inputs in yellow and outputs in red. The total could be value for nitrous oxide emissions from random traffic zero tillage are highlighted in blue, together with input value R - the random traffic zero tillage subble mulch emission ratio. Outputs have been capped with R values ranging from 1 - 1.5, zero till fertiliser requirements from 100 - 130% of subble mulch, CTF fertiliser requirements from 65 - 75% of subble mulch, and zero tillage chisel plough frequencies ranging from 0.5 - 0.2. Within this booklet, emissions from random traffic zero till, and CTF have been calculated from 100 - 125% and from 62 -

emissions

Fertiliser is applied only to the highly-porosity crop bed areas of CTF where greater soil organic matter and biological activity will tend to reduce losses, and migration into permanent wheel lanes will be restricted by their limited porosity. Leaching could occur more rapidly from beds with better infiltration, but CTF facilitates efficient in-crop fertiliser application, using liquid N via sprayers to achieve high workrates. This is the basis of the different N fertiliser requirements quoted in Table 4, which includes the energy embodied in fertilisers (Zentner 2004), and the reduction in CO₂ output which occurs because most fertiliser is produced from natural gas.

Soil Emissions

Nitrous oxide (N₂O) has approximately 310 times the greenhouse impact of carbon dioxide, so small quantities have a significant global warming effect when expressed in terms of their carbon dioxide equivalent, “CO₂ -e”. Many authors have demonstrated the association of emissions with compaction, porosity and pore connectivity (e.g. Ball et al.2008).

Methane (CH₄) has approximately 23 times the greenhouse impact of carbon dioxide, but emissions from dryland cropping are small compared with those from animal production or paddy rice production. Nitrous oxide and methane emissions are often studied together, and a number of authors have compared emissions from wheeled and non-wheeled rows and interrows of potatoes (e.g Ruser et al.1998), but this has usually been carried out in an environment of intensive tillage and random traffic.

Research into CTF impacts on greenhouse gas emissions is rare, but Vermeulen and Mosquera (2007) compared nitrous oxide and methane emissions from random traffic and “seasonal” precision CTF and these results are the basis for the values summarised in Table 5a. They demonstrate a large, consistent and significant reduction in nitrous oxide emissions from seasonal CTF, and a small improvement in the methane balance, over several crops.

It is highly speculative to use results obtained in European organic production to quantify greenhouse gas impacts on semi-arid production in Australia or China, but no other data is available, and porosity and pore continuity data is consistent with the emissions **from** random traffic zero tillage (v. conventional tillage), demonstrated by **Aulakh et al. (1984)**. Porosity of zero till is likely to be less than that of stubble mulch, increasing emissions, so zero till emissions are assumed to be greater than those from stubble mulch by an increment similar to that between controlled and random traffic. Values are set out in Table 5b. Duration time estimates for emissions and total nitrous oxide and methane estimates for each system are set out in Table 6, together with the CO₂ e values.

Overall totals are given in Table 7, in which emissions related to inputs, based on good evidence, are separated from the more speculative soil emission estimates.

Conclusions

1. Greenhouse gas emissions from inputs (fuel, herbicides and fertiliser) are demonstrably smaller from controlled traffic zero till systems, compared with (random traffic) zero tillage or stubble mulch systems.
2. Evidence on greenhouse gas emissions from soils indicates that these should also be substantially smaller from controlled traffic systems. Surprisingly, emissions from (random traffic) zero till appear greater than those from stubble mulch tillage.
3. Further work is required to establish more precise values for nitrous oxide and methane emissions under different cropping systems.

Controlled traffic or permanent raised bed farming is based on a self-evident truism “plants grow better in soft soil, wheels work better on roads”. It has been shown to increase productivity, reduce costs and improve all measures of environmental impact. Different assumptions might change the quantum of the improvement due to CTF, but or evidence suggests it will still be very large.

CTF requires more precise field guidance, and compatible machine track, tyre and operating widths. Greater standardisation would make adoption much easier in all environments.

References

- Aulakh M. S. Rennie D. A. and Paul E. A. (1984) Gaseous Nitrogen Losses from Soils Under Zero-Till Compared with Conventional-Till Management. *J Environ Qual* 13:130-136

- Ball B.C., Crichton I. and Horgan G.W. (2008). Dynamics of upward and downward N₂O and CO₂ fluxes in ploughed or no-tilled soils in relation to water-filled pore space, compaction and crop presence. *Soil and Tillage Research*. (in press)
- DPIF (2008) Selection and matching of tractors and implements. <http://www2.dpi.qld.gov.au/thematiclists/9155.html>
- McHugh, A.D. Li Hongwen, Zhang Liqin, E Shengzhe, Ma Zhongming, and Cao Xinhui (2006) Controlled traffic farming takes Conservation Agriculture into China. In *Proceedings of China-Canada Conservation Agriculture Forum*. September 21-23 Beijing, China. Pp: 75.
- Rochette P (2008) No-till only increases N₂O emissions in poorly-aerated soils. *Soil & Tillage Research* 101 (2008) 97–100
- Ruser, R., Flessa, H., Schilling, R., Steindl, H., Beese F. (1998). Soil compaction and fertilisation effects on nitrous oxide and methane fluxes in potato fields. *Soil Sci. Soc. Am.* J. 62; 1587-1595
- Ruwolt, R. (2008). CTF/No till Farming 2008 — What We Learned? 6th Australian controlled traffic conference, Dubbo NSW. *Proceedings*, p.50.
- Tullberg J.N. (2000) Traffic Effects on Tillage Energy. *Journal of Agricultural Engineering Research* 75(4).375-382.
- Tullberg J.N., Yule D.F. and McGarry D. (2007) Controlled traffic farming— From research to adoption in Australia. *Soil & Tillage Research* 97 272–281
- Vermeulen, G.D., Mosquera, J. (2008). Soil, crop and emission responses to seasonal-controlled traffic in organic vegetable farming on loam soil. In press, *Soil Tillage Res.*, doi:10.1016/j.still.2008.08.008
- Wang Xiaoyan, Gao Huanwen, Tullberg J N , Li Hongwen, Kuhn Nikolaus, McHugh A. D. and Li Yuxia(2008) Traffic and tillage effects on runoff and soil loss on the Loess Plateau of northern China. *Australian Journal of Soil Research*, 46, 1–9
- Zentner, R.P., Lafond, G.P., Derksen, D.A., Nagy, C.N., Wall, D.D., May, W.E. (2004) Effects of Tillage Method and Crop Rotation on Non-Renewable Energy Use Efficiency in the Canadian Prairies. *Soil and Tillage Research* 77; 125 – 136.

Improving No-Till Seeding Quality with Low Disturbance Furrow Openers and Residue Handling Devices

Augusto Guilherme de Araújo

*Agronomic Institute of Parana State (IAPAR), C.P. 481, CEP 86001970, Londrina, Paraná, Brazil
(Email: agaraujo@iapar.br)*

In the last two decades, no-tillage in Brazil has increased rapidly reaching more than 25 Mha in 2006. This widespread adoption of no-tillage for crop production, specially corn and soybeans, has generated new mechanization challenges, such as: seeding with high amount of residues over the soil surface; assure high seeding quality specially regarding emergence speed and furrow cover with residues and, finally, decreases the energy demand during seeding operation. This presentation will focus the results obtained by a modified type of a narrow chisel opener for fertilizer deposition, in order to reduce the demand of energy during seeding operation, and also the effects of residue handling components designed for covering seed furrow under high amount of residues (more than 8 Mg ha⁻¹).

The chisel opener is commonly used in Brazilian no-till seeders as a soil-engaging component for fertilizer deposition due to its capacity to penetrate in hard and, specially, medium to clay soils which, in general, present a surface compaction after some years of no-till adoption. There are many different designs and types of commercial chisels in the market and consequently the performance regarding energy demand and soil mobilization are variable. The depth of operation (H) for this component should not be more than 100 mm because energy demand and soil mobilization increase with depth.

The objective was to develop a new design for the chisel opener in order to reduce energy and soil mobilization for the most common operational conditions adopted by farmers. Sixty designs were evaluated and the best results were obtained for a chisel's rake angle of 20°, pointer thickness of 20 mm and frame thickness of 13 mm. During operation, the chisel compresses the soil forward and upward breaking it in a transversal direction. The selected design required less energy to break the soil and its mobilization was smaller. Results showing the relationships between design parameters of the chisel, named rake angle, pointer thickness and H/L (relation between operation depth and the distance from a vertical projection and the frame, which defines the parabolic shape of the chisel) and horizontal draft force, vertical force and soil mobilization area are discussed.

Residue handling components for no-till seeders, like row cleaners, have been used in temperate regions to remove the residues ahead of the openers as a way to clean the soil surface and raise soil temperature for the seeds. In Brazil, they have been evaluated as an alternative to avoid residue's clogging in the openers, mainly in the chisel. Meanwhile, when residue handling components operate afterwards of the openers, they can return the residues over the seed furrow protecting the soil surface from direct exposition to solar radiation and from the impact of rains and preventing from excessive soil temperature and loss of soil moisture in the seeding region, which are very important aspects to achieve a high seeding quality in tropical and dry regions.

Different types of residue handling components, both ahead and afterwards of the chisel opener, are being evaluated comparing with traditional soil-engaging components of no-till seeders under high amount of residues and distinct seeding periods. The effect of these components over soil covering, soil temperature and moisture in the seeding zone and also in the speed of emergence for corn seeds are discussed.

Resource Saving Equipment for Conservation Agriculture Leading to Higher Productivity and Profitability

Nawab Ali

Indian Council of Agricultural Research, Krishi Anusandhan Bhawan II, Pusa, New Delhi, 110 012, India

Agriculture is a complex and risk-prone profession but it is a must for the survival of human being on the planet earth. Resource conservation in agriculture through minimum tillage, *in-situ* management of crop residues, saving in water use and that of inputs like seeds, fertilizers and pesticides are needed for higher productivity and profitability on sustainable basis. This could be achieved through appropriate engineering interventions which have shown an increase of 10-35% in productivity, 20% saving of seeds, 15-20% saving in fertilizer, 15-25% enhancement in cropping intensity and 30-50% increase in farmer's gross income and return and thereby resulting in better quality living of farmers.

The goal in production agriculture is to get the higher productivity out of the limited land and water resources on sustainable basis whereas the goal in post-production agriculture is to prevent post-harvest losses and produce value added products. All these are being done through a set of agricultural operations carried out by farmers to produce biomass of plant and animal origin to meet the food and feed requirements of people and their livestock.

For each operation, appropriate tools and machines are required to achieve timeliness in operation, enhanced inputs use efficiency, operator's comfort, higher productivity, lower cost of cultivation and better quality products. Tillage is a laborious and time consuming operation and uses maximum energy in crop cultivation.

Tools and Machines

Mechanization plays a very important role in enhancing the agricultural production and productivity specially that of dryland areas leading to better profitability. Appropriate tools and equipment improve work efficiency of doing work at low cost, faster speed, with high precision and more comfort. Farm mechanization is a process of adoption of need based, location specific, efficient and precision tools, devices, equipment and machines matching to available power source, suitable for local soil, crop and socio-economic conditions. It helps to lower the operation cost, improve resource use efficiency, timely operation, enhance crop productivity and profitability. Dryland agriculture requires a tillage practice which can conserve basic resources namely soil, water and nutrients. Both, prevention of soil erosion and *in situ* moisture conservation are of utmost importance. Tillage practices also aim at complementing basic soil and water conservation measures such as graded bunds, land leveling and/or smoothening of surface. Rapidity of tillage operations for keeping the field ready for seeding immediately after the rain sets in is the key to the success of crops. It gains further importance when a second crop is to be sown subsequent to the harvest of first crop. Mechanization of agriculture has been shown to result in :

- Higher productivity to the extent of 10-35%.
- Saving in seeds and fertilizers (15-20%)
- Enhancement of cropping intensity (15-25%).
- Increase in gross income and return to the farmers (30-50%).
- Dignity to agriculture profession and better living conditions

Resource Conservation Measures

Resource conservation agriculture generally implies to the systems of cultivation with minimum tillage, *in-situ* management of crop residues; savings in water use and that of inputs like seeds, fertilizers and pesticides. Minimum tillage is aimed at reducing the soil manipulation activities to a bare minimum that is necessary to facilitate favourable seedbed condition for satisfactory germination, plant establishment and crop growth. Excessive tillage can be minimized either by eliminating the operations which are not cost-effective or combining the tillage, seeding and fertilizer application in one pass operation. Zero tillage is however an extreme form of minimum tillage. Experiments

have shown that minimum tillage has improved soil conditions due to decomposition of plant residues in-situ, facilitated higher infiltration due to vegetative matter present on the top soil and passage formed by the decomposition of old roots, less compaction to soil by the reduced movement of tractor and heavy tillage equipment and less erosion compared to the conventional tillage. These advantages are more visible in coarse and medium textured soils. Use of appropriate equipment and power source would save a considerable amount of energy and time and thereby reduction in cost of cultivation.

Energy and Cost Effective Equipment

Energy is a basic requirement for the development of every sector of Indian economy including that of agriculture and allied sector. As a result, consumption of energy in all forms has been steadily rising all over the country. Rising prices of oil and gas and potential shortage in future lead to concerns about the security of energy supply needed to sustain our economic growth.

Increased use of fossil fuel also caused environmental problems both locally and globally. As a result, promotion of energy conservation and increased use of renewable energy sources are the major two options to have a sustainable energy supply. Besides, increase in energy and water productivity need immediate attention. A good number of solar gadgets; such as solar dryer, solar water heater, solar cooker, solar refrigerator, biogas plants, biomass cook stove, biomass digesters, wind powered generator, alternate fuels for running engines have been developed and need to be promoted on a large scale.

Direct drilling equipment such as no-till drill, strip-till drill and roto-till drill for wheat after rice were compared with conventional tillage sowing as practiced by farmers. The result showed that no-tillage drilling was the most time, energy and cost effective for 70%, 67% and 6% respectively over the conventional practice. Raised bed planting has shown saving of 55%, 42%, and 44% in time, energy and cost of operation over conventional system on fresh beds. On permanent beds, these are 63%, 56% & 57% respectively,

New science-based farmer participatory consortium model for efficient management of natural resources and for improving livelihood of poor rural households has been developed and tested and found substantial reduction in run-off and soil loss, improvement in ground water level, reduction in pesticide use, better land cover and overall enhancement in productivity and farmer's income. The major driving forces for the success are selection and construction of watershed and check dam on a demand driven basis, higher farmers participation in watershed programme, good local leadership, use of improved agricultural tools and implements that provide benefits to large segment of the farming community.

As of now, technically feasible, economically viable and socially acceptable water resource conservation technology and equipment are pressurized irrigation systems. Drip and micro need to be popularized for row crops, horticulture and widely spaced high value cash crops on undulating terrains, shallow and porous soils and in water scarce areas.

Besides tillage and water conservation tools and machines, there are equipment which help to conserve and save inputs like costly seeds, fertilizers and timely harvest the crop to save from weather and pests. Some such equipment and machines are plastic mulch laying machine, inclined plate planter, self propelled rice and vegetable transplanters, power weeders, high capacity multicrop threshers and grain combines.

Water and its Nutritional Productivity

Water is one of the crucial limiting factors for increased food and fibre production to meet the demand of an ever growing population under increasing competition with other uses of water (municipal, industrial, environmental etc.). The optimum population of the planet earth depends to a large extent on the availability of water for both rainfed and irrigated agriculture to grow crops and produce food, in the most efficient way. Here comes the importance of water productivity in terms of nutrients rather than biological mass per unit of land and water. The nutritional productivity of water is calculated in terms of protein, energy, minerals and vitamins output per unit of water.

The concept of water productivity has, in recent year shifted from crop per unit area to crop per unit volume of water. Water productivity has been expressed in kg/m^3 whereas nutritional water productivity (NWP) is expressed in nutritional units/ m^3 (Protein, energy, mineral, etc.).

In estimating NWP, one source of uncertainty is the ratio of yield per unit of water consumed. Another source of uncertainty is the nutrition content of the product in which there are significant deviations. For example, the energy content of cereals varies from 2700 kcal/kg to 3500 kcal/kg. Water productivity in kg/m³ or water requirement in m³/kg for some of the food commodities have been worked out.

Future Strategies

Foodgrain production of Indian in 2007-08, was about 230 million tonnes. In order to enhance Indian foodgrain production to a higher level, an integrated approach focusing on land preparation, inputs use efficiency and farm management using appropriate mechanization is needed. As of now, it is possible to double foodgrain production in India by the end of the 11th Plan (2007-2012) with available technologies. Some of the immediate needs are package of commodity and location specific production technology and equipment; right and quality inputs of seeds, fertilizers, pesticides and water; marketing of produces; and facilities for processing and value addition in rural sector to provide better economic returns to the farmers and rural entrepreneurs. This requires investment in post-harvest facilities like cleaning and grading, cold storage and marketing, processing and value addition and wholesale and retailing of the processed products. This would also lead in arresting unhealthy urbanization and result in India becoming a large foodgrain producers for the world. Comprehensive farm management and a missionary zeal through leadership at the highest level would help to achieve the target of food and nutritional security for the people of the country.

Session 1.6: Genetic Strategies

Constraints to Zero Tillage in Mediterranean Environments

E. Acevedo*, E. Martínez and P.Silva

*Laboratorio de Relación Suelo-Agua-Planta. Facultad de Ciencias Agronómicas. Universidad de Chile.
Casilla 1004. Santiago. Chile*

**Corresponding author. E-mail address: eacevedo@uchile.cl*

The projected world food demand will require a sustainable intensification of field crops agriculture, fine tuning genotypes and agronomy for the various growing environments. No-till is central to agricultural sustainability, yet its adoption in Mediterranean environments is lagging behind, particularly in high yielding areas. These environments are characterized by having winter rainfall and hot, dry summers such that crop residue decomposition on top of the soil does not start until the break of autumn rains and decomposition occurs at low temperatures. The accumulated residues cause problems to the planters; allelochemicals limit germination and cause seedling mortality and sexual reproduction of pathogens occurs on the residue during the summer. When rainfall is high slugs thrive in the cool, humid environment provided by the straw. Eventually farmers burn the residues defeating a major purpose of conservation agriculture. Based on our experience with no-till in Central Chile, a high yielding Mediterranean environment, we briefly analyze the effects of crop residues on the soil, the effect of crop residues on the next crop of the rotation and propose agricultural practices and ideotypic traits of wheat for no-till that would help to overcome most of the production problems in these environments. The proposed traits are intended to overcome changes that occur in soil mechanical impedance, anoxia, weed control, diseases and allelopathy when no-till practices are adopted.

Key words: No-till, cereal crops, sustainable agriculture.

Globally the wheat demand is expected to increase to one billion Mg by the year 2020, what implies a fantastic intensification of the production systems to almost double the mean wheat yield, from 2.5 to 4 Mg ha⁻¹ (Rajaram, 2001). The intensification has to be done in a sustainable way and it will require an almost perfect coupling of genotypes, agronomy and crop management (GM) to increase system productivity avoiding damage to the environment. In this paper we focus on the agronomical and breeding implications of using no-till, a central management component of any agricultural sustainable system, for Mediterranean environments. We tap heavily on our 14 year experience working with no-till in the Mediterranean environments of Central Chile. Based on a parallel between no-till (NT) and conventional tillage (CT) systems we disclose phenotypic traits of interest for high yielding Mediterranean environments.

The Mediterranean Environments

The mediterranean eco-region includes all the areas with a prevalent mediterranean climate. It includes the countries around the Mediterranean Sea, California in the US, Central Chile, South-West Australia and the Cabo region in South Africa (Boydak and Dođru, 1997; UNESCO-FAO, 1962; Di Castri, 1973). The Mediterranean climate is characterized by cool rainy winters; hot, dry summers with high solar radiation and high water evaporation and a moderate influence of marine air throughout the year (Figure 1) (Leisz, 1982). It corresponds to Köppen's (1923) olive climate, due to the cropping of olives in this environment.

The Mediterranean environments, particularly those in the Mediterranean Sea, are mostly affected by intensive tillage, overgrazing and the use of fire (Boydak and Dođru, 1997; Naveh and Dan, 1973). Conservation agriculture is aimed at counteracting the negative effects of conventional agriculture on the renewable natural resources. One of the central elements of conservation agriculture is the minimum and/or no-till. The soil is not inverted and the crop residues are usually, but not always (e.g. Acevedo and Silva, 2003a) left on top of the soil aiming at maintaining and/or increasing the soil organic carbon, which is an essential element of soil sustainability (Rasmussen and Collins, 1991; Reicosky *et al.*, 1995; Martínez *et al.*, 2008).

No-till is part of a different way of doing agriculture, it responds to a new agronomy in which environmental sustainability is as central as crop yield. When the soil is not tilled and the crop residues are left on top of it, several agronomical consequences are generated. The crop residues are not incorporated into the soil and an accumulation and stratification of soil organic matter occurs (Rouanet, 1995; Valle *et al.*, 2004). The residues slowly decompose, adding organic matter to the soil which changes its physical, chemical and biological properties. This type of agronomy/agriculture has rapidly extended around the world (Acevedo and Silva, 2003a) but it is only partially used in the Mediterranean environments, particularly if these are high yielding (e.g. Central Chile). In the Mediterranean

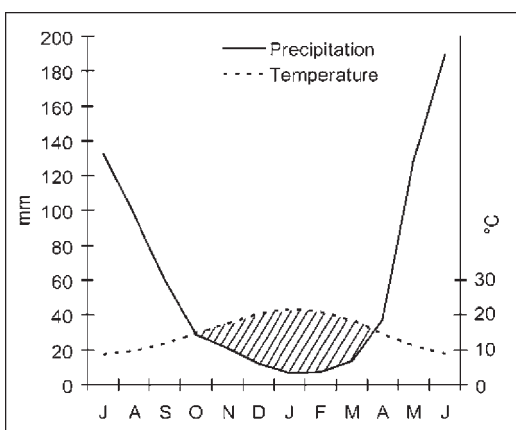


Figure 1. Climate Diagram for Talca, Chile (35°26' lat. S., 71°26' long. W., alt. 110 m.a.s.l)

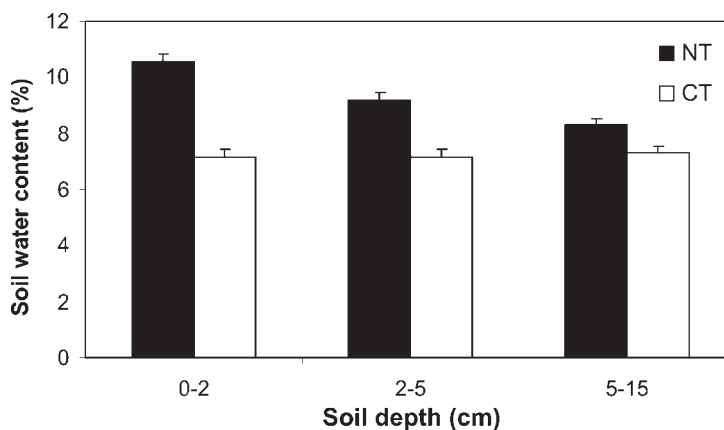


Figure 2. Available soil water in a mollisol under continuous tillage (CT) and four years of no till (NT) in Central Chile (Reyes *et al.*, 2002)

environments the summer rainfall is nil, therefore residue decomposition during this time period is limited by the lack of moisture and the crop residues stay on top of the soil for a long period of time, from December-January through April-May in the southern hemisphere, almost through the planting of the next crop, causing among others, physical problems to the planter (Acevedo and Silva, 2003a). At the break of autumn rainfall the residues start to decompose at a time when the temperatures are lower and limit the residue decomposition rate. The production of allelochemicals by the decomposing residues may also limit germination and cause seedling mortality, particularly in the case of legumes following cereals in the crop rotation (An *et al.*, 2002; Silva, 2007; Ordoñez *et al.*, 2007). These problems do not occur in environments with summer rainfall where temperature and moisture are adequate for residue decomposition. In the high yielding Mediterranean environments usually the cereal straw has low value and the farmers finally decide to burn it, defeating the purpose of organic carbon incorporation into the soil to provide sustainability to the agricultural system.

The question is to what extent could variety traits help to overcome some of the constraints to no-till in Mediterranean environments.

No-Till the Effect of Crop Residues on the Soil

When the soil residues are left on top of the soil, many phenomena occur in the soil-residue interphase which are determinant for crop growth. These include the partitioning and balance of radiation, energy, water and carbon. The soil residues act as a physical barrier altering the mass and energy exchanges, the solar radiation does not arrive to the soil surface but it strikes the residues decreasing the direct radiation flux on the soil surface and hence the direct soil evaporation (Greb, 1983; Campbell and Norman, 1998; Carr *et al.*, 2003). As a result, more soil water is available for plants (Carr *et al.*, 2003; Reyes *et al.*, 2002). The rain drops fall on the residue dissipating their kinetic energy without affecting the soil structure. The soil water infiltration may improve due to the lower kinetic energy of the water reaching the soil surface, decreasing the water runoff and soil erosion (Acevedo and Martínez, 2003). The end result is that the soil water balance generally improves increasing the soil water availability to the plants (Figure 2) (Martínez, 2007; Reyes *et al.*, 2002; Uribe and Rouanet, 2002). Black (1973) estimated that an additional 0,6 cm of available soil water resulted for each Mg of crop residue maintained on the surface of the soil in the northern Great Plains of the US. A relatively low amount of residue, covering approximately 40% of the soil is usually enough to decrease soil water erosion significantly. Finer residues such as wheat straw protect the soil better than thicker residues such as corn stalk (Acevedo and Silva, 2003a).

The lower solar radiation reaching the soil surface in no-till along with the higher water content of the soil decrease the mean soil temperature (Figure 2) lowering the rate of biological processes.

The main effect of the crop residues on the soil chemical properties is related to the increase of soil organic carbon in the form of soil organic matter. The organic matter provides essential nutrients such as N, P, K and micronutrients directly (Figure 4), stabilizes the soil structure and provides colloids that increase the soil cation exchange capacity (Green *et al.*, 1995; Burgess *et al.*, 2002; NREL, 2003; Mubarak *et al.*, 2002; Martínez, 2007).

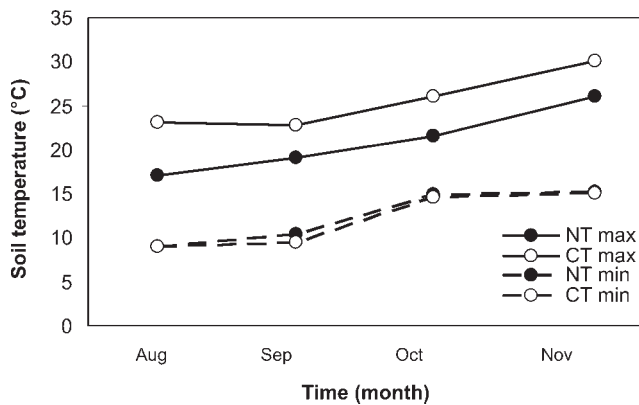


Figure 3. Maximum and minimum temperature at 2 cm depth in a mollisol under no-till (NT) and continuous tillage (CT) in Central Chile. There was a decrease in the maximum soil temperature of the soil under NT, having residues on top, along with a lower thermal amplitude than in CT. (Acevedo, unpublished).

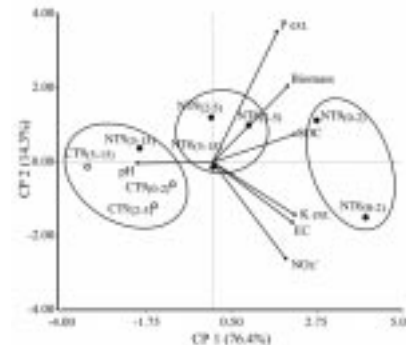


Figure 4. Tillage system x soil depth x year interaction for aerial regrass (*Lolium perenne*) biomass production (Biomass) and some soil chemical properties in 2006-2007 season. NT and CT correspond to no tillage and conventional tillage treatments, respectively, for 0-2, 2-5, and 5-15 cm soil depth. SOC is soil organic carbon, NO_3^- is soil nitrate, P ext. is the Olsen extractable phosphorus, K ext. is the extractable potassium (ammonia acetate 1N, pH 7), EC is the soil electrical conductivity and pH correspond to soil reaction (Martínez, 2007).

The initial availability to the crop of some nutrients, particularly N, is lower in no-till than in conventional tillage in spite of higher total N (Acevedo and Silva, 2003a). In an Entic Haploxeroll of Central Chile the N availability became higher in NT compared to CT only after 4 years of NT, when a new organic matter level, between 3.5 to 4.0 % in the top (0-2 cm) soil had been reached.

The microflora and microfauna of the soil increase with increasing organic matter content, mainly in the upper 5 centimeters. The microbial population of soils under direct drilling may increase by 30 to 40%. The combined and integrated action of fungi, actinomycete, bacteria and soil mesofauna transforms the organic matter coming from the crop residues into humus.

In synthesis, the crop residues on top of the soil may have multiple positive effects which include:

- Protect the soil against wind and water erosion.
- Decrease surface runoff.
- Increase soil water infiltration rate.
- Decrease direct soil water evaporation.
- Supply organic matter (C, N, P, S and others) to the soil.
- Upon decomposition provide organic colloids.
- Improve soil structure and aggregate stability.
- Avoid surface soil crusting.
- Improve soil aeration.
- Avoid extreme soil temperatures.
- Improve soil fertility.
- Improve the biological activity of the soil.

In the no-till systems, however, the beneficial effects of the increased organic matter are confounded with the effects of no tillage *per se*. Initially in the growing season the soil mechanical impedance is lower in conventional tillage than in no-till what decreases the growth rate of seedlings. Furthermore, the inappropriate use of no-till in heavy soils or in soils having unpaired drainage usually generates soil compaction (Figure 5). Martínez (2007) observed in an Entic Haploxeroll of Central Chile that plowing increased the soil macroporosity from planting to flowering. The soil under no-till had more stable aggregates but they were closer together forming a matrix throughout crop growth. As a result the soil water infiltration rate of this heavy soil under no-till was lower than under conventional tillage from sowing to flowering causing water ponding and the development of root fungal diseases such as root fusarium in wheat. Attention has to be given to water management and to farm machinery in terms of weight, tire width and air pressure as well as traffic in order to minimize soil compaction (Martínez, 2007). Medium to light

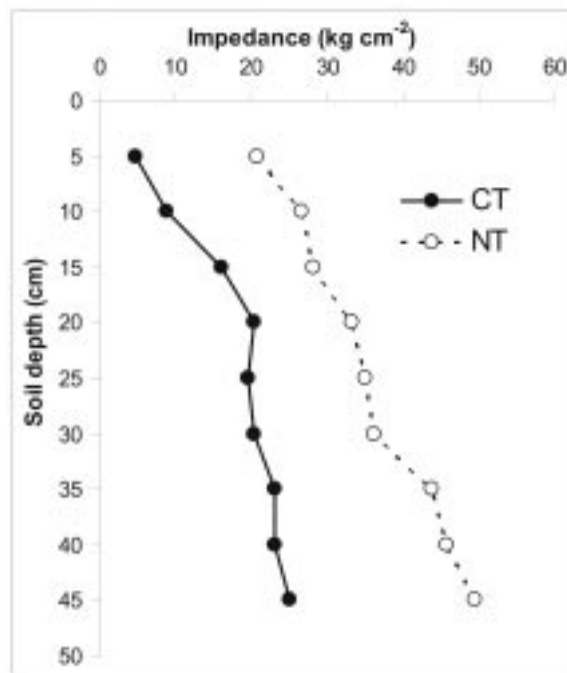


Figure 5. Soil mechanical impedance profile in an Entic haploxeroll of Central Chile showing the effect of no-till (NT) as compared to conventional tillage (CT). The soil had been managed for seven years under NT (After Martínez, 2007).

texture soils cropped under direct drilling would not show the compaction problems and they usually will have an increased soil water infiltration rate and a decreased soil compaction as a result of an increased organic matter content and higher biological activity (Sheehan *et al.*, 2004).

When the soil is compacted (clay, sandy clay) by machine traffic or the soil has a poor drainage, the soil water content may go beyond field capacity and anoxia may prevail.

No Till. Effect of Crop Residues on the Next Crop

Crop residues may produce physical, chemical and biological problems to the next crop. High yielding crops leave a high amount of residue in the field. A wheat crop yielding 7.0 Mg ha⁻¹ leaves around 10 Mg ha⁻¹ of crop residues, while an irrigated maize crop yielding 18 Mg ha⁻¹ leaves 18 Mg ha⁻¹ of corn residues. These amounts of residues may physically induce sowing problems to the next crop. The amount of water in the residue, its temperature and its chemical composition, particularly its C/N ratio determine the decomposition rate and hence the time of residence of the residue on top of the soil (García de Cortázar *et al.*, 2003). As mentioned, in Mediterranean climates the crop residues stay dry for a long period of time, from harvest (December-January) to the break of autumn rains, April-May in the southern hemisphere, therefore, little decomposition takes place in that period in rainfed agriculture. The residues of annual crops left on top of the soil start decomposing at the start of autumn rains at a time when temperatures are relatively low and decreasing, what induces slow decomposition causing the crop residues to persist on the soil for a longer period of time. Table 1 shows C/N values for residues of various crops. Crops having residues with a high C/N ratio such as winter cereals will show a lower straw decomposition rate when compared to crops with lower C/N ratio in their residues such as legumes.

No-till in the presence of high quantities of crop residues on the soil makes the weed control more difficult due to a lower efficiency of soil-active herbicides, mostly used to control weeds in legume crops. The composition of dominant weeds, insects and pathogens change in no-till. The non inversion of the soil, lower soil temperatures, higher soil water content and the residues on top of the soil add to this effect. The pressure and genetic make-up of microorganisms that complete their development cycle having their sexual reproduction in the residues increase and plagues like slugs that thrive in the wetter environment provided by the straw increase markedly, particularly under high rainfall (1000 mm year⁻¹ or more).

Table 1. Carbon / Nitrogen (C/N) ratio of residues of the main annual crops

Crop	CN
Wheat	60-90
Rice	80-90
Barley	80-90
Maize	50-60
Canola	40-50
Lupin	30-40
Lentil	30-40
Soil	10-12
Soil microorganisms	6-7

The straw decomposition generates chemical substances (allelochemicals) that may have an effect on the crop establishment of the next crop in the rotation. Residues of cereal crops being especially allelopathic to the legume crops such as lupine.

Crop Rotations

The result of a rotation of crops using no-till with crop residues left on top of the soil depend on several cropping factors including the species involved, the type, quantity and management of the straw, sowing date, changes in soil fertility and variety. Overall, the wheat crop is the most important annual crop in Mediterranean environments. It is also the crop that leaves residues on the field having the slower rate of decomposition owing to its high C/N ratio. Several crop rotations are common in Mediterranean environments such as wheat-oat, wheat-canola, wheat-lupine and wheat- irrigated maize.

Wheat-Oat Rotation

Even high amounts of wheat or oat residues (Figure 6) do not have an important effect on the establishment of these cereal crops as exemplified by wheat and oat straw on the establishment of wheat and oat in Central Chile (Table 2). The observed lower initial number of plants of the crop are compensated by fertile tillers such that the crop yield is not affected.

Table 2. Effect of residue management on the establishment of wheat and oat crops. Total amount of straw was 8-10 Mg ha⁻¹ (adapted from Vidal and Troncoso, 2003)

Straw Management	Wheat		Oat	
	Establishment (plant m ⁻²)	Grain Yield(Mg ha ⁻¹)	Establishment (plants m ⁻²)	Grain Yield(Mg ha ⁻¹)
Burned	368	6.75	373	5.73
Rowed	348	5.20	336	4.67
Chopped	318	6.37	254	4.85
Standing	307	6.17	271	4.95
LSD (0.05)	38	0.70	91	0.97

There is an increase in the incidence of some diseases in wheat when grown under NT. these include Root Fusarium, *Septoria tritici*, *Helminthosporium tritici* and *Erysiphe graminis* (Madariaga, 2003). Root Fusarium may become extremely important if the soil is compacted and the soil drainage is poor. The main weeds of this rotation are grasses such as *Lolium multiflorum*, *Vulpia* sp. and *Bromus* sp.

Wheat-Canola Rotation

The wheat straw decreases canola yield at a rate of 88 kg Mg⁻¹ of wheat residue at planting of canola (Vidal y Troncoso, 2003). This is a mechanical problem caused by the wheat straw affecting the germination and establishment of canola which has a very small seed. An increase in the incidence of the disease *Lepthosphaeria maculans* = *Phoma lingam* in canola has been observed when wheat residues are left on top of the soil. Furthermore in the presence of wheat residues the canola crop is heavily infected by slugs with a severe damage when 2 slugs m⁻² (*D. reticulatum*) are found in this crop (Acevedo y Silva, 2003a). The wheat – canola rotation facilitates the control of broad leaf weeds (during the wheat crop) and of grasses (in the canola phase).

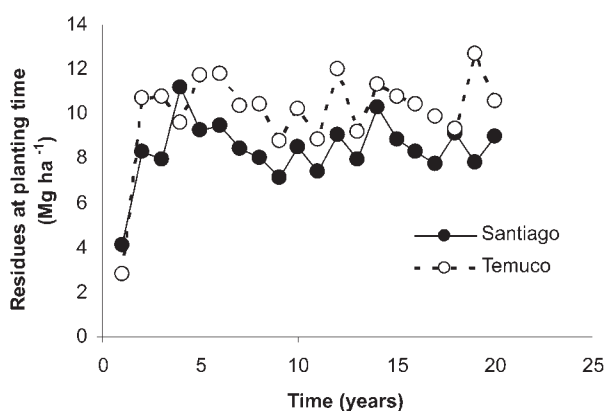


Figure 6. Simulated values of wheat residues on the soil for a rainfed wheat-oat rotation for Santiago (33°S) and Temuco (41°S) (García de Cortázar, unpublished)

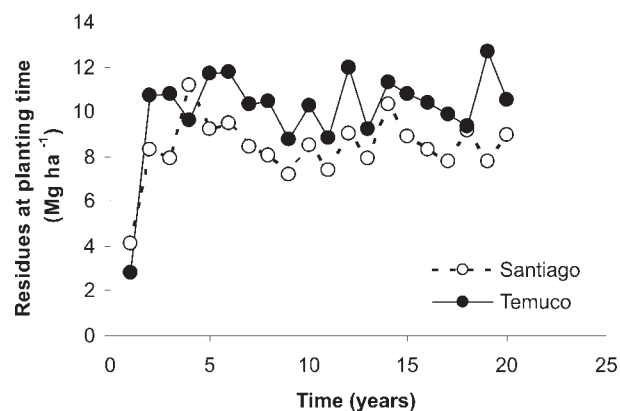


Figure 7. Simulated values of wheat residues on the soil for a rainfed wheat-lupine rotation for Santiago (33°S) and Temuco (41°S) (García de Cortázar, unpublished)

Wheat-Lupine Rotation

There is a strong depressing effect of the wheat residue on lupine yield. Above 3 Mg ha⁻¹ of wheat straw the decrease of lupine yield is 20% Mg straw⁻¹ (Vidal and Troncoso, 2003). Figure 7 shows a computer simulation of the accumulation of wheat residues in the wheat-lupine rotation at Santiago (33° S) and Temuco (41° S) under rainfed conditions. At year 4 of the rotation the wheat residues in Santiago reached a steady value of 6.5 Mg ha⁻¹ and in Temuco 7.6 Mg ha⁻¹.

Many lupin seedlings are lost immediately after emergence due to the incidence of *Fusarium* and *Rhizoctonia* sp. and to the allelopathic effects of the wheat residue on this crop. Table 3 shows that *L. angustifolius* cv Danja has a greater sensitivity than *L. albus* cv Rumbo when planted on wheat straw.

Table 3. Relative establishment (%) of *L. angustifolius* cv Danja and *L. albus* cv Rumbo on 5 and 1 Mg ha⁻¹ of wheat residue. Values are relative to a control established without wheat straw (Silva, 2007).

Species	Wheat residue	
	1 Mg ha ⁻¹	5 Mg ha ⁻¹
<i>L. angustifolius</i> cv Danja	62.3 b	30.9 d
<i>L. albus</i> cv Rumbo	85.9 a	35.4 c
LSD (0.05)	4.2	

An option to avoid allelopathic effects is to delay the sowing of lupin towards the end of winter planting on a more decomposed cereal residue. This allows a better lupin establishment, particularly in the case of *L. angustifolius* (Figure 8).

Pre-emergence herbicides are used to control broad leaf weeds in legumes such as lupin. Carrasco (2003) evaluated using Linuron, Metribuzine, Simazine and Alaclor on the yield of *L. albus* cropped on NT and CT. The herbicides had to be chosen according to the tillage system being Linuron the best herbicide in NT and Metribuzina in CT .

Wheat-Maize Rotation

Maize is a summer crop usually planted around six months after the wheat harvest. The wheat straw is substantially decomposed when the maize is planted, therefore it does not cause problems to the maize establishment (Figure 9).

On the contrary, wheat plantings (May) immediately after a medium yielding (14 Mg ha⁻¹) grain maize harvest on chopped maize straw have decreased the number of wheat plants established by 50%. Sweet corn, on the other hand, leaves a lower amount of residue (5 Mg ha⁻¹) than grain maize, with lower lignin content and a longer time period between the harvest of sweet corn and the wheat planting not affecting the wheat establishment.

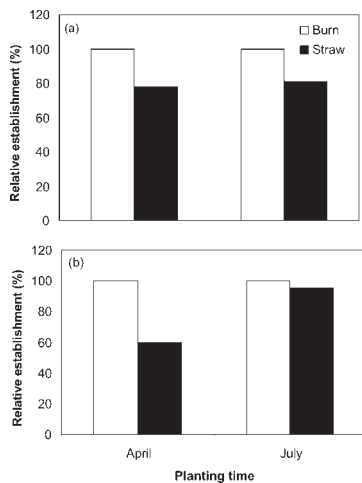


Figure 8. Relative establishment of *L. albus* (a) and *L. angustifolius* (b) under NT with respect to the establishment in a soil in which the residue had been burned. Early (April) and a late (July) sowings in the foothills of the Andes in Chilean Region VIII (Acevedo and Silva, unpublished).

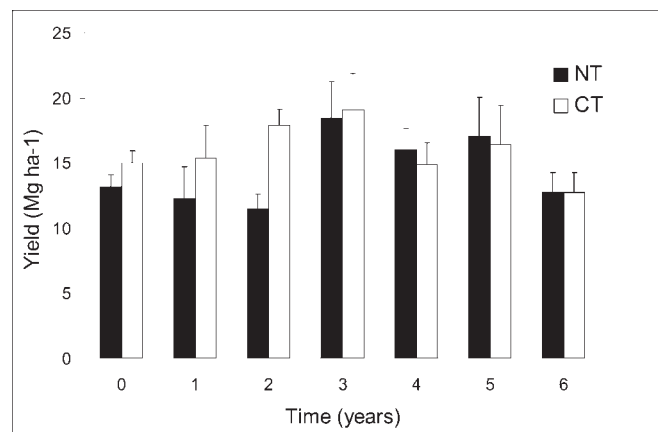


Figure 9. Maize yield under conventional tillage CT and no-till NT in Central Chile (Martínez, 2007).

We have observed that during the first four years of the wheat-maize rotation there is a decrease in N availability which is particularly expressed in the wheat phase of the rotation. The reduction in wheat yield has been as high as 34% of the yield obtained under CT and is mainly due to a decrease in the number of grains per unit area. This period coincides with the highest amount of carbon sequestration by the soil in NT. On the average (10 year) the soil fixed 500 kg C ha⁻¹year⁻¹ mainly in the form of humus (C/N @10/1) what implies 50 kg N sequestration ha⁻¹year⁻¹. After 4 years of NT the N availability was restored and even increased when the soil organic matter has reached a new equilibrium.

Ideotypic Traits of Wheat for No-Till

Due to the changes in the soil physical, chemical and biological properties and the effects of crop residues on the next crop, the agronomy of a crop under no-till differs from conventional tillage. Furthermore, the varieties developed for conventional tillage systems do not necessarily have the same performance under no-till and specific genotypes are recommended for no-till (Chevalier and Ciha, 1986; Yang and Baker, 1991; Tillman *et al.*, 1991). The reasons for the GM interaction include soil mechanical impedance, diseases (type and intensity), soil temperature, anoxia, allelopathy and weed control.

Soil Mechanical Impedance and the Rhizosphere

Compacted soils under no-till show an increase in bulk density (Ball-Coelho *et al.*, 1998; Lampurlanés and Cantero-Martínez, 2003), lower soil temperature (Drury *et al.*, 1999), and a decrease in oxygen diffusion rate (Russell, 1988). As a result no-till reduces the wheat growth rate (Braum *et al.*, 1992; Kirkegaard *et al.*, 1995). The increase in soil mechanical impedance negatively affects the growth of roots (Watt *et al.*, 2005), particularly during the initial growth phases (Lampurlanés *et al.*, 2001) due to a lower absorption of water and nutrients (Qin *et al.*, 2006). The root length density, however, is higher in the surface soil of no-till (0-5 cm) when compared to CT (Wilhelm and Wortmann, 1996; Martínez *et al.*, 2008) due to a higher fertility (Franzluebbers and Hons, 1996; Thomas *et al.*, 2007) and soil organic matter (Havlin *et al.*, 1990; Salinas-García *et al.*, 1997; Franzluebbers, 2001), what in turn favors microbial activity (Anderson and Domsch, 1989; Renz *et al.*, 1999) nutrient cycling and root growth. Furthermore, in hard soils wheat roots are more susceptible to *Fusarium* and *Rhizoctonia* (Gill *et al.*, 2004).

Vigorous wheat genotypes appear to grow better in no-till soils as shown by Watt *et al.* (2005) who compared two bread wheat genotypes, "Janz" (conventional) and a line selected for its vigorous leaf growth, "Vigour 18". Both genotypes showed distorted roots and shorter apices in NT vs. CT soil. The roots of Vigour 18, however, grew 39% faster, were thicker and were less distorted than the roots of Janz in the NT soil. The shoot growth of Vigour 18 was 64% faster than Janz in NT.

When anoxia is a problem varieties having an over expression of aerenchyma in their roots may be indicated (Malik *et al.*, 2003), or transgenics allowing the subsistence of the plants in flooded soils, similar to the gene Sub1A with the ethylene response factor found in rice (Xu *et al.*, 2006). Wheat and barley, two species intolerant to anoxia, if subject to anoxia at the seed state adopt a quiescent state which does not allow the growth of the coleoptile (Perata and Alpi, 1993). Unfortunately the wheat and barley seeds rapidly lose viability under anoxia due to fermentation of starch (Guglielminetti *et al.*, 2001; Perata *et al.*, 1997). An interesting alternative is the cross between *Hordeum marinum* (sea barley grass) and wheat to produce hybrids which are able to tolerate flooding and salinity (Mc Donald *et al.*, 2001; Colmer *et al.*, 2006).

Weed Control

A different strategy to weed control allowed the expansion of no-till of crops like maize and soybean to millions of hectares. The basic idea is to create varieties resistant to an easily degradable wide spectrum herbicide like glyphosate. In those countries where transgenics are not allowed, the use of imidazolinone resistant varieties is playing a similar role. New spring canola varieties are being produced which are resistant to imidazolinones allowing an excellent weed control in the canola crop grown under no-till. Similar to canola there are maize hybrids resistant to imidazolinones which allow a good weed control. The IMI or Clearfield hybrids (resistant to imidazolinones) have even shown an increase in grain yield when planted on wheat straw (Table 4).

Table 4. Biomass and grain yield of the maize hybrids Mexico IMI (M. IMI) treated with imidazolinones in NT in Central Chile (Acevedo and Silva, 2003b)

Treatments	Biomass (Mg ha ⁻¹)	Yield (Mg ha ⁻¹)
M. IMI width out weed control.	22.3	11.1
M. IMI (D ¹)	28.2	13.5
M. IMI (DD ²)	30.9	16.4
LSD (0.05)	5.7	4.1

¹ Dose A of imidazolinona (euro-lightning)

² Dose B of imidazolinona (euro-lightning)

Diseases

Many of the most relevant pathogens in cereals, including fusarium and septoria in wheat belong to the ascomycetes fungi. These fungi complete their life cycle (sexual phase) in the residue of the crop that infected in their pathogenic (asexual) phase, generating new types that may be more virulent than the original pathogen (Madariaga, 2003).

Much work is needed to decrease the infection of soil borne pathogens on crops like cereals and legumes. Major problems may be caused by rhizoctonia and root fusarium at the seedling stage, and root fusarium in cereals undergoing some degree of anoxia at the flowering stage.

Allelopathy

When the residue of some winter cereals (oat, wheat, barley, rye) is in a relatively high amount (more than 5 T ha⁻¹) at sowing time and it has not undergone decomposition due to lack of moisture, it is possible that phytotoxic compounds may generate along with the first autumn rains. The compounds are leached into the soil producing allelopathic symptoms in the seedlings of the next crop (Guenzi *et al.*, 1967; Kimber, 1973) in the rotation, particularly if it is a legume such as lupine (Silva, 2007).

A plausible solution to this complex problem is through crop improvement, selecting cereals genotypes having a lower degree of allelopathy in their straw or selecting legumes which are tolerant to allelopathy (Silva, 2007). This idea seems to be supported by two pieces of evidence: 1) There is genetic variability in the allelopathic capacity of some crops including wheat (Guenzi *et al.*, 1967; Kimber, 1967; Ben-Hammouda *et al.*, 1995; Ahn and Chung, 2000; Olofsdotter, 2001). 2) There is genetic variability in the tolerance to allelopathy of some crops including lupine (Herrin *et al.*, 1986; Bruce y Christen, 2001; Silva, 2007).

Silva (2007) used 50 wheat genotypes and 16 lupine genotypes and showed in field and laboratory trials that the wheat residue had allelopathic effects on *L. albus* and *L. angustifolius*. The allelopathic capacity of the wheat

Table 5. Synthesis of the main problems of no tillage with residues on top of the soil and plausible solutions in rotations involving wheat, canola, lupine and maize.

Crop	Problem (Severity ¹)	Plausible Solution
Wheat	Crop establishment after maize (*) Mechanical	-Reduce the quantity of straw (rowing, baling, animals, biofuel).
	Nitrogen deficiency (**)	-Increase N fertilizer by (30%). -Use wheat genotypes with a higher N use efficiency.
	Weeds (**)	-Rotation with oil crops and / or legume crops. -Development of wide spectrum herbicide tolerant wheat genotypes.
	Diseases (**)	-Use of tolerant varieties. -Avoid soil compaction (anoxia). -Use of fungicides.
Canola	Crop establishment (**) Mechanical	-Reduce the quantity of straw (rowing, baling animals, biofuel).
	Slugs (**)	-Rowing of the residue plus molluscicide. -Resistant varieties?
	Weeds (*)	-Rotations -Use of clearfield varieties.
Lupine	Crop establishment (***) Diseases	-Avoid soil compaction (anoxia). -Fungicide.
	Allelopathy	-Reduce the quantity of straw (rowing, baling animals, biofuel). -Change the sowing date from autumn to spring. -Use of varieties having lower sensitivity to straw.
	Slugs (**) Weeds (**)	-Rowing of the residue plus molluscicides. -Use of more efficient soil-active herbicides in NT e.g. Linuron. -Development of varieties resistant to wide spectrum herbicides.
Maize	Nitrogen deficiency. (**)	-Increase N dose (30%). -Develop hybrids having a higher N use efficiency

¹ * = low. ** = moderate. *** = high

genotypes, however, had a high GxE and low heritability, therefore she selected wheat genotypes (high and low) having a more stable allelopathic capacity across environments and identified *L. angustifolius* as a more sensitive species to the presence of wheat straw, sensitivity that was associated to a lower lupine germination rate in the presence of wheat exudates. The interaction between wheat genotype and lupine species was significant hence the selection of less allelopathic wheat genotypes had to be done independently for *L. albus* and *L. angustifolius*. Intra-specific differences in allelopathic sensitivity to the wheat extracts were also found for both lupine species. She also showed that summer rainfalls may reduce the allelopathic effect considerably and identified an inhibitory effect of the soil previously cropped to wheat on lupine establishment.

Synthesis

The main constraints to zero tillage in Mediterranean Environments and plausible solutions expressed in this document are shown in Table 5

Acknowledgments

Financial support for the Chilean work presented in this paper was obtained by the research projects FONDECYT N° 1050565, FONDEF D9911081, DI-University of Chile, SIRDS -SAG-INDAP- University of Chile Convenio on No-Till and FIA.

References

Acevedo, E. and Martínez, E. 2003. Sistema de labranza y productividad de los suelos. In: *Sustentabilidad en Cultivos Anuales: Cero Labranza, Manejo de Rastrojos* (E. Acevedo Ed.), pp 13-25., Universidad de Chile, Serie Ciencias Agronómicas N° 8, Santiago, Chile.

- Acevedo, E. and Silva, P. 2003a. *Agronomía de la Cero Labranza*. Universidad de Chile. Facultad de Ciencias Agronómicas. Santiago, Chile. Serie Ciencias Agronómicas N° 10. 118 p.
- Acevedo, E. and Silva, P. 2003b. Evaluación del híbrido Mexico IMI (tolerante a imidazoles) en cero labranza y labranza tradicional. Universidad de Chile-Semameris. 4p [online]. Available at www.sap.uchile.cl.
- Ahn, J.K. and Chung, I.M. 2000. Allelopathic potential of rice hulls on germination and seedling growth of banyardgrass. *Agronomy Journal* **92**, 1162-1167.
- An, M., Johnson, I.R. and Lovett, J.V. 2002. Mathematical modelling of residue allelopathy: the effects of intrinsic and extrinsic factors. *Plant and Soil* **246**, 11-22.
- Anderson, J.P.E. and Domsch, K.H. 1989. Ratios of microbial biomass carbon to total carbon in arable soils. *Soil Biology & Biochemistry* **21**, 471-479.
- Ball-Coelho, B. R., Roy, R. C. and Swanton, C. J. 1998. Tillage alters corn root distribution in coarse-textured soil. *Soil & Tillage Research* **45**, 273-249.
- Ben-Hammouda, M., Kremer, R.J. and Minor, H.C. 1995. Phytotoxicity of extracts from sorghum plant components on wheat seedlings. *Crop Science*. **35**, 1652-1656.
- Black, A.L. 1973. Crop residue, soil water, and soil fertility related to spring wheat production and quality after fallow. *Soil Science Society of America Proceedings* **37**, 754-758.
- Braim, M. A., Chaney, K. and Hodgson, D. R. 1992. Effect of simplified cultivation on the growth and yield of the spring barley on sandy loam soil. 2. soil physical properties and root-growth, root-shoot relationships, inflow rates of nitrogen and water-use. *Soil & Tillage Research* **22**, 173-187.
- Boydak, M. and Dođru, M. 1997. The exchange of experience and state of the art in sustainable forest management (SFM) by ecoregion: Mediterranean forests. Ecoregional review. In: *Proceedings of the XI World Forestry Congress*, 13-22 October 1997, Antalya, **6**, 179-204.
- Bruce, S. and Christen, O. 2001. Phytotoxicity of wheat leachates and ferulic acid to germination and radicle elongation of canola. *Proceedings of the 10th Australian Agronomy Conference, Hobart*. 28 January-1 February [online]. Available at www.regional.org.au/au/asa/2001.
- Burgess M.S., Mehuys G.R. and Madramootoo, C.A. 2002. Decomposition of grain-corn residues (*Zea mays*): a litter bag study under three tillage systems. *Canadian Journal of Soil Science* **82**, 127-38.
- Campbell, G.S. and Norman, J. S. 1998. *An Introduction to Environmental Biophysics*. Second Edition. Springer-Verlag, New York, USA. 286 p.
- Carr, P.M., Horsley, R.D. and Poland, W.W. 2003. Tillage and seeding rate effects on wheat cultivars: I. Grain Production. *Crop Science* **43**, 202-209.
- Carrasco, O. 2003. Control de malezas en el cultivo de lupino en cero labranza en base a herbicidas suelo activos. Tesis Lic. Agr. Universidad Mayor. Facultad de Ciencias Silvoagropecuarias. Santiago, Chile. 88 p.
- Chevalier, P.M. and Ciha, A. J. 1986. Influence of tillage on phenology and carbohydrate metabolism of spring wheat. *Agronomy Journal* **78**, 296-300.
- Colmer, T.D., Munns R. and Flowers T.J. 2005. Improving salt tolerance of wheat and barley: future prospects. *Australian Journal of Experimental Agriculture* **45**, 1425-1443.
- Di Castri, F. 1973. Climatographical comparisons between Chile and the western coast of North America. In: *Mediterranean type ecosystems, origin and structures* (F.di Castri and H.A.Mooney, Eds.), Vol.7, pp.21-36, Springer-Verlag Berlin, Heidelberg, New York.
- Drury, C. F., Tan, C., Welacky, T. W., Olaya, T. O., Hamill, A. S. and Weaver, S. E. 1999. Red clover and tillage influence on soil temperature, water content, and corn emergence. *Agronomy Journal* **91**, 101-108.
- Franzluebbers, A.J. and Hons, F.M. 1996. Soil-profile distribution of primary and secondary plant-available nutrients under conventional and no tillage. *Soil & Tillage Research* **39**, 229-239.
- Franzluebbers, A. J. 2001. Soil organic matter stratification ratio as an indicator of soil quality. *Soil & Tillage Research* **66**, 95-106.
- García de Cortázar, V., Silva, P. and Acevedo, E. 2003. Descomposición del rastrojo de trigo. *Agricultura Técnica (Chile)* **61**, 69-80.
- Gill J.S., Hunt S., Sivasithamparam, K. and Smettem K.R.J. 2004. Root growth altered by compaction of a sandy loam soil affects severity of rhizoctonia root rot of wheat seedlings. *Australian Journal of Experimental Agriculture* **44**, 595-599.
- Greb, B.W. 1983. Water conservation: Central Great Plains. p. 57-72. In H.E. Dregne and W.O. Willis (ed.) *Dryland agriculture*. *Agronomy Monographs* **23**. ASA, CSSA, and SSSA, Madison, WI.

- Green C.J., Blackmer A.M. and Horton R. 1995. Nitrogen effects on conservation of carbon during corn residue decomposition in soil. *Soil Science Society of America Journal* **59**, 453–9.
- Guenzi, W.D., McCalla, T.M. and Norstadt, F.A. 1967. Presence and persistence of phytotoxic substances in wheat, oat, corn, and sorghum residues. *Agronomy Journal* **59**, 163-165.
- Guglielminetti, L. Busilacchi, H.A., Perata, P. and Alpi, A. 2001. Carbohydrate-ethanol transition in cereal grains under anoxia. *New Phytologist* **151**, 607–612.
- Havlin, J.L., Kissel, D.E., Maddux, L.D., Classen, M.M. and Lang, J.H. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. *Soil Science Society of America Journal* **54**, 448-452.
- Herrin, L.L., Collins, F.C. and Caviness, C.E. 1986. Techniques for identifying tolerance of soybean to phytotoxic substances in wheat straw. *Crop Science* **26**, 641-643.
- Kimber, R.W. 1967. Phytotoxicity from plant residues. I. The influence of rotted wheat straw on seedling growth. *Australian Journal of Agricultural Research* **18**:361-374.
- Kimber, R.W. 1973. Phytotoxicity from plant residues. II. The effect of time of rotting of straw from grasses and legumes on the growth of wheat seedlings. *Plant and Soil* **38**, 347-361.
- Kirkegaard, J. A., Munns, R., James, R. A., Gardner, P. A. and Angus, J. F. 1995. Reduced growth and yield of wheat with conservation cropping. II. Field studies in the first year of the cropping phase. *Australian Journal of Agricultural Research* **46**, 75-88.
- Köppen, W. 1923. *Die Klimate der Erde*. De Gruyter, Berlin, Leipzig. 369 p.
- Lampurlanés, J., Angás, P. and Cantero-Martínez, C. 2001. Soil bulk density and penetration resistance under different tillage and crop management systems and their relationship with barley root growth. *Field Crops Research* **69**, 27-40.
- Lampurlanés, J. and Cantero-Martínez, C. 2003. Soil bulk density and penetration resistance under different tillage and crop management systems and their relationship with barley root growth. *Agronomy Journal* **95**, 526-536.
- Leisz, D.R. 1982. Concern and cost of managing Mediterranean-type ecosystems. Proceedings of the Symposium on Dynamics and management of Mediterranean-type ecosystems (June 22-26, 1981, San Diego, California), *USDA Forest Service, General Technical Report, PSW-58*, 3-5.
- Mc Donald, M.P., Galwey, N.W. and Colmer, T.D. 2001. Waterlogging tolerance in the tribe Triticeae: the adventitious roots of *Criteseion marimum* have a relatively high porosity and a barrier to radial oxygen loss. *Plant, Cell and Environment* **24**, 585–596.
- Madariaga, R. 2003. Vida después de la muerte: Rastrojos e incidencias de enfermedades en cultivos anuales. In: *Sustentabilidad en Cultivos Anuales: Cero Labranza, Manejo de Rastrojos* (E. Acevedo Ed.), pp 157-164, Universidad de Chile, Serie Ciencias Agronómicas N° 8, Santiago, Chile.
- Malik, A.I., Colmer, T.D., Lambers, H., Setter, T.L. and Schortemeyer M. 2003. Aerenchyma formation and radial O₂ loss along adventitious roots of wheat with only the apical root portion exposed to O₂-deficiency. *Plant, Cell and Environment* **26**, 1713-1722.
- Martínez, E. 2007. Cero labranza, carbono y capacidad productiva de un suelo aluvial en la Zona Central de Chile. *Tesis para optar al grado Académico de Doctor en Ciencias Silvoagropecuarias y Veterinarias. Universidad de Chile*, 149 p.
- Martínez E., FuenteS, J.P., Silva, P., Valle, S. and Acevedo, E. 2008. Soil physical properties and wheat root growth under no-tillage and conventional tillage systems in a mediterranean environment of Chile. *Soil & Tillage Research* **99**, 232–244.
- Mubarak, A.R., Rosenani, A.B., Anuar, A.R. and Zauyah, S. 2002. Decomposition and nutrient release of maize stover and groundnut haulm under tropical field conditions of Malaysia. *Communications in Soil Science and Plant Analysis* **33**, 609– 622.
- Naveh, Z. and Dan, J. 1973. The human degradation of Mediterranean landscape in Israel. In: *Mediterranean type ecosystems, origin and structures* (F.di Castri and H.A.Mooney, Eds.). Vol.7, pp.373-390, Springer-Verlag Berlin, Heidelberg, New York.
- NREL. 2003. Biomass feedstock composition and properties database [online]. Available at http://www.ott.doe.gov/biofuels/properties_database.html.
- Olofsson, M. 2001. Rice-A Step toward use of allelopathy. *Agronomy Journal* **93**, 3-8.
- Ordóñez R., González, P., Giráldez, J.V. and Perea, F. 2007. Soil properties and crop yields after 21 years of direct drilling trials in southern Spain. *Soil & Tillage Research* **94**, 47-54.
- Perata, P. and Alpi, A. 1993. Plant responses to anaerobiosis. *Plant Science* **93**, 1–17.
- Perata, P. Guglielminetti, L. and Alpi, A. 1997. Mobilization of endosperm reserves in cereal seeds under anoxia. *Annals of Botany (London)* **79**, 49–56.

- Qin, R., Stamp, P. and Richner, W. 2006. Impact of tillage on maize rooting in a Cambisol and Luvisol in Switzerland. *Soil & Tillage Research* **85**, 50-61.
- Rajaram, S. 2001. Prospects and promise of wheat breeding in the 21st century. *Euphytica* **119**, 3-15.
- Rasmussen, P.E. and Collins H.P. 1991. Long-term impacts of tillage, fertilizer, and crop residue on soil organic matter in temperate semiarid regions. *Advances in Agronomy* **45**, 93-133.
- Reicosky, D.C., Kemper, W.D., Langdale, G.W., Douglas, C.L Jr. and Rasmussen P.E. 1995. Soil organic matter changes resulting from tillage and biomass production. *Journal of Soil and Water Conservation* **50**, 253-261.
- Renz, T.E., Neufeldt, H., Ayarza, M.A., Resck, D.V.S. and W. Zech. 1999. Microbial Biomass, microbial activity, and carbon pools under different land-use systems in the brazilian Cerrados. In: *Sustainable land management for the Oxisols of the latin american savannas* (R. Thomas and M. Ayarza Eds.). pp 187-197.
- Reyes, J.I., Martínez, E., Silva, P. and Acevedo, E. 2002. Cero Labranza y propiedades de un suelo aluvial de Chile central. *Boletín de la Sociedad Chilena de la Ciencia del Suelo* N°**18**:78-81.
- Rouanet, J.L. 1995. Uso sostenible del suelo en zonas de laderas: el papel esencial de los sistemas de labranza conservacionista. *III Reunión Bienal de la Red Latinamericana de Labranza Conservacionista*. San José, Costa Rica. p. 165-178.
- Russell, E. W. 1988. Soil acidity and alkalinity. In: *Russell's Soil Conditions and Plant Growth* (Wild, A. Ed.), pp. 844-898. 11th Edition. Wiley, New York, NY.
- Salinas –García, J.R., Hons, F.M. and Matocha, J.E. 1997. Long term effects of tillage and fertilization on soil organic matter dynamics. *Soil Science Society of America Journal* **61**, 152-159.
- Sheehan J., Aden A., Paustian K., Killian K., Brenner J. and Walsh M. 2004. Energy and environmental aspects of using corn stover for fuel ethanol. *Journal of Industrial Ecology* **7**:117– 46.
- Silva, P. 2007. Cero labranza: Alelopatía del rastrojo de trigo sobre lupino. *Tesis para optar al grado Académico de Doctor en Ciencias Silvoagropecuarias y Veterinarias*. Universidad de Chile. 99p.
- Thomas, G.A., Dalal, R.C. and Standley, J. 2007. No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics. *Soil & Tillage Research* **94**, 295–304.
- Tillman, B.A., Pan, W.L. and Ullrich, S.E. 1991 Nitrogen use by northern-adapted barley genotypes under no-till. *Agronomy Journal* **83**, 194–201.
- UNESCO-FAO. 1962. Ecological study of the Mediterranean Zone. Bioclimatic map of of the Mediterranean Region. *Arid Zone Research XXI*. 58 p.
- Uribe, H. and Rouanet J. L. 2002. Efecto de tres tipos de labranza sobre el nivel de humedad en el perfil del suelo. *Agricultura Técnica* **62**, 555-564.
- Valle, S., Martínez, E., Silva, P. and Acevedo, E. 2004. Efecto de la cero labranza en el crecimiento radical del trigo (*Triticum turgidum* L.) y propiedades físicas del suelo. *Boletín de la Sociedad Chilena de la Ciencia del Suelo* N°**20**:151-162.
- Vidal, I. and Troncoso, H. 2003. Manejo de rastrojos en cultivos bajo cero labranza. In: *Sustentabilidad en Cultivos Anuales: Cero Labranza, Manejo de Rastrojos* (E. Acevedo, Ed.),pp 57-82. Santiago, Universidad de Chile. Fac. de Cs. Agronómicas, *Serie Ciencias Agronómicas* N°**8**, Santiago, Chile.
- Watt, M., Kirkegaard, J.A. and Rebetzke, G.J. 2005. A wheat genotype developed for rapid leaf growth copes well with the physical and biological constraints of unploughed soil. *Functional Plant Biology* **32**, 695-706.
- Wilhelm, W. W. and Wortmann, C. S. 1996. Statistical analysis of wheat root growth patterns under convencional and no-tillage systems. *Soil & Tillage Research* **38**, 1-6.
- Xu, K., Xu, X., Fukao, T., Canlas, P., Maghirang-Rodriguez, R., Heuer, S., Ismail, A.M., Bailey-Serres, J., Ronald, P.C. and Mackill, D.J. 2006. Sub1A is an ethylene-response-factor-like gene that confers submergence tolerance to rice. *Nature* **442**, 705–708.
- Yang, R. and Baker, R. 1991. Genotype-environment interactions in two wheat crosses. *Crop Science* **31**, 83-87.

Breeding for improved adaptation to conservation agriculture improves crop yields

Richard Trethowan^{1*}, Yann Manes² and Tariq Chattha¹

¹University of Sydney, Plant Breeding Institute, PMB 11, Camden, NSW 2570²International Maize and Wheat Improvement Center (CIMMYT). Apdo. Postal 6-641, Mexico D.F., Mexico
(*Email rtrethowan@camden.usyd.edu.au)

Food production must be increased to meet projected global demands. However, declining investment in agriculture, reduced inputs and an increasingly variable production environment make this a significant challenge. Combining resource efficient agronomy with better adapted crop cultivars will be vital if the productivity of the world's food producing systems is to be maintained or increased. The existence of genotype x resource conserving crop management practice interactions, traits controlling these interactions and breeding strategies that can be used to improve yield under conservation agriculture are discussed.

The adoption of reduced or zero-tillage reduces erosion, improves soil structure, minimizes costs and more importantly, enhances the water use efficiency of cropping systems. However, even when zero tillage is the common practice at the farm level, often crop breeding programs do not evaluate and select segregating germplasm in conservation agricultural systems. To compound the impact, in many developing countries advanced materials are evaluated for yield and adaptation on research stations under conventional or complete tillage. These data are then used to release cultivars to farmers. In countries such as Australia, breeders have historically selected segregating materials under conventional tillage, but tested their advanced products on-farm in multi-environment trials before release to farmers, thereby sampling farmer practices in time and space.

Yield improvement is the primary goal of all crop breeding programs and to a large extent breeders use genetic resistance to maintain yield in the face of changing disease virulence. However, achieving significant improvements in underlying yield potential is considerably more difficult. The historic rate of yield increase of 1% per year since the Green Revolution (Trethowan et al., 2007) is a combination of genetic and agronomic interventions (Bell et al., 1995). The development of short-statured wheat and rice cultivars allowed farmers to apply more N, the most basic of all agronomic interventions, resulting in significantly improved yield. The semi-dwarfing genes radically changed plant morphology, significantly improving harvest index. However, it is unlikely that such dramatic improvements in yield will be observed in the future and gains are likely to continue to be cumulative over time.

Reports indicate that water will become increasingly limiting in many cropping systems (Trethowan et al., 2005). Clearly, combining water and resource conserving agricultural practices, such as zero-tillage, with better adapted, more water-use-efficient cultivars will enhance the overall productivity and profitability of most cropping systems. Plant breeding can contribute to this improvement if genotype x farming system interactions can be exploited. This paper reviews the extent of these interactions and their genetic control and examines possible strategies that plant breeders may use to improve cultivar adaptation to conservation agriculture.

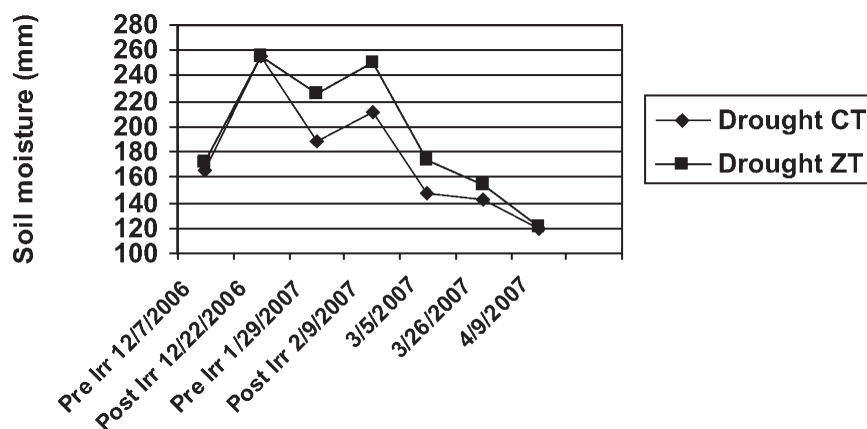
(I) Evidence of Genotype x Farming Practice Interactions in Crop Plants

The existence of genotype x tillage practice interaction is critical if plant breeders are to make progress in the development of better adapted cultivars. There is little published evidence of such interactions as much of the early work was conducted by agronomists using relatively small numbers of genotypes, all of which were developed under conventional tillage. Cox et al (1991) found no interaction in wheat. However, in a later study utilizing a more diverse range of wheat genotypes, Gutierrez (2005) found significant interactions for yield and industrial quality across vastly different environments. Non-significant interactions have been reported for barley (Ullrich and Muir, 1986), sorghum (Francis et al., 1984), rice (Melo et al., 2005) and soybean (Elmore, 1990) and conflicting results obtained for maize (Brakke et al 1983; Newhouse, 1985). In a recent study, diverse wheat genotypes were grown under contrasting tillage regimes in Australia and Mexico and no significant genotype x tillage interaction was noted (R. Trethowan and Y. Manes, unpublished data). However, in most environments the mean yield was significantly greater under zero-tillage highlighting the advantages of conservation agriculture in moisture limited environments

Table 1. Mean yield (kg ha) of tillage treatments of trials grown in Australia and Mexico in 2007 & 2008

	RK 2007†	RK 2008	GV 2007	GV 2008	
Zero-tillage	1945 a	3145 a	1359 a	2561 a	
Complete till	1658 b	2604 b	1139 b	2647 a	
	MEXRI2007	MEXFI2007	MEXDR2008	MEXRI2008	MEXFI2008
Zero-tillage	4350	6210	3340	4260	6440
Complete till	4120	5930	2730	3820	6430

† RK = red kandosol soil at Narrabri, Australia; GV – grey vertosol soil at Narrabri, Australia; MEXDR = drought trial at Ciudad Obregon, MEXRI = reduced irrigation trial at Ciudad Obregon, Mexico; MEXFI = fully irrigated trial at Cd. Obregon, Mexico

**Figure 1.** Results of soil moisture from drought conventional and zero tillage trials grown in Mexico in 2007

(Table 1). Moisture samples taken from the same trial in both CT and ZT drought treatments in 2007 confirm that zero tillage keeps more soil moisture than conventional tillage treatment, as expected (figure 1).

The non-significant genotype x tillage practice interaction may reflect a lack of genetic diversity for those traits conferring adaptation to conservation agriculture in the materials tested.

(II) Traits to Consider When Developing Crops Better Adapted to Conservation Agriculture

Once the existence of a genotype x farming practice interaction has been established, the plant breeder requires easily measured traits to drive the selection process, particularly in the early generations when the numbers of progenies from each cross combination are large. Coleoptile length (Rebetzke et al., 2007; Trethowan et al., 2001) and thickness (Rebetzke et al., 2004), emergence from depth (Trethowan et al., 2005), seedling vigour (Liang and Richards, 1999), rate of stubble decomposition (Joshi et al., 2007), root depth (Reynolds and Trethowan, 2007), allelopathy (Bertholdsson, 2005), N-use-efficiency (Ginkel et al., 2001), disease resistance (Trethowan et al., 2005) and seedling temperature tolerance (Boubaker and Yamada, 1991) are all considered important traits that influence crop establishment in zero-till systems.

Clearly, some of these traits are interrelated, such as emergence from depth and coleoptile length. However, not all the variance observed in coleoptile length explains emergence and stand establishment (Rebetzke et al., 2007) hence we can consider them to be independent characters. Although many of the references for these traits pertain to wheat, the same principles of adaptation apply to all crops.

The difficulties of applying N in conservation agricultural systems can result in N deficiency (Hobbs et al., 1998) and selection for improved N-use-efficiency can improve general adaptation (Ginkel et al., 2001). In some farming systems weed growth during early crop development can limit yield and selection for cultivars with increased early vigour or greater early biomass development will reduce weed competition. In addition, allelopathy can be a significant constraint and genetic variability for response to weed infestation does exist and can be exploited (Bertholdsson, 2005). Some Australian grain growers consider that the high levels of surface residue from previous crops makes these systems difficult to manage (R McClean, personal comm.). However, variability among wheat cultivars for the rate of stubble decomposition does exist and could enhance the acceptance of such cultivars (Joshi et al 2007).

Thermo-tolerance will also improve cultivar adaptation to early season temperature fluctuations, as the rate of emergence and general seedling vigour are influenced by temperature fluctuations. Good early vigor combined with vegetative frost tolerance is advantageous in areas where cold temperatures come rapidly after planting and early frost can occur. Nevertheless, changes in disease patterns linked to stubble retention remain the primary constraint to cultivar adaptation to conservation agriculture. The introduction of zero-till tends to increase the incidence of wheat diseases such as crown rot (*Fusarium pseudograminearum*), tan spot (*Pyrenophora tritici-repentis*) which over summer on the surface residues (Mezzalama et al, 2001), or fusarium head blight in the case of wheat rotating with maize. Nevertheless, significant genetic variation for these diseases exists in the wheat gene pool and although the inheritance may be complex, as in the case of crown rot resistance, it is possible to make significant progress in genetic resistance.

Except in the case of disease resistance where the impact on yield is obvious, most of the other traits mentioned above affect only the early stages of the crop cycle. Their impact on yield under CA practices is only putative, and remains to be confirmed. This could be done as follows:

- Evaluation of elite lines showing differential response under conventional tillage and zero tillage for expression of the traits mentioned above.
- Collection of materials which show extreme expression of the traits mentioned, followed by head-to head testing under zero tillage and conventional tillage.
- Creation of isogenic materials for traits such as coleoptile length to study responses to zero and conventional tillage.

(III) Breeding Strategies to Improve Adaptation to Conservation Agriculture using Wheat as an Example

The first step in any breeding program is to assemble sufficient genetic variability for the key target characters. There is limited variability within the primary wheat gene pool for the traits discussed in section II. However, the probability of success is improved if genetic variability can be increased. The landraces and synthetic wheats, produced by re-synthesizing hexaploid bread wheat by crossing both modern and ancestral tetraploid durum wheats with *Aegilops tauschii*, the donor of the D-genome (Mujeeb-Kazi, 2006), offer significant genetic diversity that can be crossed directly to modern bread wheat. Both these sources provide useful variability for root depth (Reynolds et al, 2007), emergence from depth (Trethowan et al, 2005), alternative sources of dwarfism that do not significantly reduce coleoptile length (Rebetzke et al, 2007), early vigour (Liang and Richards, 1999), increased specific leaf area (Olesen et al., 2004), increased seed size (Liang and Richards, 1999), improved water and N use efficiency, better seedling tolerance to temperature extremes and improved disease resistance.

Transgenes conferring herbicide tolerance can also improve crop adaptation to zero-tillage as they effectively control weed competition and need only to be deployed in one element of the crop rotation. An example is the deployment of herbicide tolerant soybean in rotation with wheat, very common in Argentina for example; weed growth in the subsequent wheat crop is significantly reduced (Cook, 2006).

A possible breeding plan for the development of wheat cultivars with improved adaptation to zero-tillage is outlined below.

- I. Screen adapted and unadapted germplasm for response to conservation agriculture measuring yield, disease and product quality to determine the extent of genotype x tillage interactions.

Locally adapted cultivars, introductions from CIMMYT and or regions where conservation agriculture is dominant, landraces and synthetic derivatives are tested under contrasting residue management practices. Yield and product quality are determined and disease screening is conducted concurrently.

- II. Identify/introduce parental materials that represent extreme expression of the traits in section II, assuming these traits really improve yield under CA practices.

Screen available germplasm for trait expression and acquire additional diversity from gene banks and the published literature. Assess all materials head-to-head and select those with the most extreme expression of the trait in the best agronomic and disease resistance background.

- III. Combine genetic diversity in crosses with emphasis on adaptation to the target conditions

Genetic diversity for the key characters in section II must be combined with those traits considered key to the target region. These include characteristic such as yield potential, stress tolerance, product quality and disease resistance. This may require backcrossing to an adapted parent or top-crossing using the adapted line as the top-cross parent. In some cases it may require multiple cycles of crossing and selection.

- IV. Implement a selection strategy to identify genotypes with good emergence and establishment and disease resistance in a zero-tillage system

Large segregating populations (F2 – F5) are screened and selected under zero-tillage. In crosses with significant variability for coleoptile length, additional pressure on emergence may be applied by deep planting these generations. If possible, field evaluation for adaptation to zero-tillage should be combined with disease inoculation. A selected bulk or modified pedigree scheme are effective methods that can be used to advance each generation.

- V. Evaluate fixed lines for response to conservation agricultural practices in the target region.

Once fixed lines have been selected, generally by selecting individual plants or spikes in the F5 or F6 generation, they are screened for disease resistance prior to testing in multi-location yield trials. These trials will represent a range of conservation agricultural practices across the target region and are usually conducted over several years. Grain yield, product quality and disease resistance are key selection goals.

- VI. Select those materials with high yield, appropriate quality and stable performance across farmer practices within the target region for release.

A significant portion of the success of any plant breeder lies choosing the correct parents and the importance of Step III cannot be overestimated. Attempting to combine too much variability is a recipe for failure as it becomes impossible to grow sufficiently large enough segregating populations to select adapted materials combining all the targeted traits. A stepwise process, where traits are combined through successive cycles of breeding, will enrich the gene pool and in time the adaptation of the derived cultivars. Of equal importance is the management of gene frequency through appropriate selection pressure in the segregating generations. For instance, deep planting is a quick and easy way to select for longer coleoptiles and better emergence, but will work only in crosses where the right genetic variability exists. Selection in zero tillage with heavy residues will probably improve emergence although it is not clear how many successive generations of selection are necessary to do so. As in any cultivar development program, the exposure of segregating generations to diseases, particularly the rusts of wheat, is critical. Once rust resistance has been established, inoculation of materials for zero-till specific disease such as tan spot and crown rot will increase the proportion of fixed lines carrying all the desired characters needed for release to farmers.

Conclusion

This paper focuses on genetic aspects of adaptation and assumes an optimized farming system. In reality this is never the case and genetic improvement and improvements in crop management will proceed hand in hand. Optimizing the choice of cultivar and resource conserving farming practice can improve the adaptation and yield potential of traditional crops. However, as climate and markets change, the distribution of crops regionally may alter if the productivity and profitability of today's farming systems are to be maintained

References

- Bell MA, Fischer RA, Byerlee D and K. Sayre. 1995. Genetic and agronomic contributions to yield gains. A case study for wheat. *Field Crops Research* 44: 55-58.
- Bertholdsson NO. 2005. Early vigour and allelopathy - two useful traits for enhanced barley and wheat competitiveness against weeds. *Weed Research (Oxford)*, 45: 94-102.
- Boubaker M and Yamada T. 1991. Screening spring wheat genotypes (*Triticum* sp.) for seedling emergence under optimal and suboptimal temperature conditions. *Japanese Journal of Breeding*, 41:381-387.
- Brakke JP, Francis C A., Nelson LA and Gardner C O. 1983. Genotype by cropping system interactions in maize grown in a short season environment. *Crop Science* 23: 868-870.
- Cook J. 2006. Toward cropping systems that enhance productivity and sustainability. *PNAS*, 103:18389-18394.
- Cox D.J. 1991. Performance of hard red winter wheat cultivars under conventional-till and no-till systems. *North Dakota Farm Research*, 48:17-20.

- Elmore R W. 1990. Soybean cultivar response to tillage systems and planting date. *Agronomy Journal*, 82: 69-73.
- Francis C A, Mohammad Saeed, Nelson L A, and Moomaw R. 1984. Yield stability of sorghum hybrids and random-mating populations in early and late planting dates. *Crop Science*, 24:1109-1112.
- Gutierrez A. 2006. Estabilidad del rendimiento y calidad de semilla e industrial de trigos harineros en ambientes de riego y temporal y sistemas de labranza. PhD thesis, Colegio de Postgraduados, Montecillo, Texcoco, Edo. de Mexico.
- Ginkel M van, Ortiz-Monasterio I, Trethowan RM and Hernandez E. 2001. Methodology for selecting segregating populations for improved N-use efficiency in bread wheat. *Euphytica*, 119:223 – 230.
- Hobbs PR, Sayre KD, and Ortiz-Monasterio JL. 1998. Increasing wheat yields sustainably through agronomic means. NRG paper, 98-01. Mexico, D.F.:CIMMYT.
- Joshi A K, Chand R, Arun B, Singh R P and Ortiz R. 2007. Breeding crops for reduced-tillage management in the intensive, rice-wheat systems of South Asia. *Euphytica*, 153:135-151
- Liang, Y. L.; Richards, R. A. 1999. Seedling vigor characteristics among Chinese and Australian wheats. *Communications in Soil Science and Plant Analysis*, 30:159-165.
- Melo, P. G. S.; Melo, L. C.; Soares, A. A.; Lima, L. M. de; Reis, M. de S.; Juliatti, F. C.; Cornelio, V. M. O. 2005. Study of the interaction genotypes x environments in the selection process of upland rice. *Crop Breeding and Applied Biotechnology*, 5: 38-46.
- Mezzalama, M., K.D. Sayre and J. Nicol. 2001. Monitoring root rot diseases on irrigated, bed-planted wheat. *Proceedings of the Warren E. Kronstad Symposium*. J. Reeves, A. McNab, and S. Rajaram (eds.). pp148-151. Mexico, D.F.:CIMMYT.
- Mujeeb-Kazi A. 2006. Utilization of genetic resources for bread wheat improvement. p.61-97. R.J. Singh and P.P. Jauhar. (eds.), CRC Series.
- Newhouse K E. 1985. Genotype by tillage interactions in maize (*Zea mays* L.). *Dissertation Abstracts International B (Sciences and Engineering)*, 45: 1973B
- Olesen J E, Hansen P K, Berntsen J and Christensen S. 2004. Simulation of above-ground suppression of competing species and competition tolerance in winter wheat varieties. *Field Crops Research*, 89: 263-280
- Rebetzke G J, Richards R A, Sirault X R R and Morrison A D. 2004. Genetic analysis of coleoptile length and diameter in wheat. *Australian Journal of Agricultural Research*, 55:733-743.
- Rebetzke GJ, Richards RA, Fettell NA, Long M, Condon AG, Forrester RI, and Botwright TL. 2007. Genotypic increases in coleoptile length improves stand establishment, vigour and grain yield of deep-sown wheat. *Field Crops Research*, 100:10-23.
- Reynolds MP and R.M. Trethowan. 2007. Physiological interventions in breeding for adaptation to abiotic stress, 2007. pp 129-146. *In* J.H.J. Spiertz, P.C. Struik, and H.H. Van Laar (ed.) *Scale and complexity in plant systems research, gene-plant-crop relations*. The Netherlands: Springer.
- Reynolds M, Dreccer F, and Trethowan RM. 2007. Drought Adaptive Mechanisms from Wheat Landraces and Wild Relatives. *Journal of Experimental Botany*, 58: 177-186
- Trethowan RM, Singh RP, Huerta-Espino J, Crossa J, and M. van Ginkel. 2001. Coleoptile length variation of near isogenic Rht lines of modern CIMMYT bread and durum wheat. *Field Crops Research*, 70: 167-176.
- Trethowan RM, Reynolds MP, Sayre KD and Ortiz-Monasterio I. 2005. Adapting wheat cultivars to resource conserving farming practices and human nutritional needs. *Annals of Applied Biology* Vol 146, pp. 404-413
- Trethowan RM, Reynolds MP, Ortiz-Monasterio JI and Ortiz R. 2007. The Genetic Basis of the on-going Green Revolution in wheat production. *Plant Breeding reviews*, Volume 28:38-58.
- Kuchel H, Williams K J, Langridge P, Eagles H A and Jefferies S P 2007. Genetic dissection of grain yield in bread wheat. I. QTL analysis. *Theoretical and Applied Genetics*, 8:1029-1041.
- Ullrich, S. E., Muir, C. E. 1986. Progress in the evaluation, use in breeding, and genetic analysis of semi-dwarf mutants of barley. Semi-dwarf cereal mutants and their use in cross-breeding II. Pp 31-38.

Adapting Wheats to Zero Tillage in Maize-Wheat-Soybean Rotation System

Man Mohan Kohli* and Jorge Frascina

BIOCERES, Moreno 878-4th Piso (S2000DKP) Rosario, Argentina; Instituto Nacional de Tecnología Agropecuaria, INTA, CC 21, 2850 Marcos Juárez, Cordoba, Argentina

Adoption of conservation agriculture, especially zero tillage and associated practices, in the Southern Cone region of South America have revolutionized the cereals and oilseeds production systems over the last two decades. Of the total 50 million hectares under zero tillage in the region, there are approximately 20 million hectares sown to grain crops in Argentina, up from less than one million hectares a decade ago. Since wheat is an export commodity for Argentina, it became important to adapt its varieties and germplasm to the newer set of cultural practices. The evaluation and exploitation of genetic variability have been for the following adaptation characteristics: uniformity of early crop establishment associated with soybean/maize stubble; need for high or low tillering capacity and plant height depending on the number of years of zero tillage and/or the rotation followed; resistance to frost damage in the vegetative (tillering) stage; stronger straw strength; synchronous heading; resistance to foliar and spike diseases especially tan spot, septoria leaf blotch and fusarium head blight; rapid grain filling or quick finish to allow early seeding of the following crop; lack of late tillers; higher yield potential etc. While it has been difficult to establish a genotype x tillage interaction in every situation, superior genotypes for either tillage environment can be observed. Their identification based on the traits mentioned above is a key to developing newer wheats adapted to zero tillage conditions. To achieve this goal, the breeding programs need to adapt to the dynamics of the physical, chemical and biological changes occurring in the soil system which permit the crops to achieve ever increasing yields as a result of higher water holding capacity and accumulated soil fertility over time.

Key words: Wheat, *Triticum*, Breeding, Adaptation, Zero Tillage, Conservation Agriculture, Lessons

The world cereal need of 2.5 billion metric tons by the year 2020 projected by the International Food Policy Research Institute (Rosegrant *et al.*, 2001) or of 2.8 billion tons by the year 2030 as projected by the FAO (FAO, 2002) is not a far fetched target to be met with the technology available at present and others that are under development. However, these production increases are not likely to occur by bringing increased area under agriculture as done in the past. Most of the opportunities to bring new agricultural land under cultivation have already been exploited. While there are large unexploited tracts of land in Africa and South America, only some of it will eventually come into agricultural production. Bringing world's unexploited but potentially cultivable lands into agricultural production poses formidable challenges not only in terms of sustainable technologies but also needs expensive infrastructure development.

Besides global challenges on food production, the farmers in the Southern Cone countries of South America (Argentina, Bolivia, Brazil, Chile, Paraguay and Uruguay) faced traditional challenges, such as soil erosion or degradation, the loss of cropland to non-farm uses, an ever increasing demand for production inputs, the volatile world food prices and a dire need to produce more but with sustainable technologies. Intense cropping without proper rotations, lack of fertilization and exploitive soil tillage were major elements of soil degradation and deterioration of the best agricultural areas of the region. Soil erosion and a decreased fertility were major factors for stagnation of Argentine cereals and oilseed production between the 1940s and 1970s. These tasks required reshaping the region's farming systems to allow simultaneous achievement of a higher level of productivity, sustainability and profitability in order to be adopted widely. The production revolution seen over the last two decades is primarily based on the soil and water conservation programs.

Adoption of conservation agriculture, especially zero tillage and associated practices have not only helped increase the cereals and oilseeds production but also improved the farm economy by making agriculture a profitable enterprise. As a result, the area under zero tillage in the region increased from less than one million hectares in 1989/90 to almost 50 million hectares in 2005/06 (Fig. 1). During the same period the combined production of wheat, maize and soybeans almost tripled from 76 million tons to over 230 million tons (FAO, 2008).

In Argentina, the rapid adoption of conservation tillage practices combined with adequate rotation and fertilization as well as introduction of Round Up resistant soybean varieties have resulted in a historic increase in grain production. Almost two thirds of the 30 million hectares sown to grain crops in Argentina are under zero tillage and the

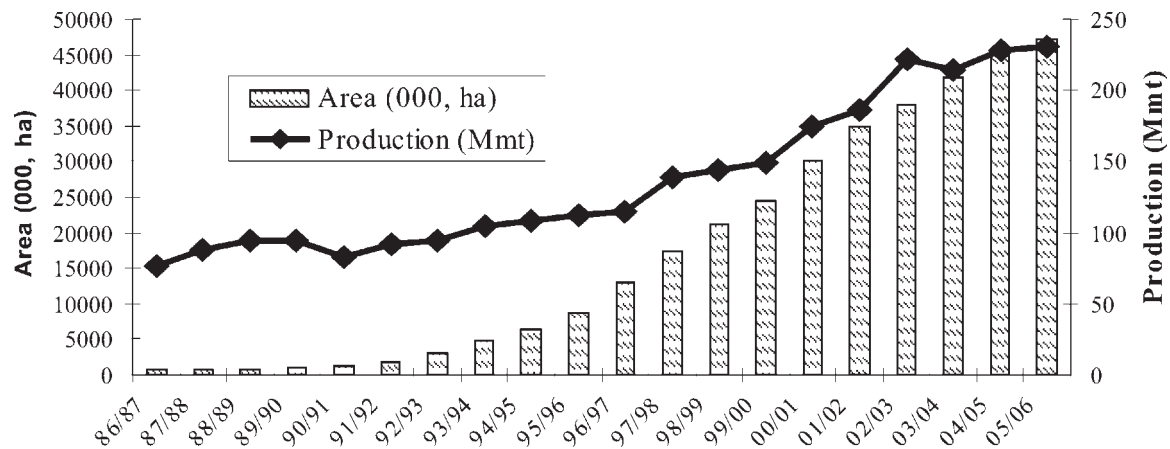


Figure 1. Increase in the area under zero tillage and combined production of wheat, maize and soybeans in the Southern Cone countries

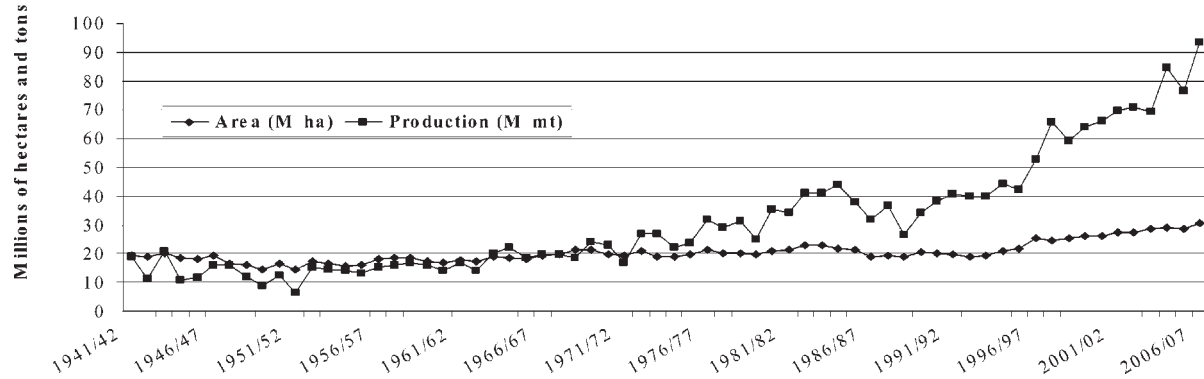


Figure 2. Evolution of Argentine cereals and oilseed area and production, 1941-2007 (SAGPyA, 2008)

production of cereals and oilseeds has increased from 40 million tons to almost 100 million tons in a decade (Fig. 2).

Considering that zero tillage was introduced, modified and promoted by the farmers all over the region, it took some time before the researchers realized its benefits and adopted the technology on their experimental fields. Benefits from zero tillage practices are now well recognized including reduced erosion, improved soil structure and infiltration, reduced runoff and water conservation etc. From the stand point of crop improvement, varieties developed under conventional tillage have been used till now but the agronomic characteristics that provide better adaptation to zero till conditions are continuously being identified.

Inclusion of Wheat in the Agricultural Rotation

In the drier parts of the wheat region, the precipitation towards the end of the summer crops (maize and soybean) leaves an excess of water in the soil thus providing a unique opportunity to grow a winter crop and add more stubble cover on the soil. A wheat crop is seen to use this water very efficiently by transforming it into biomass and grain and also provide well distributed stubble with a high C/N ratio (Fraschina *et al.*, 2008). Another less seen contribution of the winter cereal crops to the system is their root mass. The characteristic root system of wheat conducts a true "biological tillage" by breaking the compaction caused by the transit of the machinery during harvest of the summer crop. Gerster *et al.*, 2006, believe that wheat, with its stubble cover and root mass, contributes to an adequate implementation of the zero tillage system. In general, the quantity of stubble a wheat crop will leave on the soil surface depends more on the grain yield of a variety than the variety *per se*. However, at same yield level, there are some varieties that leave relatively more stubble than others (Fraschina *et al.*, 2006).

Given that most of the wheat crop in Argentina and other parts of the region is grown in rotation with soybean and maize, the knowledge of specific traits needed to improve its adaptation has led to large scale germplasm screening. Some of the lessons learnt in the process and key germplasm characteristics identified under zero tillage are discussed in this paper.

Agronomic Characters of Importance under Zero Till Conditions

Early Plant Vigor and Crop Establishment

The maintenance of crop residue on the soil surface is one of the major components of zero tillage in the Southern Cone region. Depending on the quantity and quality of the crop residue and its degradation before the seeding of wheat crop, early crop vigor and stand establishment have become important characteristics to screen for. In a series of experiments, Abbate *et al.* (1997) observed significant genetic variability among Argentine wheats for early crop growth. At mid tillering stage the average dry weight of the foliar mass of a variety varied between 500 and 745 g/m². While the purpose of the study was to measure radiation use efficiency (average 2.5 MJ/m²/d¹) and rate of crop growth (average 25 g/m²/d¹) to correlate it with the total number of grains/m² and grain yield, these differences have become very useful to identify varieties with much needed early ground cover in the dryland agriculture.

Given that higher water accumulation under zero tillage allows the farmers in Argentina to seed facultative or early winter wheats, a new set of experiments is underway to determine similar variability for early vigor in this germplasm (Abbate pers.comm). Initial results presented in the Fig. 3. demonstrate that varieties with winter growth habit (BAG 21, BIO 2004, Nogal and JN 5007) differ significantly in their capacity to produce early biomass on per plant or per plot basis. Higher biomass production per plant of the intermediate or facultative types at the tillering stage also coincided with higher biomass production per plot and seemed to be genetically controlled.

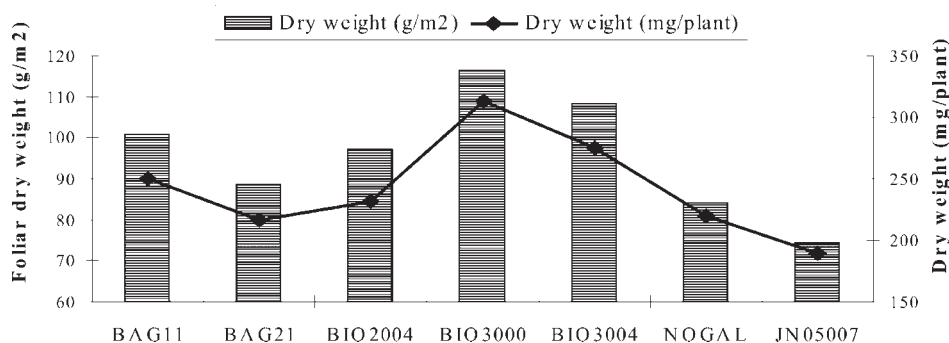


Figure 3. Differences among wheat varieties for total biomass production at mid tillering stage

Uniform crop establishment in fields with higher quantity of stubble, especially after maize, has been another common problem. The difficulty arises from the lack of seed placement at uniform depth, often on the stubble and not in contact with the soil, thereby promoting frost damage in the seedling stage. While a large kernel size would theoretically provide nutrition for a longer period of time to reach the first leaf through coleoptile stage, no such differences were observed. It seems to be a problem for the engineering companies to solve with new seeding machines that are capable of providing a uniform stand even under higher stubble situations.

Tillering Capacity, Plant Height and Stubble Yield

Depending on the number of years of zero tillage, crop rotation schemes and climatic conditions of a region, the need for high or low tillering capacity and stubble yield has become apparent. In its initial stages of adoption or for the lack of maize or other cereal crops in the rotation in the warm dryland regions, the fields under zero tillage retain very little quantity of crop residue. As a result, wheat varieties with higher tillering capacity and biomass production (such as tall dwarfs) were better adapted than lower tillering varieties. However, as the stubble retention on the soil surface increases with the passage of years and/or from the inclusion of cereal crops in the rotation system, lower tillering varieties are preferred because wheat stubble not only decomposes slowly but also provides a hot bed for the disease pathogens.

Wheat Group of INTA, Marcos Juarez, conducted two on farm trials in the drier part of the Pampas region during 2006-07 to demonstrate significant differences in stubble production associated with high or low tillering capacity and plant height among spring and facultative wheat varieties. Both farms, in Monte Buey and Corral de Bustos, have used zero tillage for almost two decades. The rotation followed in Monte Buey, wheat-soybean II/maize/soybean I, represents a crop of wheat every third year; while that in Corral de Bustos, wheat-soybean II/maize, represents a wheat crop every second year. The data presented in the Table 1 shows that the facultative wheats, seeded early, retain marked differences in the stubble they leave on ground at the harvest time at both locations. However, in the case of spring wheat varieties these differences are only clear if the crop comes on the maize stubble (Corral de Bustos), representing higher water profile in the soil. Spring crop seeded on the soybean stubble (Monte Buey), meaning less water in the profile at the time of planting, leads to more competition among higher tillering germplasm. As a result there is more tiller loss in this germplasm compared to low tillering varieties which end up producing more stubble and even grain yield.

Table 1. Tillering capacity, plant height and stubble yield of selected facultative and spring wheats at two locations in the dry Pampas region of Cordoba Province, Argentina

Varieties	Tillering capacity/ Plant height	Stubble (tons/ha)	
		Monte Buey (wheat on soybean stubble)	Corral de Bustos (wheat on maize stubble)
Facultative wheats			
Baguette 11	Low/Short	8.6	11.4
BIOINTA3004	Interm./Interm	11.7	11.5
BIOINTA3000	Interm./Tall	11.6	12.1
Klein Gavilan	High/Tall	13.2	12.7
Spring wheats			
Baguette P 13	Low/Tall	11.8	9.8
Klein Tauro	Low/Tall	11.9	9.2
BIOINTA1001	High/Interm.	10.2	12.7
Cronox	High/Interm.	10.7	10.7

Resistance to Frost Damage in the Vegetative (tillering) Stage

Resistance of genotypes to changes in high and low temperature is a critical trait for germplasm adaptation to zero tillage in the Southern Cone region. There are common spells of high temperature regimes (high 20s and low 30s C°) of several days in the middle of the winter season that promote higher crop growth. Whenever such a period of lush growth is followed by a sudden fall in the temperature leading to frost, severe loss (burning) of biomass in the susceptible germplasm is observed. There are significant varietal differences in both facultative and spring wheat germplasm. In addition, these differences are further accentuated by the type of rotation used and the amount of crop residue on the soil surface which modifies the duration of the low temperature. In general, a susceptible wheat variety is more likely to suffer severe damage following a maize crop (higher crop residue) than a soybean crop which leaves less stubble.

A field classification of major Argentine wheat varieties for their reaction to early frost damage is presented in the Table 2. Although farmers have been seeding both resistant and susceptible wheat varieties through the years, their strong inclination to add maize or some other cereal crop to the rotation system (to generate more stubble) in the drier regions is slowly changing the varietal picture in favor of frost resistant varieties. Therefore, breeding for frost resistance has become an important goal in the wheat program. A genetic analysis of the frost resistant germplasm shows that most of them have some vernalization requirement Fu *et al.* (2005). However, varieties carrying similar genetic combination for known vernalization genes (Vrn) still show marked differences in the frost resistance indicating thereby the presence of additional modifying factors or other frost resistance genes in the germplasm.

Plant Height and Stronger Straw Strength

Heavy ground cover, as one of the key components of zero tillage, is promoted in the region not only to reduce the erosion but also to help retain higher humidity in the soil profile. Additional dynamics of the physical, chemical

Table 2. Field classification of major Argentine wheat varieties to frost reaction

Facultative wheats	VrnA1*	VrnB1	VrnD1	Frost resistance**	Spring wheats	VrnA1	VrnB1	VrnD1	Frost resistance
ACA 303	w	s	s	S	B 75 ANIVERSARIO				S
BCHACARERO	s	s	s	S	BAGUETTE 9	s	w	w	MR
BGUAPO	w	s	w	R	BAGUETTE P 13	w	w	s	S
BAGUETTE 10	s	w	w	MR	BIOINTA 1000	w	s	w	S
BAGUETTE 11	s	w	w	S	BIOINTA 1001	w	s	s	MR
BAGUETTE 19	s	w	w	MR	BIOINTA 1002	w	w	s	R
BIOINTA 2002	w	s	w	MR	BIOINTA 1004	s	w	w	MR
BIOINTA 3000	s	s	s	S	CRONOX	w	s	s	MR
BIOINTA 3003	w	w	w	R	ICHURRINCHE	s	s	w	S
BIOINTA 3004	s	s	s	S	ICONDOR	s	s	w	S
KL CARPINCHO	w	s	s	S	KL CASTOR	w	w	s	MR
KLESCORPION	w	s	s	S	KL CHAJA	s	w	w	S
KL GAVILAN	s	w	s	MR	KL TAURO	w	s	s	S
PPUNTAL	w	w	w	R	ONIX	w	s	s	MR
S NOGAL	w	w	w	R	PGAUCHO	w	s	s	MR

*Vernalization gene analysis conducted by Dr. Marcelo Helguera, INTA, Marcos Juarez

** R= Resistant, MR= Moderately resistant and S= Susceptible

and biological changes occurring in the soil system are making it a better productive system in a continuous manner. The higher water holding capacity and accumulated soil fertility over time have allowed farmers' to use agronomic practices that achieve ever increasing yields in all crops. Higher crop yields mean more stubble for ground cover leading to the next cycle of improvements of the system.

In the highly productive systems in the humid regions, lodging associated with plant height and weak straw is a problem. In parts of Southern Argentina inter seeding of soybeans between the standing rows of wheat before its harvest is being evaluated (Abbate pers comm.). This gives the farmers an advantage to seed soybeans almost a month in advance resulting in higher yields and economic benefits. Under this system of inter seeding, varieties with weaker straw strength are unacceptable. Given the wide variability in germplasm for plant height, selection of semi dwarf varieties is a general norm. Although semi-dwarf varieties suffer a serious reduction in height and biomass under drier conditions, this situation is less likely to occur on well managed zero tillage farms. In general weaker straw strength of the regional germplasm is associated with selection for low input environments. As a result of this negative trait the locally bred varieties are losing ground to high yielding French germplasm with stronger straw strength.

As the productive systems improve with zero tillage and the economic criteria favors to maintain its dynamics, stronger straw strength in high yielding varieties will become an important selection asset.

Resistance to Diseases

Frequent rainfall and moderate temperature during the winter and early spring produce a highly predisposing environment for several disease pathogens that attack wheat in the Southern Cone region (Antonelli, 1983; Kohli, 1985). However, only a few of them, especially of fungal origin, develop in a sufficient manner or have wide distribution to constraint wheat production seriously. A few of these acquire more significance under conservation agriculture due to little or no removal of the stubble from the soil surface or when the correct rotation scheme is not followed. Relatively slow decomposition of the wheat stubble in the major wheat growing region allows it to be colonized by facultative parasites which constitute as a bridge for the crop the following year (Annone and Kohli, 1996).

Wheat-soybean sequence of crops every year in the acid soils of Brazil led to serious infection by Take All root disease caused by *Gaeumannomyces graminis* var. *tritici*, earlier known as *Ophiobolus graminis* (Reis, 1990). Although Take All infection was observed to increase by incorrect liming practices, it was wheat followed by wheat that really accentuated the seriousness of the disease under Zero Tillage system (Table 3). Incorporation of black oats and horse radish in the rotation system to replace wheat during the one or two winter seasons, not only improved the soybean yields but also the wheat yield significantly.

Table 3. Effect of tillage system and liming on the spread of Take All disease of wheat in Brazil (Reis, 1990)

Tillage system	Take All incidence (%)		Average
	Control	Limed	
Zero tillage	10.2	36	23.1 a*
Conventional Tillage	7.6	6.4	7.0 b
Average	8.9 B	21.2 A	

* Averages followed by different letters indicate significant statistical differences (0.05P).

Table 4. Stubble quantity managed under different tillage systems and its relation to the inoculum of *B. sorokiniana* and *D. tritici-repentis* in Brazil (Modified from Reis *et al.*, 1992)

Treatment	Conservation tillage		Conventional tillage	
	Zero	Minimum	Disc plough	Mould Board plough
Wheat residue (g/m ²)	271.1	170.8	36.1	12.4
Percent	100	63	13	6
<i>B. sorokiniana</i> (spores/m ²)	159 x10 ⁶	9.99x10 ⁵	2.11x10 ⁵	7.27x10 ⁴
<i>D. tritici-repentis</i> (pseudotecia/m ²)	11653	7310	1548	516

Foliar and spike diseases, caused by various species of *Alternaria*, *Fusarium*, *Helminthosporium* and *Septoria*, are all related with the wheat stubble left on the soil surface and have become more severe under zero tillage system. Of these, tan spot caused by *Pyrenophora tritici-repentis* (Died.) Drechs. (telomorph of *Drechslera tritici-repentis* (Died.) Shoem. has become of worldwide importance and is associated with the increase in the conservation agriculture (Gilchrist *et al.*, 1984; Hosford, 1982; Kohli *et al.*, 1992, Rees and Platz, 1992). Early in the adoption of zero tillage in Brazil, Reis and colleagues (1992) measured the number of *Pyrenophora* and *Drechslera* spores under different tillage systems to demonstrate the need for correct crop rotation as a key to the success of conservation agriculture (Table 4). In this case again, the addition of black oats in the rotation system has become critical to the continued wheat production in the humid parts of the region.

In addition to tan spot the frequency of the epidemics caused by *Fusarium* head blight, FHB, (*Fusarium graminearum*) under zero tillage has also increased significantly. Given that maize is one of the favored crops to add extra stubble in the rotation system, it has also become a major source of FHB inoculum to infect wheat (Table 5). Galich *et al.* (1994) demonstrated the impact of maize crop on the FHB infection; indicating thereby a strong need evaluate the rotation system practiced to generate high quantity of stubble. In spite of its economic importance, leaf rust disease caused by *Puccinia recondita*, does not modify its infection pattern based on the tillage system.

Table 5. Disease index and severity of *Fusarium* on wheat based on tillage system and preceding crop (Galich *et al.*, 1994)

Preceding crop	Severity (%)		Disease index	
	Zero tillage	Minimum tillage	Zero tillage	Minimum tillage
Maize	47.0	33.6**	46.3	31.0**
Soybean	38.3	34.8*	37.1	31.8**

*: Statistically significant at 0.05 P and **: Statistically significant at 0.01 P.

While there is significant variation in the germplasm for resistance to individual diseases, most of the high yielding varieties lack a combination of resistance to diseases prevalent each year. The most difficult of the combination is to foliar blights such as septoria leaf blight and tan spot and FHB in the southern humid regions and that of spot blotch, *Alternaria* leaf blight and FHB in the northern humid regions. In a series of experiments conducted in Uruguay to understand the tillage x germplasm interaction, its most important component was defined by fungicide application to control the diseases (Table 6).

The climatic conditions of the years were variable enough (data not shown here) to impact the disease development significantly, which in turn effected the cultivar performance and its interaction with the tillage system. In a combined analysis over the years, the cultivar x fungicide interaction remained strongly significant over the years (P 0.004) while cultivar x tillage interaction remained significant at a lower level (P 0.063).

Table 6. Statistical analysis (Pr > F) in Type 3 tests of fixed effects of tillage interactions

Effects	2001	2002	2003
Tillage	0.366	0.08	0.869
Fungicide	<.0001	<.0001	0.002
Tillage x Fungicide	0.004	0.229	0.979
Cultivar	<.0001	<.0001	<.0001
Tillage x Cultivar	0.075	0.005	0.414
Fungicide x Cultivar	0.0005	0.003	0.002
Tillage x Fungicide x Cultivar	0.66	0.382	0.77

Synchronous Heading, Rapid Grain Filling and Quick Finish

The Southern Cone wheat germplasm, in general, lacks synchronous heading. In extreme cases the heading period in some regional cultivars can extend over weeks. While non synchronous heading escapes severe damage caused by spike diseases or frost, increased flower abortion and grain filling under high temperature conditions result in lower grain yield and physical quality characteristics. The rapid adoption of high yielding French germplasm in Argentina is not only due to its stronger straw strength but also to synchronous heading which allows uniform grain development and better spike fertility.

Baethgen (1998) reported the grain filling period to be one of the two critical periods in grain yield formation in the region. He also identified minimum temperature and solar radiation as two fundamental factors affecting this period. However, there are large parts of the region affected by high temperatures during the grain filling period. In addition wheat cultivation has expanded to newer and warmer regions in the lowlands of Bolivia, central Brazil and Paraguay.

In order to determine the variability for grain filling in Northern Paraguay, 1000 grain weight (TKW) at 25 and 35 days after heading was measured as a percent of TKW at the harvest time. Compared to Estanzuela Cardenal (Cordillera 3 in Paraguay) of Baethgen study, a rapid grain filling variety, and other local varieties which filled almost 80 and 90 percent of their weight at 35 days, several others filled the grain almost 100 percent, Fig. 4. Such a variation in grain filling characteristic under high temperature conditions is of key importance to be exploited especially when a second crop of soybean needs to be seeded on the same land.

Besides rapid grain filling, a quick finish without shattering is another useful character to allow an earlier seeding of the soybean crop. A quick finishing variety, such as PROINTA Puntal, can be harvested almost a week or more earlier than other varieties seeded on the same date. Data from official trials conducted at INTA Balcarce, Argentina, where lower temperatures generally favor longer grain filling period, PROINTA Puntal matured on an average 4.9 days before the average of the trial over a five year period, Fig. 5, (Abbate unpublished). Such quick finish did not seem to hurt its average yield over the years (5704 kg/ha), which was 451 kg/ha over the average of the trial. However, a comparison of P. Puntal with Jagger and Baguette 10, another popular variety of French origin, conducted at INTA Marcos Juarez did not demonstrate any significant difference in the rate of grain filling between them (Fraschina unpublished).

Lack of Late Tillers

Significant differences among the varieties for their susceptibility to producing late tillers have been observed. The production of late tillers which affects the normal harvest is caused by precipitation after a prolonged period of drought, freezing damage or by lodging of a crop. At present such a condition is being dealt by the farmers through application of desiccants. Given the genetic variability available for this character, its inclusion in the desirable traits to be selected is becoming important.

Higher Yield Potential

Ferrari (1998) conducted long term yield trials on wheat/soybean-maize and wheat/soybean rotation schemes on two types of soils to report a 3-8 percent decrease in grain yield under zero tillage when compared to conventional tillage. It raised serious questions regarding specific needs to identify or develop high yielding germplasm adapted to zero tillage conditions considering a genotype x tillage interaction shown by Hall and Cholick (1989). As a result,

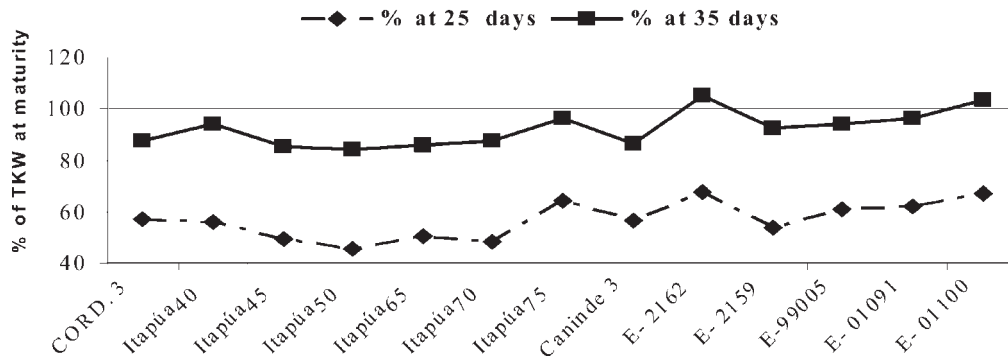


Figure 4. Relative grain weight of selected wheat varieties at 25 days and 35 days after heading compared to it at harvest time. Yjovy, Paraguay, 2003-04.

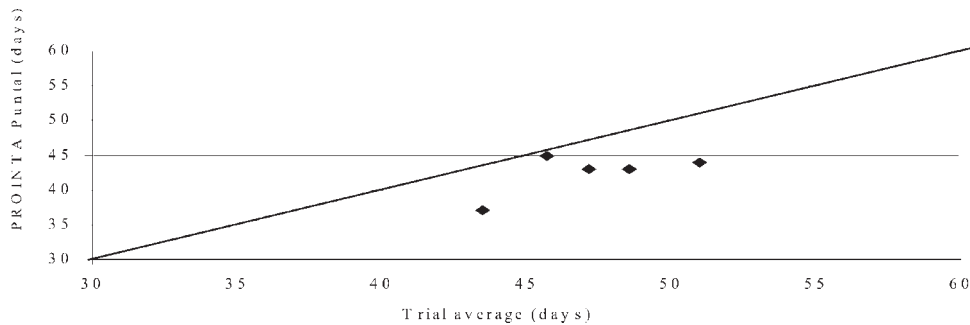


Figure 5. Days between heading and maturity of PROINTA Puntal wheat variety compared to the trial average at INTA Balcarce, Argentina

Kohli *et al.* (1999) analyzed a large number of agronomic characteristics to propose an ideotype that will adapt better under zero tillage conditions. Trials conducted in Uruguay during 2001-03 confirmed the Cultivar x Tillage interaction but also observed it to be seriously effected by the level of fertilization and disease control, Fig. 6, (unpublished data).

Malbran *et al.* (2008a) studied similar interaction of facultative wheat varieties under very dry conditions in Argentina (Fig 7). In their study the precipitation during the critical period, when grain yield and quality is defined, was 54 percent lower than the historical average. In addition, high temperature during this period accentuated the evapo-transpiration and demand for more water by the crop. Such conditions allowed visualizing the effects of the tillage systems on the crop development, grain yield and quality parameters. Contrary to the earlier results, grain yield of all varieties under test improved under the zero tillage. Some advanced lines (LACL 04 and 09) performed

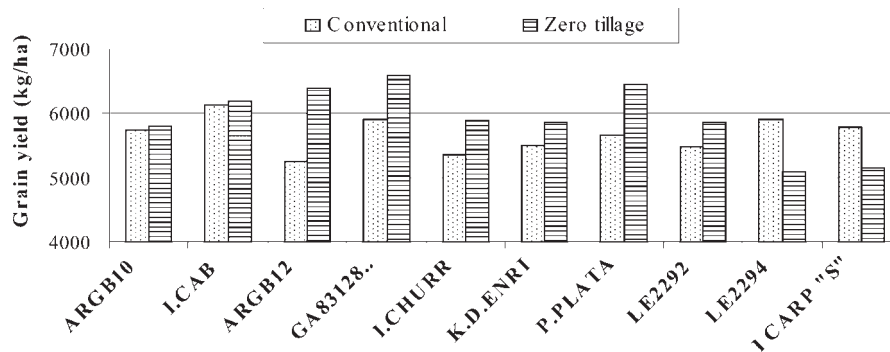


Figure 6. Grain yield of ten cultivars under two tillage systems, La Estanzuela, Uruguay

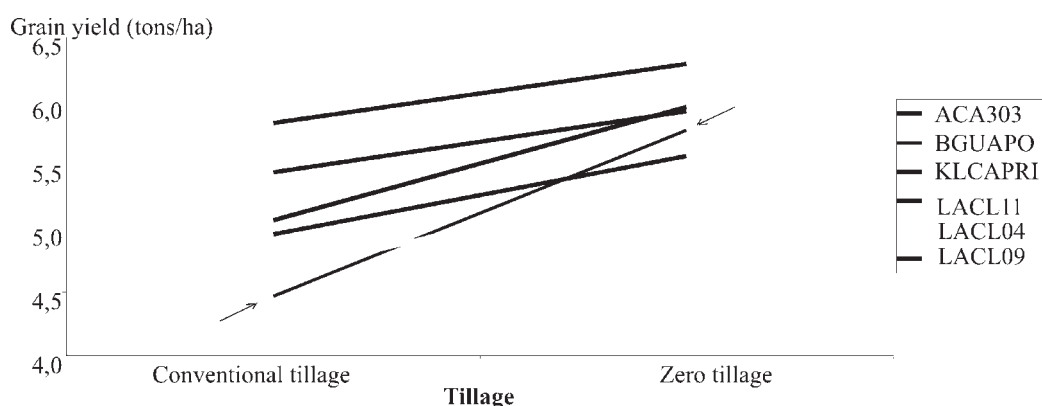


Figure 7. Grain yield of six facultative wheats under two tillage systems in Argentina. (modified from Malbran *et al.*, 2007)

relatively better under conventional tillage conditions while Buck Guapo variety produced much higher yield under the zero tillage. Quality parameters measured in this study, such as percent protein and gluten, test weight and thousand kernel weight, suffered a serious loss under the zero tillage conditions due to lower nitrogen availability in the trial. A similar study on the spring wheats failed to demonstrate similar interactions. (Malbran *et al.*, 2008b).

Another recent study compared grain yield of several wheat advanced lines at an experiment station (INTA Marcos Juarez, MsJz.) and a nearby farmer's field at Corral de Bustos (CB) Figs. 8 a, b, c, d. MsJz adopted the zero tillage in the year 2000 while CB field had adopted the system more than a decade earlier. In the year 2000, higher yields obtained at MsJz are indicative of germplasm adaptation to conventional tillage. In the year 2007, although the grain yield increased at both locations, the facultative wheats still perform relatively better at MsJz (Fig 8b) indicating that varieties specific to zero tillage are still not developed (high incidence of the FHB). While spring wheats yield similar at both locations, there are significant differences among the lines selected at each location (Fig 8d). The only plausible explanation can be the lack of stubble cover at MsJz compared to CB trials, which not only points to a strong influence of the stubble on the selection of varieties but also shows wider germplasm variability for grain yield in the spring wheat germplasm. A correlation analysis between these two locations over the years (not shown here) demonstrates that, four out seven years, they fall in different groups indicating thereby a strong year x cultivar x management interaction observed in Uruguay.

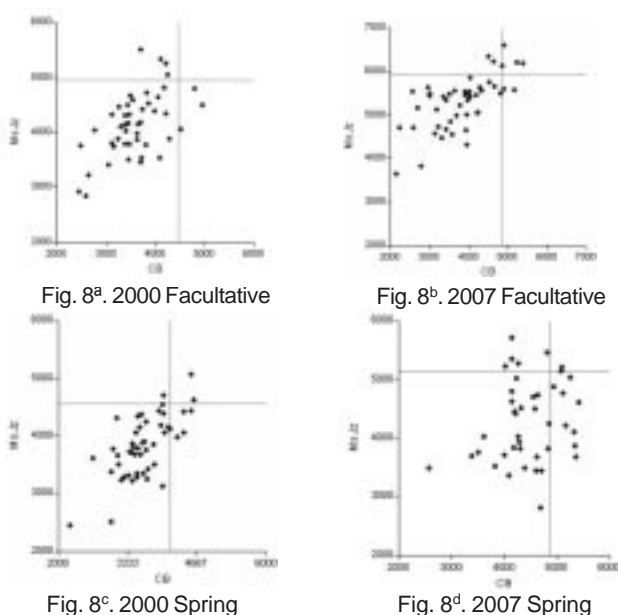


Figure 8. Grain yield of wheat advanced lines in two environments differing in stubble quantity on the soil in the year 2000 and 2007

In general, Argentine farmers have an impression that early seeding of facultative wheats not only allows good initial stand helped by higher soil humidity under zero tillage but also results in higher grain yield. However, in a recent study, Fraschina *et al.* (2008) found no difference between the grain yield potential of the facultative and spring wheat varieties. The only significant difference observed during one year was due to lower nutrient use efficiency caused by winter drought and late rains that effected spring wheats more than the facultative wheats.

The results discussed so far demonstrate that any Cultivar x Tillage interaction observed in a study depends on multiple factors including crop rotation followed, stubble quantity and quality, fertilization, frost injury, disease incidence and the environmental conditions of the year etc. As the development of newer germplasm under zero tillage conditions receives more attention and becomes successful, a significant increase in the grain yield is expected to follow.

Conclusions

Adoption of conservation tillage practices, especially zero tillage, in the Southern Cone countries has not only reduced erosion related soil losses drastically but also increased the productivity and profitability of wheat/soybean-maize or wheat/soybean-maize-soybean rotation schemes. Over the years wheat yields under zero tillage have increased benefiting from higher water accumulation and soil fertility caused by better stubble management. Although some Tillage x Cultivar interactions have been observed in the dryland areas, they are not always clear and/or significant. Such interactions are accentuated by the amount of stubble, nutrient availability and the environmental conditions of the year which in turn impact the disease incidence and severity.

In order to improve adaptation of wheat germplasm to zero tillage, selective exploitation of genetic variability in some agronomic characters such as crop cycle, early stand establishment, tillering capacity, frost and disease resistance and grain yield is seen essential. The specific combination of these traits required to develop a variety may differ from one geographical region to another depending on its climatic conditions and the crop rotations followed. Yet, the development of zero tillage specific germplasm will not only help achieve ever increasing yields but also guarantee the sustainability of production systems over a long period of time.

Acknowledgements

We thank Dr. Pablo Abbate of INTA Balcarce for sharing some of his unpublished data with us.

References

- Abbate, P.E., Lazaro, L. and Andrade, F.H. 1998. ¿Es posible incrementar el numero de granos por unidad de superficie en trigo? In: *Explorando Altos Rendimientos de Trigo* (M.M. Kohli and D. Martino Eds.). La Estanzuela, Uruguay, Octubre 20 al 23, 1997. Uruguay CIMMYT-INIA.
- Antonelli, E. 1983. Principales patógenos que afectan la producción del trigo en Argentina. In: *Simposio sobre Fitomejoramiento y Producción de Cereales*. Special Report 718. Agric. Exp. Station and Crop Science Dpt, Oregon State University. pp. 93-114, Marcos Juárez, Córdoba, Argentina. 7 al 12 de noviembre de 1983. INTA-Oregon State University-CIMMYT.
- Annone, J. G. and Kohli, M. M. 1996. Principales Enfermedades del Trigo Asociadas con la Siembra Directa en Argentina: Importancia y Medidas de Protección. In: *IV Congreso Internacional Siembra Directa*. 27 al 30 de marzo. Villa Giardino, Córdoba, Argentina.
- Baethgen, W. 1998. Utilización de modelos de simulación para estimar potencial de rendimiento de trigo. In: *Explorando Altos Rendimientos de Trigo* (M.M. Kohli and D. Martino Eds.). La Estanzuela, Uruguay, Octubre 20 al 23, 1997. Uruguay CIMMYT-INIA.
- FAO. 2002. World agriculture towards 2015/30, an FAO study. Rome.
- FAO. 2008. FAOSTAT. <http://www.fao.org>
- Ferrari, M. 1998. La siembra directa y el rendimiento de los cultivos en la Pampa Húmeda. In: *1er Seminario Siembra Directa: Experiencias el INTA mirando al futuro*. Pp 191-196. Oct 1997. Buenos Aires. Hemisferio Sur. INTA, 1998.
- Fraschina, J., Salines, J., Bainotti, C., Gomez, D., Cuniberti, M. and Alberione, E. 2006. Evaluación de variedades de trigo en campos de productores en siembra directa. Campaña 2005. In: *Trigo: Proyecto regional producción agrícola sustentable en la provincia de Cordoba*. Marzo, 2006, INTA. Argentina.
- Fraschina, J., Salines, J., Bainotti, C., Gómez, D., Donaire, G. and Alberione, E. 2008. Evaluación de variedades de trigo en campo de productores durante los años 2005, 2006 y 2007. Comparación de ciclos. In: *XVI Congreso Quo Vadis*. AAPRESID, Rosario, Argentina.

- Fu, D., Szucs, P., Yan, L., Helguera, M., Skinner, J., Vonzitzewitz, J., Hayes, P. Dubcovsky, J. 2005. Large deletions within the *VRN-1* first intron are associated with spring growth habit in barley and wheat. *Mol Gen Genomics* **273**: 54-65.
- Galich, M.T.V., Galich, A., Masiero, B., Galarza, C. and Gudelj, V. 1994. Aspectos de manejo de cultivo que influyen en la infección de *Fusarium graminearum* en trigo. In: *Actas del III Congreso Nacional de Trigo y Primer Simposio Nacional de Cereales de Siembra Otoño Invernal*. pp. 209210. Bahía Blanca, Buenos Aires, Argentina. 2628 de octubre de 1994.
- Gerster G., Cordone, G. and Bacigaluppo S. 2006. El trigo en la rotación. Crecimiento de raíces en suelos compactados. *Trigo Actualización 2006*, EEA INTA Marcos Juárez, **IAT n° 1**.
- Gilchrist, L., Fuentes, S., and M. de la Isla de Bauer. 1984. Identificación de *Helminthosporium tritici-repentis* (= *Pyrenophora trichostoma*) agente causal de un tizón de la hoja de trigo en México. *Agrociencia* **56**: 151-162.
- Hall, E.F. and Cholick, F.A. 1989. Cultivar x Tillage Interaction of Hard Red Spring Wheat Cultivars. *Agron. J.* **81**:789-792.
- Hosford, R.M., Jr. 1982. Tan Spot. Pp 1-24. In: *Tan Spot of Wheat and Related Diseases. Workshop*. R.M. Hosford, Jr. (Ed.) pp 116. North Dakota State University, Fargo.
- Kohli, M.M. 1985. Identifying wheats adapted to more tropical areas of the Southern Cone of South America. In : *Wheats for More Tropical Environments*. pp. 111-115, UNDP/CIMMYT.
- Kohli, M.M., Mehta, Y.R. and Ackermann, M.D. 1992. Spread of tan spot in the Southern Cone region of South America. In: *Advances in Tan Spot. Proceedings of the Second International Tan Spot Workshop*. L.J. Francl, J.M. Krupinsky, M.P. Mc Mullen (Eds). pp.86-90. North Dakota State University, Fargo, ND. June 25-26, 1992.
- Kohli, M. M., Annone, J. G. and García, R. (1999) Germoplasma de trigo específicamente adaptado a Siembra Directa: Análisis de factibilidad. In: *7º Congreso Nacional de Siembra Directa*. AAPRESID. Mar del Plata, 18 al 20 de agosto de 1999.
- Malabran, I; Acciaresi, H.A. and Chidichimo, H.O. 2008a. Evaluación del comportamiento de trigo frente a distintos sistemas de labranza en relación al rendimiento y la calidad comercial II: Genotipos de ciclo largo. In: *VII Congreso Nacional de Trigo*. Santa Rosa, La Pampa, Argentina. 2-4 de julio, 2008.
- Malabran, I; Acciaresi, H.A. and Chidichimo, H.O. 2008b. Evaluación del comportamiento de trigo frente a distintos sistemas de labranza en relación al rendimiento y la calidad comercial II: Genotipos de ciclo corto. In: *VII Congreso Nacional de Trigo*. Santa Rosa, La Pampa, Argentina. 2-4 de julio, 2008.
- Rees, R.G. and Platz, G.J. 1992. Tan spot and its control-Some Australian experiences. In: *Advances in Tan Spot. Proceedings of the Second International Tan Spot Workshop*. pp. 1-9. (L.J. Francl, J.M. Krupinsky, M.P. Mc Mullen Eds.). NDSU, Fargo, ND. June 25-26, 1992.
- Reis, E.M. 1990. Control of disease of small grains by rotation and management of crop residues in southern Brazil. In: *Proc. Intl. Workshop on Conservation Tillage Systems; Conservation Tillage for Subtropical Areas*. pp 140-146. CIDA/EMBRAPA-CNPT, PF, Brazil, 1990.
- Reis, E.M., Santos, H.P.S., Lhamby, J.C.B. and Blum, M.C. 1992. Effect of soil management and crop rotation on the control of leaf blotches of wheat in southern Brazil. In: *Congreso Interamericano de Siembra Directa*. pp.217-236. AAPRESID. Villa Giardino, Cordoba.
- Rosegrant, M.W., Paisner, M.S., Meijer, S., and Witcover, J. 2001. Global Food Projections to 2020: Emerging trends and alternative futures. 224 pp. IFPRI Report. 2001.
- SAGyP. 2008. <http://www.sagpya.mecon.gov.ar>

Challenges and Prospects to Realize Diversified Agriculture in the Tropics: The Brazilian Savannah Case

Carlos R. Spehar

*Faculdade de Agronomia e Medicina Veterinária, Instituto Central de Ciências Ala Sul,
C. Postal 4.508 Brasília, DF, Brasil CEP 70.910-970
(Email: spehar@unb.br)*

In view of predicted world population, the pressure over natural environments shall increase considerably. Induced changes in climate, causing weather fluctuations, compound to affect crop performance by drought or excess rain when they are not needed. Additionally, more demand on agricultural products requires high amounts of fertilizers, forcing prices to move upwards. Combination of these factors and their interface are serious threats to agriculture and to mankind. The Brazilian Savannah development has been marked by key events to face intrinsic and extraneous challenges, leading to efficient production. The large-scale occupation, intensified in the 1960's by beef cattle ranchers, was marked by vicious clearance of exceedingly diverse vegetation and disregard to the environment. Great advances on research, especially crop breeding have revolutionized this scenario, turning the savannah into a major food and raw material producer. Prevailing cropping systems, however, have based mostly on soybean and maize, causing income reduction, due to bad soil management and pest and disease problems. These have forced changes of which the most recent comprise the use of zero-till, associated with crop diversification. The former has picked up quite rapidly, while there is a slow move towards introducing innovative crops for soil protection and income source. Considerations about diversified and balanced agro-systems are presented, indicating directions for participatory research and development. The successful experiences and respective outcome serve as template, guiding initiatives in similar, potentially developing, world-wide areas.

Key words: breeding, diversification, innovative crops, zero-till, participatory research.

Many tropical regions of the world have not realized the potential for environmentally balanced efficient production. The Brazilian Savannah, as an example of can be done, had incipient agriculture until the 1960's, despite covering a large cultivable territory all year round. Mostly subsistence activities were secluded into patches of naturally fertile soils in midst of the Cerrado, the local name for savannah. Technological approaches to land use had been extended from traditional areas in Brazil (Spehar, 2008).

Commodity cycles in the traditional areas were confined to former Atlantic Rain Forest, at the expense of devastating exuberant flora and fauna. Possessing reasonably fertile soils, by requiring little input soon after land clearing, they could be exploited for a long period, before replenishing nutrients. Farmers had a chance to capitalize, although were not aware that soils would be depleted, either by the exported end product or poor management (Spehar, 1998; 2008). Such agricultural systems were not sustainable.

In view of this, the savannah land of Brazil had a negligible contribution, with its unfertile soils (Ferralsol group) bearing little production capacity in their natural state (Goedert, 1986). The main activities were restricted to beef cattle ranching, wood for fuel and charcoal, subsistence staples, and native fruits production on extractive basis.

Only a sparse population was found in its domain, originated from pioneer beef cattle ranchers' settlement. No considerable trading, having impact on the country's economy was registered and production was inefficient, requiring large areas. The ratio cow/area was very low, around 5.0. Long distances, associated with lack of technology and understanding on how to manage environmental attributes, were major setbacks (Spehar, 1998).

Pioneer research had identified, as early as 1950's, the need of lime and phosphate to amend savannah soils (Harrington & Sorenson, 2006). These were starting points for strategic management, triggering the changes to the Cerrado scenery.

At that time, technology, however, was not fully available, although few experiments with grain crops were conducted in the savannah core. These actions, expressing the concern about food supply to the inhabitants of Brasília - the newly built capital, yielded encouraging results to further action. The pioneer initiatives, demonstrating responsiveness of crops, once soils were improved, inspired public policies for research and development, culminating with the creation of institutes in the early 1970's (Spehar, 2008).

The Key to Development

The savannah lands of Brazil, although possessing setbacks were managed long before the modern conquest (Spehar, 1998). Beef cattle ranching activity relied on scheduled burning for the re-growth of native grasses. At this phase their forage is most utilized by livestock, yielding economical results only because of its reduced production cost. There was little prosperity and the living conditions of local populations were very modest, based on mining scarce nutrients from soils (Spehar, 2006).

There were favourable aspects that long attracted the attention of producers from other parts of Brazil. These were i) defined rainy season and ii) vast flat areas, easy to mechanize and suitable for annual crops. Modern settlement, however, needed the support of knowledge and technology to incorporate entrepreneurial agriculture. Even when these became available, it was difficult for common farmers to undertake the conquest of savannahs. The main factors reducing the prospect of rural populations were isolation from the rest of the country, lack of education and training to overcome soil problems and to profit from major investments opportunities (Spehar, 2008). So, this huge area, covering one fourth of the country, remained neglected for a long time (Spehar, 1998).

It must be emphasized that, along time, naturally fertile land in Brazil was restricted and over farmed in the traditional zone. Natural resource exploitation model, marking the tradition on agriculture and rural development, was a dead end in itself (Navarro, 2001).

A combination of forces drove the Cerrado and other parts of the country into a new paradigm of development, shifting from extensive ranching into intensive, modern and profitable agriculture. Incorporation of technologies, culminating with no-till and crop diversification, is discussed, giving examples and insights useful in similar conditions.

Natural Trends and the Human Factor

The success in Brazilian Savannah settlement relied on the support for research and development. Without sound information on soil amendment, constructing fertility, the inertia would still prevail. Even though the necessary knowledge to make use of savannah land was being generated, it needed on-farm testing and application (Spehar, 2008).

The actions of research, including crop adaptation, soil and plant management and protection, the ones on development and extension have been associated with effective entrepreneurial attitude of pioneer farmers. The emptiness was gradually filled by settlement of medium to large farm holds, which brought expertise and capacity from the traditional zone of agriculture in Brazil. Their associations, with the inclusion of family farmers, have facilitated technical assistance with improved efficiency (Spehar, 2008).

Concomitant to the settlements, acquisition of technology was strategic. Embrapa (the Brazilian Corporation for Agricultural Research and Development), at the national level, in addition to the state institutes, played a key role. So did demonstrations and validations, while preparing farmers to launching commercial production. The organized extension service, with similar functioning structure, was equally important (Spehar, 2008).

Improved agricultural colleges, associated with research, development and extension, acting together with farmers' participation, was paramount to assure best practices accessibility, leading to biological and economically efficient production (Spehar, 2006).

Permanent search for appropriate technology has resulted in creative solutions being added to the existing frame. Absence of soil movement, associated with protective crops in diversified systems has been the most recent approach. It has been accessible to the range of farmers: from family farms up to large-scale homesteads. As a result, all sectors related to agriculture, have benefited from the process of settling the savannah (Spehar, 2006).

The output has caused positive impact on Brazil's economy, turning the country into a major food supplier, diminishing national famine threat. Before this accomplishment, large quantities of food and agricultural raw material were imported, originating huge deficit in the balance of trade. Considerable decrease in prices of agricultural goods at the consumer level has been the consequence of applied technology. The resulting food, fiber, wood and more recently agro-fuel productions, besides supplying the country's demand, have attracted the international commodity market (Spehar, 2006).

The national development plan, supporting the Brazilian capital move to the hinterland, had relevant effect on the changes. The need to overcome major limitations and the adjustments to it are pointed out, aiming at realized

improvement at the farm. Even though Brazil has reached apparent stability, by the help of Cerrado's conquest, there are set backs in need to be addressed, one of them is lack of diversified production systems.

Land Incorporation, Agricultural Evolution and Threats

The old model of soil exploitation, related to land tenure concentration, aggravated the state of the country's economy. Available land was in the hands of few estate owners, where extensive, sole-crop agriculture compensated for reduced efficiency. As a consequence, small family holds, located in southern Brazil, originated from foreign immigrants, became limited in their perspective for future generations and. With population increase, farmers were forced to search for new areas (Spehar, 2008).

These family farm establishments were the place where skills developed, in addition to the aspirations already maintained by the immigration spirit. At the same time, soybeans became an important cash crop. Its prices in the international market were attractive, with advantages added by subsidies, creating conditions for expansion. Motivated, farmers soon mastered technology for soil improvement. The big jump at this phase was the introduction of high performance soybean genotypes from Southern USA into Southern region (Spehar, 1994). The two areas are located at the same latitude, even though in different hemispheres.

Agricultural advances in the Cerrado have been a result of acquired technology and respective application in the farm. It amplified the prospect for reclaiming and improving soils, turning them agriculturally viable (Spehar, 1998). Extension service and education were added and complemented by strategic public policies, incorporating savannah land into production. Key research advances shall be discussed further in the paper.

The initial efforts, based on the understanding of environment and soil functionality, were to adapt major staple and commodity crops to these conditioners; and to define soil and plant management for competitive yields. Socio-economic studies, to understand the local existing populations and their production scheme were carried simultaneously (Spehar, 1998). In addition, farming conditions and farmers' skills were improved, with the prospect of social organization in the new environment.

On the infrastructure side, the access to new capital, placed in the core of Cerrado, was made possible by new roads, connecting the most distant regions in country. The aim of these communication infrastructures was to integrate the vast territory into the nation and to facilitate the flow of inputs and agricultural products.

Additional factors such as, low prices of land, incentives for clearing virgin savannah, and facilities for storage stimulated farmers to move from southern Brazil to the agriculture frontier. Road transportation, however, was economically viable at that time, when crude oil was abundant at low prices. Efficient energetic solutions for economical exploitation have led into agro-fuel. In addition, applied technology, increasing average yields of main commodities is needed to compensate shipment costs (Table 1). Inter-modal transportation is under construction, to diminish cost factor in most distant areas (Spehar, 2008).

Table 1. Yield evolution ($t\ ha^{-1}$) for major crops, from 1975 to 2005, compared to the potential identified by research

Crop ¹	Average Yield			Increase Rate (1975-2005)	Potential Yield ²
	1975	1993	2005		
Soybean	1,32	2,20	2,81	113	4,5
Maize	1,57	2,70	4,36	177	10,5
Upland Rice	1,03	1,20	2,32	125	3,5
Phaseolus Beans	0,48	0,71	1,83	281	3,0
Wheat	2,80	3,95	5,23	87	7,0
Cotton	1,60	2,63	3,64	127	4,5
Coffee	0,82	1,33	2,35	187	3,5

Adapted from Spehar, 2006. ¹rain fed crops, except wheat; ²average research yields.

Integrated transportation associated with the improvement of seaport and storage capacity and hydroelectric power availability have consolidated development. Soybean price and respective production cost, for different regions, however, illustrate the need to rationalize infrastructure. If the national average yield of $2.7\ t\ ha^{-1}$ is considered, farmers in most distant states may not pay the production cost. (Table 2). Efficiency increase, although necessary, demands farmers' training to achieve highest output/input ratio, reducing the gap between potential and obtained yields.

Table 2. Distance effect on income for major soybean producing States

State	Distance ¹ (Km)	Received Price ²	Production Cost ³ (US \$ ha ⁻¹)	Net Income ⁴
Rio G. do Sul	500	613	545	68
Paraná	500	613	545	68
São Paulo	500	613	545	68
Minas Gerais	700	587	545	43
Mato Grosso ^a	1,200	555	570	-15
Mato Grosso ^b	1,800	525	550	-25
Goiás	1,200	555	570	-15
Bahia	1,000	565	570	-5
Tocantins	1,200	555	570	-15

¹Average distance of production areas to port or industry; ²Average price in 2006; ³Regional average yield = 2.7 t ha⁻¹; ⁴Net income = received price - production cost; ^asouthern; ^bnorthern.

Adding to efficiency, the use of ecological solutions, diminishing demand for high energy requiring input and reducing CO₂ emissions, has placed the Cerrado into a reference for tropical agriculture. This is the case of no-till, by suppressing soil movement, a new paradigm for advanced agriculture (Spehar, 2006). The change from raw material supplier into transformed products, with appropriate incentive, has attracted industry to its domain, adding value to raw material (Spehar, 2006). Major achievements need to be implemented, by encompassing crop diversification with associated efficiency, leading to clean agriculture to supply food demand (Spehar, 2005). Moreover, production systems should consider the induced climatic changes, with direct impact on agriculture. These require strategic partnerships to adjust production systems in the whole planet (Spehar, 2008).

Agricultural Potential and Development

The Brazilian savannah was unknown in the world and over shaded by the Amazon rain forest. Its importance for agriculture is higher than the plains of North America, Europe, Argentina and Australia (Spehar, 2006). The common points with the even larger African Savannahs are the poorly fertile soils, although being best supplied by water.

Savannah realms dominate the central part of Brazilian highlands, being influenced and affecting other major eco-physiographic regions such as Amazon Rain Forest, semi-arid Caatinga, Atlantic Rain Forest and Pantanal (Spehar, 2006). They cover huge catchments, being the origin of many rivers of major South American basins. Agricultural activities in the domains should be equitable and environmentally balanced, for long-term, agro-ecological exploitation (Spehar & Landers, 1997).

Technologies for plant and soil management, and the use of economical rates of lime, gypsum, phosphate, potassium, nitrogen and micronutrients, have changed the scenario (Goedert, 1986). Adapting crops and livestock to the environment and respective husbandry have been associated to soil amendment (Spehar, 1994). The technological outcome yielded competitive systems, to be validated in the territory, allowing marginal areas to develop.

There are important factors to depict from this unique experience. These are related to research and development focused on major problems, previously identified by survey. Considerations on the weight of environment components have been necessary to acquire technology for exploitation at economical levels (Spehar, 2006).

Resource characteristics, such as the climatic influences, the soil types, main vegetation features and composition, its fauna and mineral deposits are the key to utilize and manage them suitably. The association of agronomists, biologists and ecologists has been the up-to-date approach directed at the agro-eco-system, respecting the natural forces conditioning this unique biologically rich biome (Spehar, 2006).

Changes Leading into Modern Production

Outstanding performance on grain, fiber, and fruit crops marks the participation of savannahs in the national production (Spehar, 2006). Considerable contribution is being achieved by the use of only a small fraction of the total arable land. If all crops, including pasture, are considered, quite a large proportion (about 40 %) of the savannahs has been occupied (Spehar, 2008).

Table 3. Physical and chemical analysis of a typical savannah Ferralsol

Area	Physical				Chemical				
	Sand	Silt	Clay	OM ¹	pH	Al	Ca+Mg	P	K
	g dm ⁻³					cmol _{c+} kg ⁻¹		mg dm ⁻³	
Virgin	340	190	450	2.0	4.7	1.9	0.4	0.9	16
Amended ²	-	-	-	-	5.6	0.0	3.4	8.0	50

1- Organic Matter; 2 – Addition of lime, phosphate fertilizer and the FTE micronutrient source, as investment; potassium added annually.

Annual crops and pasture associations of aluminium-tolerant upland rice, combined with brachiaria grass, marked the beginning. The overgrazing for many years, by “mining” scarce nutrients, has led to chemical conditions close to native savannah (Spehar, 1998). The early erratic experience opened the way for zero-till, associated with crop-livestock systems. Comparison of virgin to improved soil (Table 3), illustrates the extent of changes in fertility needed to prepare for commercial production. In summary, 4 t lime and 240 kg P₂O₅ ha⁻¹ are used in reclamation. Most important is to master what and when to replenish on the basis of expected yield. Organic matter (OM) is reasonably high in most virgin areas and extensive experimentation data illustrate its value in cation exchange capacity (CEC), water retention and soil favourable physical properties (Silva et al., 1994).

Thus, degraded pastureland can be reverted by accommodating annual nutrient demanding crops and pasture, associated with rational beef and milk productions (Spehar, 2006). This ensures a quite spectacular prospect, indicating the savannah is to become the largest area of continuous agriculture in the tropics. Predictions for 2050, based on present figures and improved technology, indicate major gains impacts on the economy (Table 4). Advances are expected on the implementation of already occupied area, where grain crops increase their participation by three fold, while beef production doubles. Other crops will increase their value, like sugar cane and other agro-fuel crops. With added value, the impact on the agribusiness has a projected value of US \$ 350 billion dollars (Spehar, 2006). This envisions a consolidated and prosperous Brazilian hinterland, turning farmers independent of government support for education, health, housing and transportation, while their capitalization should reflect positively in the regional infrastructure (Spehar, 2006).

Table 4. Cerrado utilization, production and value: present and future

Utilization	Area (ha) (million)	Present (2008)		Future (year 2050)	
		Production (million)	Value (US\$ billion)	Production (million)	Value (US\$ billion)
Pasture	60.0	78 AU ¹	7.8	140 AU	14.6
Grain Crops	15.0	50 t	9.5	160 t	33.6
Other ²	33.5	-	3.5	-	20.0
Total	108.5	-	20.8	-	68.2

Adapted from: Spehar (2006). ¹AU=Animal Unit, irrespective of development phase and weight; ²vegetables, fruits, cotton, coffee, sugarcane, wood.

In summary, the key research and development outputs that have contributed to these advances are: definition of amendment techniques to overcome soil chemical set backs; improved crops, tolerant to savannah climatic and soil hindrances; crop husbandry for economical production and suitable soil management. More is waiting to develop, using the lessons of experiences and accumulated knowledge, adjusting technology for creative solutions and breaking of paradigm (Spehar, 2008).

Commodity Cropping Advances and Impacts

Upland rice-pasture pioneer cropping was followed by winter cereals. More than 20 years ago, it was demonstrated wheat was adaptable to the savannahs, fetching 5t ha⁻¹ on irrigated areas (Silva et al., 1976; Silva & Andrade, 1983). Genetic improvement was the key for its adaptation. Nutritional hindrances were first identified, inspiring other studies to solve similar problems on major field crops (Spehar, 2006). Irrigated wheat, after continuous variety selection, has reached 8t ha⁻¹. It is the highest yield in the world, considering 120 days of plant cycle, between emergence and maturity. Selected genotypes in the tropics can be tested and adapted for similar areas.

Barley, grown until 10 years ago only in subtropical areas of Brazil, has been adapted to the savannahs. Cultivar acquisition, a result of partnership with private enterprises, shows high yields in experimental fields (5 to 6 t ha⁻¹) and protein content lower than 12%, within the quality standard required by malt industry. The results with summer and winter cereals are a demonstration of advances for their cultivation in the tropics (Embrapa, 2005).

Identification of late flowering soybeans, in low latitudes, has been the major factor for savannah development. The incorporation of long juvenile trait, inductive of late flowering, allowed plant growth for combine harvest, with higher yields than traditional cultivars, extending soybeans into tropical and equatorial regions (Spehar, 1995; Spehar & Souza, 1999). In addition, savannah soils abide actinomycet fungi, which are antagonistic to nitrogen-fixing bacteria, preventing nodulation. Selected genotypes suffered from N-deficiency due to *Streptomyces* spp. (Coelho & Drozdowicz, 1979). Thus, adaptation of soybeans combined genotypes with tolerant Bradyrhizobium strains.

Selection of early to mid-cycle cultivars has contributed to reduce climatic risks and to the opportunity of double cropping and sowing expansion (Embrapa, 2006; Spehar, 1995; Spehar & Souza, 1999). Acquisition of genetically modified (GM) cultivars has reduced pesticide use, with lower production costs and environmental gain. To add value, family farmers have grown organic soybean, by using genotypes with special characteristics, creating alternative for food and trade. Moreover, produce transformation in the property allows adding value on milk, hogging and poultry productions.

Crop improvement by accumulating adaptive genes has been extended to other commodities. In general, it comprises germplasm introduction, characterization, selection, hybridization, progeny evaluation and regional and uniform trials, culminating in the recommendation of hybrids and cultivars. The continuity on this procedure has resulted in considerable increase in numbers of superior genotypes, possessing high and stable yields on integrated production systems (Spehar, 2005). New genotype release has been associated with seed production, assuring access to effective input (Spehar, 1994).

The virtual absence of frost and extended rainy season, are favourable conditions creating opportunity for diversified cropping (Spehar, 1998). When irrigation is available, at least three full grain crops per annum are possible. Cropping associations and sequences can be arranged, ensuring production stability. Soybeans and maize monocrops need the synergetic effects of other potential species. Thus, phaseolus beans, wheat, barley, and less exploited grains and fibbers are gradually fitting in (Spehar, 2006).

Among the summer cereals, maize has shown considerable yield gain. Coming from the long tradition in agriculture, this crop has been incorporated into the food habits and raw material for livestock feeding. Its importance in the savannah land has grown, closely connected with soybean expansion. This crop has been a measure of technology adoption, where yields vary from less than 1 t ha⁻¹ to outstanding performance (>10 t ha⁻¹). Hybrids and open-pollinated varieties have created conditions for its economical cultivation to suit different farming conditions, responding for 35% maize production.

Contrasting with the best yielding hybrids, requiring high input, including seed cost, there are the open pollinated varieties (Machado & Fernandes, 2001). These are of low cost, useful to amplify double cropping under certain risk conditions, to reduce diseases and pests, to increase offer, improving food and feed security.

Rice cultivation in the savannah has declined, since soybeans have taken its place in savannah agriculture. The reason behind reduced area has to do with susceptibility to drought and diseases and the low grain quality, due to weather instability. Selection of dry land rice varieties, aimed at high grain quality and disease resistance, has created conditions for its return to the savannahs at a high technological standard. In rainier areas, the end-product is comparable to paddy rice from other regions in the country (Embrapa, 2007).

Sunflower is a crop showing outstanding performance in the savannah soils. Research has consolidated the crop as an alternative for diversification. Sixty-five thousand hectares have been grown in the Brazilian savannahs, or about 80% total. This has been based on crop adaptation to succeed soybeans in double-cropping scheme (Embrapa, 2005).

Cotton has been associated with the local culture since old times. It is a crop that, in certain occasions, became important to the Brazilian economy. Before the big rush to the savannahs, there were early settlements, established in naturally fertile patches. In these, cotton predominated at family farm holds (Spehar, 2006). Decline in prices and increasing pest problems due to its sole cultivation were major setbacks. Technology adjustments to savannah soils resulted in modern cotton production, or 74% of total. Its insertion into cropping systems has been

a result of variety acquisition, definition of nutritional needs and proper plant husbandry. Its rotation with other annual and perennial crops has improved management, diminishing pest and disease problems (Embrapa, 2005).

Kenaf, industrial fiber plant, has shown as potential crop for the savannahs, after being introduced in the 1990s. The extraordinary adaptability has been demonstrated in cropping systems, in succession to main summer crops (Spehar, 2008). Increasing demand for its fiber make it prone to be cultivated in large areas, by using available technology for cultivar, seed production, husbandry, soil fertilization, harvest and fiber extraction.

Innovation in Savannah Cropping Systems

With increasing demand for healthy and innovative food, agro fuel and other raw material, some under-explored crops have the opportunity in the production systems. Crop diversification on commercial basis has just been touched. Non conventional sowing such as relay and mixed species is being under study, although suffering from limited resources. This area deserves much attention and, unfortunately has received little. Only a few initiatives have been put into action, generating interesting pioneer results (Spehar, 2008).

By studying the performance of synergistic plants, such as pigeon pea (*Cajanus cajan*), kenaf (*Hibiscus cannabinus*), grain amaranth (*Amaranthus* spp), quinoa (*Chenopodium quinoa*) and other named innovative crops, new advances can be achieved to enhance production (Rocha, 2008). Examples are presented to illustrate possibilities.

The Grain Amaranth and Quinoa Example

Quinoa (*Chenopodium quinoa*) and amaranth (*Amaranthus caudatus*, *A. cruentus* and *A. hypochondriacus*) are grain species introduced and adapted to savannah cultivation. They have some common characteristics, such as high quantity and quality protein, and absence of gluten. These attributes make them useful to special diets due to protein quality, low cholesterol food (Spehar, 2007a; 2007b). Even though belonging to distinct botanical families, i.e., Chenopodiaceae and Amaranthaceae, their general composition in carbohydrates, fat and protein is proportionally close to the cereals. They are excellent source of iron, calcium and manganese, surpassing the other grains. That is why, after being neglected by the scale agriculture of the world and kept secluded to the regions of their origin, they are being re-discovered in modern times. Many other crops will follow.

These two grains, also known as pseudo-cereals, can be utilised as feed and in ration for domestic animals. In swine and poultry, they are more advantageous than maize and soybeans, for being naturally balanced in essential amino-acids (Spehar, 2007a; 2007b). This quality gives them also the chance to participate in human diets, improving the standards of food quality in the world. Their adaptability into the savannah environments, gives the opportunity for a better prospect of food security in developing countries.

Since there was virtually no work with these crops in Brazil, until the late 1980's, an ambitious programme was initiated. After germplasm introduction and selection, pioneer cultivars have been acquired and a technological package has become available for commercial production. The best performing progenies were included in sowing date and plant population trials. Foliar analyses have indicated their needs in nutrients, defining maintenance fertilization. Harvest techniques and post-harvest handling have culminated with a technological package for commercial production (Spehar, 2007a; 2007b).

The average yield of pioneer cultivars is superior to 2.0 t ha⁻¹, possessing market-sought characters. The great opportunity of introducing them in double-cropping, following maize, soybean or phaseolus beans is the low cost in seed increase and other input., while fetching attractive price in the market (Table 5). As production increases, reductions in price are expected, even though profitable and advantageous to the system (Spehar, 2003).

The quinoa and grain amaranth cases have become reference to other pioneer initiatives aiming at introduction of diversity into cropping systems. The highly diversified native vegetation inspires the attempt to create new paramount production chains aiming at a long term prospect (Spehar, 2006).

Similar small grain plant species can be combined for *cocktail* relay sowing, giving opportunity fill gaps during the rainy season. Considering most savannah areas of the world have limited rain fall, their sowing over the maturing soybean maize, phaseolus beans and other summer crops allows best moisture use.

Table 5. Quinoa and maize production cost, income and net profit¹

Item	Unit	Quantity		Price	
		Maize	Quinoa	Maize	Quinoa
Mineral Oil	l	0.50	-	2.25	-
Desiccant	l	3.00	-	30.15	-
Seed	kg	20.0	15.0	141.00	15.00
Seed Treatment	kg	0.30	-	18.00	-
Fertilizer 8-20-20	kg	500.00	400.00	255.00	204.00
Insecticide	kg	0.03	-	5.50	-
Herbicide 1	l	0.50	0.50	38.00	38.00
Herbicide 2	l	3.00	-	25.40	-
N Band Application 1	kg	160.00	80.00	49.00	24.50
N Band Application 2	kg	160.00	60.00	62.90	23.60
Weed Management		-	-	-	90.00
Indirect Cost	R\$			474.78	474.78
Total Cost	R\$			1,101.98	824.88
Yield	T ha ⁻¹			7.20	2.00
Income	R\$			1,440.00	2,000.00
Net Profit	R\$			338.02	1,175.12

¹ US \$1.00=R \$2.10; values and exchange rates for 2006.

The Challenge for Diversification

Production systems, to develop and reach stability levels, have to be harmonized with the natural forces (Spehar, 2008). Agricultural systems that include rotation, association and succession of crops, of unique botanical characteristics, i.e., different genus and families, are a target to be pursued, mainly in the tropics. Suitable combinations contribute to improve the biology of these systems, in addition to food security and the onset of new markets (Spehar & Souza, 1993; Spehar, 2007a; 2007b).

There are great challenges to achieve a diversified and balanced system. Crop improvement relies on the introduction of plants with special characteristics. Thus, drought and acid soil tolerance, efficiency of nutrient and waster use, tolerance to shade and adaptability to unconventional sowing, such as relay, are desirable. These plants should maximize the commercial product (grain, for example), while leaving considerable amounts of residues to protect the soil. They should contribute new products for human and livestock, cycle nutrients and increased income (Ascheri, et al., 2002; Spehar, 2002; Spehar & Santos, 2002; Spehar, 2007a; 2007b). Their inclusion results biological, economical, social and environmental optimization.

Adaptation has been based on progeny selection, followed by trials for cultivar acquisition; definition of cultivation methods, such as sowing dates, plant population, fertilization and sowing methods; identification of uses in domestic culinary and industry; connection of demand with farmers, launching the production chain (Ascheri, et al., 2002; Rivero, 1994; Spehar, 2007a; 2007b; Spehar & Santos, 2002; Spehar et al., 2003, Teixeira et al., 2002). Broadcast by media agents has contributed greatly to initiate demand, by the prospect of improving diets of city dwellers. The combination of interests on innovative crops to improve diversified farming, shall cause positive impact in the production chains.

In the effort to adapt novel crops, high importance is ascribed to genotype selection (Rocha, 2008). These, before recommendation to farmers, are evaluated in different environments, using the respective control (Spehar, 2007a; 2007b).

On the other hand, experimentation based on small plots, is not always replicated in farming areas, aimed at commercial production. In general, these are small seeded plants, with specific soil requirements, for which there is need to define a minimum technological package (Spehar, 1998; Spehar, 2000). By converting limitations into advantages, low-cost, sowing methods can be improved to fit these crops into existing gaps. Under this prospect there is opportunity for income on competitive basis (Spehar et al., 2003).

On the biological aspect, new diseases and pests have become epidemics, which are promiscuous to the main crops. Among them, there quite a few examples such as: white fly (*Bemisia* spp.), white mold (*Sclerotinea*

sclerotiorum) and *Pratylenchus brachyurus* nematode. On the latter, little is known about novel crops reaction (Inomoto et al., 2007).

Considering sanitary benefits, the research results, for crops whose production chain is still being developed, are indicators of the changes that are to take place in agricultural systems (Spehar, 2007a; Spehar, 2007b). In addition to grain amaranth and quinoa, other such crops are being studied, as kenaf (*Hibiscus cannabinus*), sesame (*Sesamum indicum*), safflower (*Carthamus tinctorius*), guar (*Cyamopsis tetragonolobus*), okra, aibika and musk mallow (*Abelmoschus* spp.), enlarging the prospect for diversity. These species may combine relay and mixed cropping, for maximal yields (Spehar, 2008).

In order to materialize the technologies for diversification, amplifying the range of possibilities, it is necessary to invest in all levels, mainly on communication. The on-farm experimentation, should involve crop and soil management, aiming at the validation of techniques. Comprehensive agronomic coverage should be complemented by adding value and leading to commercial production. These actions should be contemplated by appropriate public policies favouring diversified cropping.

Advantages by the Insertion of Innovating Crops

Synergy to production systems is the first advantage in need to be best understood. Wild sunflower (*Thitonia diversifolia*), for example, is a mycorrhiza multiplier, favouring the succeeding crops that might be dependant of these soil borne fungi. They form associations with most plants, improving phosphorus uptake efficiency. The plant is perennial and herbaceous, turning its management easy to be done and being useful in weed control (Spehar, 2008). Knowledge on plant performance, in multi-cropping, should take into account interactive these effects. There is a lot to be done, discovering the benefits of associations, sequences and rotations, similar to the natural environments. In native savannah, inhabitants create means for reciprocal survival (Spehar, 2007a).

Many of these newly introduced crops do not multiply soil borne fungi and pests such as nematodes of great impact, especially in sandy soils (Inomoto et al., 2007). The great options turn higher the chances to establish favourable, synergistic and biologically balanced cropping systems.

One relevant point turning feasible the introduction of less exploited crops is the innovation in sowing methods. Even though relay sowing is desirable to improve farmer performance, much information is needed to consolidate the technique (Trecenti, 2005). A major advantage is given by the great multiplication rate, allowing farmers to produce their own seeds. They may also be used as a second choice, when the first option for double cropping does not work. Synergy to the cropping system may become an asset, when market has not yet been initiated. The advantages pointed out here need to be more studied and understood, being demonstrated to the farmers, before diversification takes place.

Addressing Questions

The feasibility of commercial production of agriculture innovating species, taking the examples of grain amaranth and quinoa is still limited. This is partly due to the reduced knowledge about their value to agricultural systems and market (Spehar, 2007a; 2007b). Increasing support for comprehensive projects on research and development, covering genetic improvement, crop husbandry, soil management, trading and uses, is needed, similarly to what has been done with major commodities (Spehar, 2008).

Innovating plants, to be inserted in the world market, need to have a minimum technological package defined, with producers' participation. The outcome should be economically efficient yields, on top of biological balance and better soil management (Spehar, 2008). Experimentation in farmers' fields, involving their direct participation, should be previously defined by competence, leadership and consequent interest in developing these crops, to popularize their use.

In the experimentation, some key factors should be taken into account such as variety acquisition belonging to differentiated maturity groups; spatial arrangement, sowing pattern and dates suitable for each genotype to express best performance by input; and appropriate nutrition to reach these efficient yields (Spehar, 2007a; 2007b). Such work has been carried out *in loco*, i.e., in agricultural properties, aim at demonstrating the benefits of innovative crops. The value of these actions is based on special events concomitant to experimentation such as field days and technical meetings, to ensue the participation of production chain representatives. Multiplication of events, such as these, is an excellent opportunity for contacts and agreements aiming at market and uses (Spehar, 2008).

The little promotion of crops and their advantages has limited them as options for food and raw material. The farmer does not cultivate them in face of limited knowledge of best techniques and trading; this, in turn depends on consumers, who do not know where to purchase the products (Spehar, 2008). Efforts geared at economical analysis, taking into account projected prices by emerging market, shall encourage adhesion of reluctant producers. Complimentary actions, by broadcasting information among producers and demanding public, aim at establishing new links among the segments, initiating the chain.

Prospect for Diversified Agriculture

Advantages being demonstrated, the need to involve interested people on both ends of the chain comes next. This is why, concomitant to experimentation, initiatives should be taken to develop and promote the innovative products (Spehar, 2008).

Product trading is the major set back to be circumvented by equally strategic pioneer actions. In market formation, up to the point of its production flow, there is need to stimulate involved sectors. The respective chains of innovative species shall evolve from comparative advantages; in traditional species this was realized along dozens or hundreds of years (Spehar, 2008). Given present technological advances, especially on communications, time can be shortened. Thus, it is proposed the use of virtual environment, connecting the links and making the chain, on independent trading. This should help farmers and consumers, but relies on education, training and special public policies to stimulate diversification (Spehar, 2008).

Well defined strategic actions, supported by public policies, on research and development, promotion of cultivation and uses on diversified basis, shall be target. It is expected that, in the years to come, innovative crops become a reality in farmers' fields. Well balanced farming for the tropics relies on these actions leading to clean food, fiber, agro-fuel and other derived products (Spehar, 2006). Needless to say but well enough to remind, the new agriculture, supporting a quickly changing world, should face the mirror of nature. The observations and coexistence of man and other living beings, in close ties of traditional agriculture should be revived in present times, using technology advance.

References

- Ascheri, J.L., Spehar, C.R. and Nascimento, N.E. 2002. Caracterización química comparativa de harinas instantaneas por extrusión de quinoa (*Chenopodium quinoa* Willd.), maíz y arroz. *Alimentaria*, 39, n.331, p. 82-89.
- Coelho, R.R.R. and Drozdowics, A. 1978. The occurrence of actinomycetes in a cerrado soil in Brazil. *Revue de Ecologie et Biologie du Sol*, 15 (4): 459-473.
- Embrapa.. *Tecnologias de Produção de Soja - Região Central do Brasil* 2006. Londrina: Embrapa Soja: Embrapa Cerrados: Embrapa Agropecuária Oeste. 220 p (Sistemas de Produção, 9).
- Embrapa. 2005. *Embrapa Cerrados: Conhecimento, Tecnologia e Compromisso Ambiental*. Planaltina, DF: Embrapa Cerrados – Institutional Document (Doc. n. 4).
- Goedert, W.J. 1986. (Ed.) *Solos dos cerrados - tecnologias e estratégias de manejo*. Brasília: Embrapa/Nobel, 422 p.
- Harrington, J.F. and Sorenson, B.W. 2006. *Desenvolvimento das terras no Cerrado: a experiência do IRI*. AGRISUS, Editora Agronômica Ceres: Piracicaba, SP (IRI Research Institute, Pub. Misc. 86).
- Inomoto, M.M., Motta, L.C.C., Machado, A.C.Z. and Sazaki, C. S. S. 2007. Reação de Dez Coberturas Vegetais a *Pratylenchus brachyurus*. *Nematologia Brasileira*, Brasília, v. 30, n. 2, p. 151-157.
- Machado, A.T. and Fernandes, M.S. 2001. Participatory maize breeding for low nitrogen tolerance. *Euphytica*, Dordrecht, 122 (3): 567-573.
- Navarro, Z. 2001. Desenvolvimento rural no Brasil: os limites do passado e os caminhos do futuro. *Estudos Avançados*, 15 (43): 323-331.
- Rivero, J.L.L. 1994. Genética y mejoramiento de cultivos altoandinos. Belastain, J.B.P. (Ed.). La Paz, Bolívia: INADE/PELT-COTESU. 457p.
- Rocha, J.E.S. 2008. Seleção de genótipos de quinoa com características agronômicas e estabilidade de rendimento no Planalto Central. Faculdade de Agronomia e Medicina Veterinária, Universidade de Brasília, 115 p. M.Sc. Thesis.
- Silva, A.R., Caldas Leite, J., Magalhães, J.C.A.J. and Neumaier, N. 1976. *A cultura do trigo irrigada nos cerrados do Brasil Central*. Circular Técnica, Centro de Pesquisa Agropecuária dos Cerrados, nº1.

- Silva, A.R. and Andrade, J.M.V. 1983. Efeito de micronutrientes no chochamento do trigo de sequeiro e nas culturas de soja e arroz, em latossolo vermelho amarelo. *Pesquisa Agropecuária Brasileira*, Brasília, v.18, n. 6, p. 593-601.
- Silva, J.E., Leimanski, J. and Resck, D.V.S. 1994. Perdas de material orgânica e suas relações com a capacidade de troca catiônica em solos da região do Oeste Baiano. *Revista Brasileira de Ciência dos Solos*, Campinas, v.18, p. 541-547.
- Spehar, C.R. Grain, Fibber and Fruit Production in the Cerrado Development. 2008. In Faleiro, F.F. and Farias, A.L. (Eds.) *Savannas: Desafios e estratégias para o equilíbrio entre sociedade, agronegócio e recursos naturais*. p. 477-501. Embrapa Cerrados : Planaltina, DF.
- Spehar, C.R. 2007a. *Amaranto: Opção para diversificar a agricultura e os alimentos*. 136 p. Embrapa Cerrados : Planaltina, DF.
- Spehar, C.R. 2007b. *Quinoa: Alternativa para a Diversificação Agrícola e Alimentar*. 103 p. Embrapa Cerrados : Planaltina, DF.
- Spehar, C.R. 2006. Conquering the Brazilian Savannah and consolidation of agriculture. In. Paterniani, E. (Ed.) *Ciência, Agricultura e Sociedade*. p. 195-226. Brasília: Embrapa Informação Tecnológica.
- Spehar, C.R. 2005. Opções de cobertura e suas influências em áreas de Cerrado. In *Encontro de Plantio Direto no Cerrado*, 8. p. 81-86. Tangará da Serra, MT, 2005. Tangará da Serra: APDC.
- Spehar, C.R. 2002. Utilização da quinoa como alternativa para diversificar alimentos. In: *Simpósio sobre Ingredientes na Alimentação Animal*. Uberlândia, MG: Colégio Brasileiro de Nutrição Animal/UFU. p.49-58.
- Spehar, C.R. 2000. Adaptação da quinoa e do amaranto ao plantio direto na propriedade familiar. In: *Encontro Latinoamericano Sobre Plantio Direto Na Propriedade Familiar*, 1998, Pato Branco, PR. IAPAR, v.1. p.1-7.
- Spehar, C.R. 1998. Production systems in the savannas of Brazil: Key factors to sustainability. In Lal, R. (Ed.) *Soil Quality and Agricultural Sustainability*. Chelsea, Michigan: Ann Arbor Press, 1998. p.301-318.
- Spehar, C.R. 1995. Impact of strategic genes in soybean on agricultural development in the Brazilian tropical savannas. Review. *Field Crops Research*, 41, p. 141-146.
- Spehar, C.R. 1994. Breeding soybeans to the low latitudes of Brazilian Cerrados (Savannas). *Pesquisa Agropecuária Brasileira*, Brasília, 29 (8): 1.167-1.180.
- Spehar, C.R. and Landers, J.N. 1997. Características, limitações e futuro do plantio direto nos cerrados. In: SEMINÁRIO INTERNACIONAL DO SISTEMA PLANTIO DIRETO, 1997, Anais. Passo Fundo, RS: Embrapa-Trigo. p.127-131.
- Spehar, C.R. and Santos, R.L.B. 2002. Quinoa (*Chenopodium quinoa* Willd) BRS Piabiru: Alternativa para diversificar os sistemas de produção de grãos. *Pesquisa Agropecuária Brasileira*, Brasília, v.37, n.6 , p. 889-893.
- Spehar, C.R. and Souza, L.A.C. 1999. Selecting soybean [*Glycine max* (L) Merrill] tolerant to low-calcium stress in short term hydroponics experiment. *Euphytica*, 106: 35-38.
- Spehar, C. R. and Souza, P.I.M. 1993. Adaptação da quinoa (*Chenopodium quinoa* Willd.) ao cultivo nos cerrados do Planalto Central: Resultados preliminares. *Pesquisa Agropecuária Brasileira*, v.28, n.5, p.635-639.
- Spehar, C.R., Teixeira, D.L., Lara Cabezas, W.A.L. and Erasmo, E.A.L. 2003. Amaranto BRS Alegria – alternativa para diversificar os sistemas de produção. *Pesquisa Agropecuária Brasileira*, Brasília, v.39, n.1, p.85-91,
- Teixeira, D.L., Spehar, C.R. and Souza, L.A. C. 2002. Caracterização agrônômica de amaranto na entressafra do cerrado. *Pesquisa Agropecuária Brasileira* Brasília, v.38, n.1, p.85-91.
- Trecenti, R. 2005. *Avaliação de características agrônômicas de espécies de cobertura vegetal do solo em cultivos de entressafra e sobressemeadura, na Região Central do Cerrado*. Brasília, DF : Universidade de Brasília, 106p. M. Sc. Thesis.

Strategies for Developing Rice-Wheat Genotypes for Conservation Agriculture

B. Mishra¹ and Ravish Chatrath²

¹*Sher-E-Kashmir Univ of Agricultural Sciences & Technology, Jammu, India*

²*Directorate of Wheat Research, Karnal, Haryana, India*

Continuous adoption of rice-wheat system with maximum exploitation of natural resources has weakened the resource base. If we continue to exploit the natural resources at the present rate, productivity and sustainability are bound to suffer. Therefore, to achieve sustainable higher productivity efforts must be focused on reversing the trend in natural resource degradation by adopting efficient resource conservation technologies. Development of efficient genotypes for conserving natural resource base is increasingly looked as one of the viable options. The time has come for an integrated rice-wheat research towards development of varieties with efficient input use and complete compatibility with each other. Conservation agriculture aims at application of modern agricultural technologies to improve production while protecting and sustaining the natural resources. Application of CA promotes the concept of optimizing yields and profits while ensuring provision of local and global environmental benefits and services. Acreage under conservation agriculture which is characterized by minimal soil disturbance before seeding and by diverse strategies to increase crop residue retention on the soil surface to insure maximum ground cover over time has dramatically increased in many countries over the past 3 decades. There are now about 28 million ha of zero till seeding in Latin America with the bulk concentrated in the southern cone countries of Brazil, Argentina and Paraguay. Much of this acreage is zero-till with residue retention under rainfed condition. CA in the form of conservation tillage (zero/reduce/bed planting) and incorporation of crop residues have been introduced in the irrigated regions of IGP to reduce the cost of cultivation, saving the resources like water, fertilizers, energy and time, improve the soil health and enhance the system productivity. By 2025, 15 out of 75 million hectare of Asia's flood-irrigated rice crop will experience water shortage. Yet more rice needs to be produced with less and less water to feed the burgeoning population. Rice is an important target for water use reduction because of its relatively large water requirement compared to other crops. This aspect of rice cultivation is undergoing radical changes and technologies are being aggressively developed for more water productive cultivation practices. System of Rice Intensification (SRI), direct seeding under puddled soil, alternate wetting and drying, aerobic rice cultivation are some of these practices. The suitable varieties for different agroclimatic situations should be screened or developed through breeding for SRI, direct seeding, aerobic rice cultivation etc. The available information indicated that where high yielding lowland rice varieties grown under aerobic soil conditions but with supplemental irrigation as a measure to save water have shown severe yield penalty. Achieving high yields under irrigated but aerobic soil conditions require new varieties of aerobic rice that combine the drought resistant characteristics of upland varieties with high yielding characteristics of lowland varieties. The variety so developed should perform well both under aerobic condition as well as under normal irrigated condition, so that chance of getting a good harvest in a good rain fall year is not skipped. Rice variety that has competitive ability to suppress weed growth or which give a reasonably good yield under unweeded conditions should be developed to reduce investment on weeding including herbicide use. So far the development of rice and wheat cultivars were focused on individual crops under good seed bed condition involving more number of tillage operations. The breeding programme should consider system approach to suit the requirement of conservation agriculture. In areas where new resource conservation technologies are gaining popularity, farmers require cultivar adapted to the new practices. For surface seeding and reduced/zero tillage planting, the cultivar should possess faster root development to enable rapid establishment of the crop, thereby getting the seedling past an early and harsh environment and taking the best advantage of available soil moisture. Recently significant genotype x tillage interactions was reported in tests involving diverse genotypes, requiring plant breeders involved in wheat improvement to tailor the genotype to different resource conservation technologies. Varieties that possess faster root growth, and good vigour may present opportunities for increased productivity under reduced tillage condition. Biotechnological interventions in mitigating abiotic stresses are set to play a major role in conservation agriculture. Among abiotic stresses drought, extreme temperatures, and saline soils are the most common stresses that plants encounter. Genetic engineering for developing stress tolerant plants, based on the introgression of genes that are known to be involved in stress response and putative tolerance, might prove to be a faster track towards improving crop varieties for conservation agriculture.

Key words: Rice, Wheat, Genotypes, Conservation agriculture, Input use efficiency

Strategies for Developing Rice-Wheat Genotypes for Conservation Agriculture

The key feature of the Green revolution strategy included the expansion of irrigated area, the introduction of high yielding and input responsive dwarf rice and wheat varieties, and the promotion of fertilizer usage. Other supporting element included the expansion and strengthening of research and extension services, and agriculture support policies.

The combined effect of the increased use of these variables resulted in a substantial increase in food grain production from 55 m tons in 1951 to more than 200 m tons. During the past 30 years, agricultural production has been able to keep pace with population demand for food. This came about through significant area and yield growth. Area growth was a result of new lands being farmed and through increases in cropping intensity, from a single crop to double or even triple crops per year. However, the majority of the farm households have less than 5 ha of land. All farmers use improved varieties of wheat and rice with fertilizer. Mechanization levels are high, especially in the western regions, with resource poor farmers renting farm implements for tilling and harvesting. Animal power is still common in eastern parts of RWCS, but many farmers are moving to contract ploughing with tractors.

The problem associated with rice-wheat systems threatens the sustainability of this vital component of food security in India. The gains from the input intensive agriculture of the green revolution era, with high inputs, high yielding varieties, irrigation and other infrastructural facilities have been largely realized. At the farm level, priority should be given to the quantification of site specific problems. In most parts of India, farmers are responding to the problems of rice-wheat systems themselves by adopting precision farming techniques. Using their own ingenuity, the farmers are beginning to diversify crops through rotation, use alley cropping techniques and reduced tillage operations and increased water use efficiency.

Sustainability of Rice-Wheat System in India

Due to continuous use of the rice-wheat systems in the country, concern about the declining sustainability has been widely expressed (Regmi *et al.*, 2002; Ladha *et al.*, 2000). Decline in the yield on long term experimental plots, stagnating farmer yields, declining productivity growth rates and factor productivity in both farm and research settings and degrading soil and water resources have raised questions about the sustainability of rice-wheat cropping system. Continuous use by farmers of the rice-wheat system has been reported to reduce soil and crop productivity. Analysis of several long-term experiments on rice-wheat indicated a negative average yield ($-0.02 \text{ t ha}^{-1} \text{ yr}^{-1}$ or $0.5\% \text{ yr}^{-1}$) trend of rice (Duxbury *et al.*, 2000).

Although RWCS has been a boon from food security viewpoint, it being an intensive cropping system, is heavily taxing the two most important natural resources soil and water (Prasad and Nagarajan, 2004). Trends of resource fatigue, stagnating yield and little area available for horizontal expansion suggest that rice-wheat production systems of Indo-Gangetic plains may not keep pace with anticipated increase in demand for food driven by population and income growth. On the supply side, natural resource management problem, including the unsustainable exploitation of water and soils, inefficient use of chemical inputs, declining environmental quality and emerging disease and pest problems. On the demand side they are being transformed by market forces and changing consumer demand.

Can New Technologies be an Answer?

The continuous intensive cultivation of rice and wheat for the last three decades has put tremendous pressure on the land. Stagnating yield at levels far below the potential productivity and even yield declines are now occurring in south Asian countries including India. The time has come for an integrated rice-wheat research towards development of technologies and varieties with efficient input use and complete compatibility with each other. Promising technologies to ensure timely sowing and good plant stands, crucial for rice-wheat system productivity and efficiency are needed to be developed and popularized among the farming community of Indo-Gangetic plains. Scientist working with various research and development institutions have developed new tillage and other resource conserving technologies such as surface seeding, zero tillage/reduced tillage, bed planting, mechanical transplanting, laser leveling etc. The development and deployment of resource conserving technologies with farmers in the rice wheat systems have been a major success of research and development institutions (Hobbs *et al.*, 2002).

Promotion of resource conservation technologies in IGP have been underway during early 1990s but it is only in the past 6 to 7 years that the technologies are finding rapid acceptance by the farmers due to availability and affordability of seed cum fertilizer zero till drill by the farmers. Efforts have been made to develop and extend conservation agriculture in IGP (Indian region) through the combined initiatives of several SAUs, ICAR institutes and International institute like CG system, specifically, Rice-Wheat consortium for the Indo-Gangetic plains. Unlike, in the rest of the world, spread of technologies is taking place in the irrigated regions in the IGP where rice-wheat cropping system dominates. CA systems have not yet taken roots in other major agro-ecoregions like, rainfed,

semi-arid tropics, the arid regions or the mountain agro-ecosystems. CA in the form of conservation tillage (zero/reduce/bed planting) and incorporation of crop residues have been introduced in the irrigated regions of IGP to reduce the cost of cultivation, saving the resources like water, fertilizers, energy and time, improve the soil health and enhance the system productivity.

Importance of Timely Wheat Sowing

The most common practice for establishing rice in the RWCS is puddling before transplanting rice. This results in degraded soil physical properties, particularly for fine textured soils, and subsequently results in degraded soil physical properties and subsequently creates difficulties when it comes to providing a good soil tilth for wheat (Sharma *et al.*, 2002). Delaying wheat sowing (normal to late) resulted in decrease in yield by 15.5, 32.0, 27.6, 32.9 and 26.8 kg/ha/day under NHZ, NWPZ, NEPZ, CZ and PZ, respectively for timely sown varieties. The corresponding yield loss was 7.6, 18.5, 17.7, 17.0 and 15.5 per cent (Tripathi *et al.*, 2005). To improve the productivity of the rice wheat system, the wheat crop must be planted at the optimal time. Late planting not only reduces yield but also reduces the efficiency of the inputs applied to the wheat crop. The major cause of late wheat planting is the long turnaround time after the rice harvest. In order to overcome these problems many resource conservation technologies are practiced. These result in more efficient use of the natural resources used to produce a crop. Some of the major resource conservation technologies are:

Zero Tillage

Resource Conservation Technologies (RCTs) are co-evolving in participation with national and international scientists, farmers, private manufacturers and other stakeholders. Recent estimates suggest that these technologies now occupy around 2.0 a million hectares area under zero/reduced till. The ZT technology has several advantages over CT and some important ones includes saving of more than 90 % diesel, which comes to 61 litres/ha compared to conventional system. Thus, it reduces the cost of cultivation (Rs 3000/ha), saves forex, advances the time of wheat sowing (4-5 days), requires less water for the first irrigation and results in less infestation of *Phalaris minor*, which is a serious problem in northwest India. Besides this, it provides eco-friendly wheat cultivation by reducing 135 kg CO₂/ha (assuming 2.6 kg CO₂ production/ litre of diesel burnt), which is one of the major causes for global warming (Chauhan *et al.*, 2001).

Surface Seeding

Surface seeding is the simplest zero tillage system being followed which involves placement of wheat seed on to a saturated soil surface without any land preparation. This is a traditional farmer practice for wheat, legume and other crop establishment in eastern India and Bangladesh. Wheat seed is either broadcasted before the rice crop is harvested or after the harvest of the rice crop. Surface seeding of wheat on to unploughed, wet soil before or after rice harvest is working very well in heavy, poorly drained soils. This technique is particularly relevant to farmers with small land holding and little or no power sources (Hobbs *et al.*, 2000). The key to success with this system is having the correct soil moisture at seeding. Once the roots germinate and extend in to the soil, the root can follow the saturation fringes as it drains down the soil profile. In China, farmers apply cut straw to mulch the soil, reduce evaporative losses of moisture and control the weeds (Yonglu *et al.*, 2000; Gupta *et al.*, 2000)

Reduced Tillage: A Better Option for RWCS

Reduced tillage is becoming popular among farmers around the globe. The practice is gaining popularity in rice-wheat cropping areas. It has been suggested that no till farming is more than just elimination of ploughing; it involves developing a complete package of agro-ecologically sound management practices to fit the overall schemes of farm systems trends of specific regions (Lal *et al.*, 2004). The concept challenges the scientific basis of ploughing as an original universal method of soil preparation. From the plant breeding point of view, reduced tillage and its effects differ from those of conventional tillage in different ways (Joshi *et al.*, 2007).

Ridge Tillage Systems

In bed planting, wheat or the other crops are planted on raised beds. This practice has increased dramatically in the last decade in the high yielding irrigated wheat areas of Mexico. The main reasons for the adopting of ridge

tillage systems in Mexico and elsewhere in world are as follows:

1. Management of irrigation water is improved
2. Bed planting facilitates irrigation before seeding and thus provides an opportunity for weed control before planting.
3. Plant stands are better
4. Weeds can be controlled mechanically, between the beds early in the crop cycle
5. Wheat seed rate is lower
6. Herbicide dependence is reduced and hand weeding and rouging are easier
7. Less lodging occurs
8. Beds provide better drainage and results in less water logging damage to wheat

Wheat Genotypic Requirement for the New RCTs

In areas where new resource conservation technologies are gaining popularity, farmers require cultivar adapted to the new practice (Joshi *et al.*, 2004a, 2006). For surface seeding and reduced/zero tillage planting, the cultivar should possess faster root development to enable rapid establishment of the crop (Trethowan and Reynolds, 2005; Singh *et al.*, 2007), thereby getting the seedling past an early and harsh environment and taking the best advantage of available soil moisture. Early studies failed to detect genotype x tillage practice interactions. The probable reasons for these conclusions may be of small number of genotypes tested and perhaps the fact that they were bred under conventional tillage (Trethowan and Reynolds, 2005). Recently significant genotype x tillage interactions were reported in tests involving diverse genotypes, requiring plant breeders involved in wheat improvement to tailor the genotype to different resource conservation technologies (Sharma *et al.*, 1997; Sayre, 2002; Klein, 2003 and Singh *et al.*, 2007). Watt *et al.* (2005) found that some of the varieties grew best in unploughed soil. They suggested that faster root growth, and vigorous genotypes may present opportunities for increased productivity under reduced tillage. The tillage x genotype interactions suggest that varietal development should be targeted to new RCT requirements (Joshi *et al.*, 2007). Following this approach, wheat breeders of the CIMMYT have begun to select parental lines on the basis of performance under various tillage systems (Trethowan and Reynolds, 2005).

Tailoring Wheat Genotypes for Different Resource Conservation Technologies

Kronstad *et al.* (1978) suggested that to develop varieties of wheat adapted to different tillage options, some of the points of consideration are:

1. Growth factors influenced by tillage need to be identified
2. Genetic variability for growth factors affected by tillage must be large enough to provide sufficient selection scope
3. Selection criteria to identify superior lines in segregating populations must be established.
4. Progeny with improved characteristics for reduced tillage must possess all other desirable agronomic traits for an adapted and competitive cultivar.

Francis (1991) outlined the dimension of future cropping systems based on current trends and suggested that for a reduced tillage system having greater amounts of crop residue, possible plant breeding solutions would be to incorporate increased seedling vigor, early stress tolerance (cold) and tolerance to eco-fallow/zero tillage practice. Another approach to breed crops for new RCTs would be to grow segregating populations from crosses involving parents that adapt well under such situations and incorporate useful traits like better emergence, profuse tillering and resistance to disease common under these situations (Joshi *et al.*, 2007). However, for proper identification of segregating lines, these generations need to be grown under the targeted environment and practice.

Various plant breeding techniques have been advocated for improvement of crop plants with cropping system perspective. Singh and Huerta-Espino (2004) advocated a single backcross approach for effective shifting of a greater proportion of progenies in the segregating generations towards higher mean values thereby enhancing the chance of getting superior lines. Wang *et al.* (2003) showed that selected bulk approach gave slightly better genetic gain than other approaches. Showing segregating populations derived from selected bulks also appear attractive for wheat improvement for new RCTs. Several studies suggest new physiological tools can complement conventional breeding programmes (Fischer *et al.*, 1998; Reynolds *et al.*, 1998).

Input Use in Rice

Rice production consumes about 30% of all freshwater used worldwide. Flood-irrigated rice uses two to three times more water than other cereal crops such as wheat and maize. In Asia, flood-irrigated rice consumes more than 45 % of total freshwater used (Barker *et al.* 1999). The increasing water crisis threatens the sustainability of irrigated rice production (Gleick, 1993; Postel, 1997). By 2025, 15 out of 75 million hectare of Asia's flood-irrigated rice crop will experience water shortage (Tuong and Bouman 2003). Yet more rice needs to be produced with less and less water to feed the ever-growing population. Rice is an important target for water use reduction because of its relatively large water requirement compared to other crops (Wang *et al.*, 2002; Tuong and Bouman, 2003). Fortunately this aspect of rice cultivation is undergoing radical changes and technologies are being aggressively developed for more water productive cultivation practices. SRI, direct seeding under puddle soil, alternate wetting and drying, aerobic rice cultivation are some of these practices. Reducing crop duration without affecting productivity is another approach.

Cost of rice cultivation is mainly dependent on input costs and input use efficiency. At present the agronomic efficiency of input is about 25-30 % only. Per kg of nutrient applied 13.1 kg of rice is produce at present, which needs to be enhance to at least 18kg. Emphasis is needed on genetic enhancement to conserve natural resources and for higher input use efficiency of the genotypes. Variety Swarna was found to fairly well across locations both under N depriving and N abundant conditions. Similarly genotypes responsive to P, micronutrients, organic manure etc. needs to be developed or screened.

Aerobic Rice Cultivation

International Rice Research Institute (IRRI) developed the “aerobic rice technology” to address the water crisis problem in tropical agriculture. Because it is grown in soil with oxygen it is called “aerobic rice” as compared with anaerobic soil where oxygen is absent because of irrigation. In aerobic rice systems rice is grown like an upland crop with adequate inputs and supplementary irrigation when rainfall is insufficient (Bouman, 2001). The new concept of aerobic rice may be an alternate strategy, which combines the characteristics of both upland varieties with less water requirement and irrigated varieties with high response to inputs. The water use for aerobic rice production was 55-56 per cent lower than the flooded rice with 1.6-1.9 times higher water productivity and net returns to water use was two times higher. It indicates that aerobic rice may be viable option where the shortage of water does not allow the growing of lowland rice. Lafitte *et al.* 2002 reported that most lowland cultivars could survive in well-watered aerobic soils. Several technologies have been developed to reduce water loss and increase the water productivity of the rice crop. They are saturated soil culture (Borell *et al.* 1997), alternate wetting and drying (Li, 2001; Tabbal *et al.* 2002), ground cover systems (Lin *et al.* 2002) and system of rice intensification (Stoop *et al.* 2002). However, the fields are still kept flooded for some periods in most of these systems, so water losses remain high. Aerobic rice is high yielding rice grown under non-flooded conditions in non-puddled and unsaturated (aerobic) soil. It is responsive to high inputs, can be rainfed or irrigated, and tolerates (occasional) flooding (Bouman and Tuong 2001). There is need to address the physiological responses of rice to aerobic conditions and pay special attention to the yield components (Bouman *et al.* 2005). The suitable varieties for different agroecological situations should be screened or developed through breeding for aerobic rice cultivation. The available information indicated that where high yielding lowland rice varieties grown under aerobic soil conditions but with supplemental irrigation as a measure to save water have shown severe yield penalty (McCauley, 1990). Achieving high yields under irrigated but aerobic soil conditions require new varieties of aerobic rice that combine the drought resistant characteristics of upland varieties with high yielding characteristics of lowland varieties (Lafitte *et al.* 2002). The variety so developed should perform well both under aerobic condition as well as under normal irrigated condition, so that chance of getting a good harvest in a good rain fall year is not skipped.

System of Rice Intensification (SRI)

The SRI was developed in Madagascar by Fr. Henri de Lau Lanie in association with NGO- association Tefy Saina (ATS) and many small farmers in the 1980's is becoming popular in many countries including India. SRI is a system rather than a technology. It is based on the insight that rice has the potential to produce more tillers and grain than presently observed and that early transplanting along with optimal growth condition like wide spacing, optimum humidity, a vibrant healthy soil and aerobic soil conditions during vegetative growth can fulfill this potential (Uphoff, 2002). Water saving in SRI may be as high as 40 % compared to conventional practice. In a trial at DRR,

Hyderabad, SRI gave 16.6 % higher grain yield over normal transplanting. The varietal response to SRI and normal cultivation was wide. SRI method gave nearly 46 to 48 % higher yield in hybrids, 5.2 to 17 % in HYVs while negative results were observed in case of Pusa basmati due to its shy tillering habit under wider spacing. All the varieties are not promising for SRI cultivation method and response of cultivars to SRI varies as per their ability to exploit the natural resources. There is need to develop varieties that can give better response to SRI cultivation. A variety developed for SRI must have compact plant type, profuse tillering ability, better root system, bolder grains, low water requirement, responsive to organic inputs (use of inorganic inputs are 25 to 50% only) and resistance to pest and diseases. The significant aspect of the SRI cultivation is that the rice matures at about 10-15 days earlier compared to conventional practice and thereby vacate the land for timely sowing of succeeding wheat crop. Therefore, the genotypes used for SRI should be able to produce more with less duration.

Direct Seeded Rice

Direct dry seeding (DDS) in rice has advantage of faster and easier planting, reduced labour requirement and drudgery with earlier crop maturity by 7-10 days, better efficient water use and high tolerance of water deficit, less methane emission and higher income due to less cost of production (Balasubramanian and Hill, 2002). In both direct dry and wet seeded rice weed management is a major problem. Suitable genotypes needed to be developed for suitability under dry condition with better root system and competitiveness to weed. The genotypes with weed suppressing ability would be a boon for the rice farmer's across the cultivation method and regions. Scientists are now able to identify some plant types that has the ability to compete successfully with weeds and give a good harvest even under no weeding condition. In North East variety Sahsarang 1 is said to have some abilities to compete with weeds. Development of such a genotypes would reduce the requirement for tillage, save labour and herbicide use and thereby conserving resource base in agriculture.

Organic Farming

For the attainment self sufficiency in the food grain production, we are in need of high yielding varieties in the place of local varieties. In the same, to produce organically we are in need of seed materials, which are very much responsive to organic and interact complementally with components of organic farming. About 65 per cent of our country's cropped area is not irrigated where the farming practices are still largely 'organic by default'. The use of chemical fertilizers is comparatively low in eastern and northeastern part of the country and yet there is sufficient food production. This defies the myth that the output would fall if the farmers go back to organic farming. It is high yielding varieties of seeds, which are important and not excessive chemical fertilizers and pesticides. However the organic farming in India is still in its infancy and due research efforts are required to support the various requirements of organic farming. Presently the varieties suited to conventional farming conditions are used in organic farming conditions also. The presence of conditions in organic farming that is different from conventional farming calls for developing varieties suitable for organic conditions. Efforts should be focused on use of organic in basmati rice where nitrogen requirement for the crop is less as compared to non basmati rice.

Conversion of Rice from C3 to C4 Crop

In C3 plants photorespiration reduces net carbon gain and productivity by as high as 40 %, as a result of this C3 plants are less competitive in certain environments. On the other hand C4 plants exhibit many desirable agronomic traits, high photosynthesis rate, faster growth and high water and input use efficiency. Therefore, efforts are on to convert rice to C4 crop for realizing higher photosynthesis rate and yield. Development of such a genotype would save a huge amount of water, which could be utilized for increasing irrigated area.

Biotechnological Interventions

Abiotic stresses adversely affect plant growth and development and are major constraints in enhancing plant productivity. Growing plants with enhanced tolerance to abiotic constraints will help in conserving agricultural resources. Among abiotic stresses drought, extreme temperatures, and saline soils are the most common stresses that plants encounter. Success in breeding for better adapted varieties to abiotic stresses depend upon the concerted efforts by various research domains including plant and cell physiology, molecular biology, genetics, and breeding. Recently large information has been generated on genetic systems related to plant adaptation under stress environments. The information can be used in molecular breeding and also the development of transgenics. Recently transgenics developed using genes conferring tolerance to osmotic stress such as DREB1, trehalose, LES proteins,

Mannitol etc have shown enhanced tolerance to drought. Genes related to signal transduction and membrane transport have used for developing salt and drought tolerance. Hence, genetic engineering for developing stress tolerant plants, based on the introgression of genes that are known to be involved in stress response and putative tolerance, might prove to be a faster track towards improving crop varieties. However, lot of work is to done to apply the transgene technology under field conditions. Once the technology is fully developed, it will save resources and enhance productivity of crop plants. Not only that, genetically engineered pants can be used in ameliorating soil conditions by absorbing toxic chemicals present in the soil. Therefore, biotechnology has great potential in conservation of agricultural resources.

Further increasing the yield potential of rice and wheat seems inevitable. This can be achieved by using hybrids, synthetics or improving the photosynthetic efficiency or crops. While traditional plant breeding has been effective improving the crop yields, biotechnology can make this more effective (Hobbs *et al.*, 2000). Molecular tools derived with increasing knowledge about the molecular genomics bases of agronomic traits can be applied to develop improved cultivars that enable producers to increase the yields and quality.

References

- Balasubramanin and J. E. Hill. 2002. Direct seeding of rice in Asia : emerging issues and strageic research needs for the 21st Century. In : Pandey, S. et al. (Eds) Direct seeding : Research strategies and opportunities. PP. 15-39. IRRRI publications.
- Barker, R., Dawe, D., Tuong, T.P., Bhuiyan, S.I., Guerra, L.C., 1999. The outlook for water resources in the year 2020: challenges for research on water management in rice production. In: Assessment and Orientation towards the 21st Century. Proceedings of the 19th session of the International Rice Commission, 7–9 September 1998, Cairo, Egypt. Food, Agriculture Organization, pp. 96–109.
- Borell, A., Garside, A., Shu, F.K., 1997. Improving efficiency of water for irrigated rice in a semi-arid tropical environment. *Field Crops Res.* 52, 231–248.
- Bouman, B.A.M., Peng, S., Castaneda, A.R., Visperas, R.M., 2005. Yield and water use of irrigated tropical aerobic rice systems. *Agric. Water Manage.* 74, 87–105.
- Bouman, B.A.M., Tuong, T.P., 2001. Field water management to save water and increase its productivity in irrigated rice. *Agric. Water Manage.* 49, 11–30.
- Chauhan, D. S., Sharma, R. K., Tripathi, S. C., Kharub, A. S. and Chhokar, R. S. 2001. New paradigms in tillage technologies for wheat production. *Research Bulletin No.8.* (ISSN 0972-6098): (Bilingual). Directorate of Wheat Research, Karnal. Pp 1-16.
- Duxbury, J.M., Abrol, I. P., Gupta, R. K. and Bronson, K. F. 2000. Analysis of long term soil fertility experiments with rice-wheat rotations in south Asia. In: Abrol I.P. et al. (Eds.), Long-term Soil Fertility Experiments in Cropping Systems. *Rice-Wheat Consortium for the Indo-Gangetic Plains*, New Delhi, 7-22.
- Fischer, R. A., Rees, D., Sayre, K. D., Lu Z-M, Condon, A. G. and Larque-Saavedra A. 1998. Wheat yield progress is associated with higher stomatal conductance and photosynthetic rate, and cooler canopies. *Crop Science* 38: 1467-1475.
- Francis, C. A. 1991. Contribution of plant breeding to future cropping system. In: Slepier DA, Barker TC and Bramel-Cox PJ (eds) Plant Breeding and sustainable agriculture: consideration for objectives and methods. Special publication number 18. Crop Science Society of America, Madison, pp 83-93.
- Gleick, P.H.(Ed.). 1993. Water crisis : a guide to the worlds fresh water resources. Pacific Institute for Studies in Development, Environment, and Security, and the Stockholm Environment Institute/Oxford University Press, New York, 473 pp.
- Gupta, R. K., Hobbs, R. P., Salim, M., Chowdhary, N. H. and Bhuiyan, S. I. 2000. Study of research and extension issues in the Schuan Province of China for farm level impact on productivity of rice-wheat systems. *Rice-Wheat Consortium 8th Traveling Seminar Report Series 2*, New Delhi, India.
- Hobbs, P. R., Gupta, R. K., Ladha, J. K. and Harrington, L. 2000. Sustaining the green revolution by resource conserving technologies: The Rice-Wheat Consortium's example. *ILEIA Newsletter*, December 2000: 8-10.
- Hobbs, P. R., Singh, Y., Giri, G. S., Lauren, J. G. and Duxbury, J. M. 2002. Direct seeding and reduced tillage options in the rice-wheat systems of the Indo-Gangetic Plains of South Asia. P. 201-205. In: Pandey S, Mortimer M, Wade L, Tuong TP and Hardy B. "Direct seeding in Asian rice systems: strategic research issues and opportunities". International Rice Research Institute, Philippines.
- Joshi A K, Chand R, Arun B, Singh R P and Ortiz Rodomiro. 2007. Breeding crops for reduced-tillage management in the intensive, rice-wheat systems of South Asia. *Euphytica* 153: 135-151.
- Joshi, A. K., Chand, R., and Arun, B. 2004a. A compendium of training programme on wheat improvement for eastern India and warmer regions of India: Conventional and non-conventional approaches. NATP project, ICAR, BHU, Varanasi, India.
- Kronstad, W. E., McCuiston, W. L., Swearingen, M. L. and Qualset, C. O. 1978. Crop selection for specific residue management systems. In: Sschwald WR (ed) Crop residue management systems. American Society of Agronomy, Madison, pp 207-217.
- Ladha, J. K., Dawe, D., Pathak, H., Padre, A.T., Yadav, R. L., Singh, Bijay, Singh, Yadvinder, Singh, Y., Singh, P., Kundu, A. L., Sakal, R., Ram, N., Regmi, A. P., Gami, S.K., Bhandari, A. L., Amin, R., Yadav, C. R., Bhattarai, E. M., Gupta, R. K. and Hobbs, P. R. 2000. How

- extensive are yield declines in long term rice-wheat experiments in Asian Field Crop Research (In press).
- Lal, R., Hansen, D.O., Hobbs, P., Uphoff, N. 2004. Reconciling food security with environment quality through no-till farming. In: Lal R, Hobbs P, Uphoff N, Hansen DO (eds) Sustainable agriculture and the rice-wheat system, Ohio State University, Columbus, Ohio. Marcel Dekker, Inc., New York, pp 495-512.
- Lafitte, R.H., Courtois, B., Arraudeau, M., 2002. Genetic improvement of rice in aerobic systems: progress from yield to genes. *Field Crops Res.* 75, 171–190.
- Li, Y., 2001. Research and practice of water-saving irrigation for rice in China. In: Barker, R., Li, Y., Tuong, T.P. (Eds.), *Water-Saving Irrigation for Rice*. Proceedings of the International Workshop, 23–25 March 2001, Wuhan, China. International Water Management Institute, Colombo, Sri Lanka, pp. 135–144.
- Lin, S., Dittert, K., Sattelmacher, B., 2002. The Ground Cover Rice Production System (GCRPS)—a successful new approach to save water and increase nitrogen fertilizer efficiency? In: Bouman, B.A.M., Hengsdijk, H., Hardy, B., Bindraban, P.S., Tuong, T.P., Ladha, J.K. (Eds.), *Water-wise Rice Production*. Proceedings of the International Workshop on Water-wise Rice Production, 8–11 April 2002, Los Banos, Philippines. International Rice Research Institute, Los Banos, Philippines, pp. 187–196.
- McCauley, G.N. 1990. Sprinkler vs. flooded irrigation in traditional rice production regions of southeast Texas. *Agronom. J.* 82: 677-687.
- Prasad, Rajendra and Nagarajan S. 2004. Rice-wheat cropping system—Food security and sustainability. *Current Science* 87(10):1334-1335.
- Postel, S. 1997. *Last oasis : Facing Water Scarcity*. Norton and Company, New York, pp. 239.
- Regmi, A. P., Ladha, J. K. Pasuquin, E. M., Hobbs, P. R., Shrestha, M. L., Ghauti, D. B. and Duveiller, E. 2002. Potassium in sustaining yields in a long term rice-wheat experiment in the Indo-Gangetic Plains of Nepal. *Biol. Fert. Soils*. (In press).
- Reynolds, M. P., Singh, R. P., Ibrahim, A., Ageb, O. A. A. Larque-Saavedra, A. and Quick, J. S. 1998. Evaluating physiological traits to complement empirical selection for wheat in warm environment. II. Growth, water use and water use efficiency. *Australian Journal of Agricultural Research* 43: 529-539.
- Sayre, K. D. 2002. Management of irrigated wheat. In: Curtis BC, Rajaram S, Gomez Macpherson H (eds) *Bread wheat: improvement and production*. Food and Agriculture Organization, Rome, Italy, pp 395-406.
- Sharma, A. K., Singh, G. P., Rane, J. and Nagarajan, S. 1997. Alternate selection approaches for targeted cropping sequences. In Proc: International group Meeting Wheat Research Needs beyond 2000 AD. Narosa publishing House, New Delhi. P 227-231.
- Sharma, P. K., Ladha, J. K. and Bhusan, L. 2002. Soil physical effects of puddling in rice-wheat cropping system. In: Ladha JK (eds) *Improving the productivity and sustainability of rice-wheat system: issues and impact*. ASA Special Publication. ASA, Madison, WI.
- Singh, G., Tyagi, B. S., Singh, G. P., Ravish Chatrath, Jag Shoran, Nagarajan, S and Singh, S. K. 2007. Identification of early state traits as markers for high yielding wheat genotypes under zero tillage conditions of rice wheat cropping system. *Indian Journal of Agricultural Sciences*, 77(7): 432-437.
- Singh, R. P., Huerta-Espino, J. 2004. The use of single back cross, selected bulk breeding approach for transferring minor genes based rust resistance into adapted cultivars. In: Black CK, Panozzo JF, Rebetzke GJ (eds) *Proceedings of the 54th Australian cereal chemical conference and 11th Wheat breeders assembly*, 21-24 September 2004, Canberra, Australia. Cereal Chemistry Division, RACI, North Melbourne, Vic., Australia, pp 48-51.
- Stoop, W., Uphoff, N., Kassam, A., 2002. A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: opportunities for improving farming systems for resource-poor farmers. *Agric. Syst.* 71, 249–274.
- Tabbal, D.F., Bouman, B.A.M., Bhuiyan, S.I., Sibayan, E.B., Sattar, M.A., 2002. On-farm strategies for reducing water input in irrigated rice; case studies in the Philippines. *Agric. Water Manage.* 56, 93– 112.
- Trethowan, R. M. and Reynolds, M. 2005. Drought resistance: genetic approaches for improving under stress. In: *Proceedings of the 7th International wheat conference*, 27 November-2 December 2005, Mar del Plata, Argentina.
- Tripathi, S. C., Mongia, A. D., Sharma, R. K., Kharub, A. S. and Chhokar, R. S 2005. Wheat productivity at different sowing time in various agroclimatic zones of India. *SAARC J. of Agriculture*. 3: 191-201.
- Tuong, T.P., Bouman, B.A.M., 2003. Rice production in water-scarce environments. In: *Proceedings of the Water Productivity Workshop*. 12–14 November 2001, Colombo, Sri Lanka. International Water Management Institute, Colombo, Sri Lanka.
- Uphoff, N. and Erick Fernandes. 2002. System of Rice Intensification gains momentum. *LEISA India* September, 22-27.
- Wang, J., van Ginkel, M., Trethowan, R., Ye G, DeLacy I, Podlich, D. and Cooper, M. 2003. Simulating the effects of dominance and epistasis on selection response in the CIMMYT wheat breeding programme using QuCim. *Crop Science* 44: 2006-2018.
- Wang, H., Bouman, B.A.M., Dule, Z., Wang, c., Moya, P.F. 8-11 April, 2002. Aerobic rice in northern China. Opportunities and challenges. In Bouman, B.A.M., Hengsdijk, H., Hardy, B., Bindraban, P.S., Tuong, t.p., Ladha, J.K. (Eds), *water-wise rice production*. Proceedings of the international workshop on water –wise rice production. International Rice Research, Los Banos, Philippines, pp. 143-154.
- Watt, M., Kirkegaard, J. A., Rebetzke, G. J. 2005. A wheat genotype developed for rapid leaf growth copes well with the physical and biological constraints of unplowed soil. *Functional Plant Biology*. 32: 695-70.
- Yonglu, T., Gang Huang, Yao Yu and Lixun Yuan. 2000. High yielding techniques for wheat under rice-wheat cropping system in Sichuan Province of China. In: Hobbs PR and Gupta RK (eds) *Soil and crop management practices for enhanced productivity of the rice wheat cropping system in Sichuan Province of China*. Rice-Wheat Consortium Paper Series 9. New Delhi, India.

Session 1.7: Indigenous Knowledge and Practices

Blending Indigenous and Scientific Knowledge for Innovative CA Development using Participatory Action Research

H.J. Smith

ARC-Institute for Soil, Climate and Water, Private Bag X79, Pretoria, 0001, South Africa
(Email: hjsmith@arc.agric.za)

Sustainable agricultural systems which emphasize the use of practices such as Conservation Agriculture (CA), that integrate natural processes into food production and land rehabilitation, but simultaneously improve the livelihoods of farmers and contribute to the long-term sustainability of the resource base, hold the key to successful agricultural development. However, many of the processes that exist in sustainable agriculture systems, both biophysical and socio-economic, as well as their interactions, are complex and poorly understood and require an innovative approach of research and development. The ARC-ISCW has consequently adopted a systems approach that uses *participatory action research (PAR)* as a key methodology, which actively involves farmers in all stages of agricultural research and development. This approach aims to achieve the following two major outcomes: a) to integrate (blend) scientific and indigenous knowledge in CA design; and b) to improve the awareness and innovation capacity among various stakeholders, a critical ingredient for sustainable land management.

During the planning and design phase of a PAR project cycle, farmers and researchers have the opportunity to design interventions using their own experiences, blending indigenous and scientific knowledge and agreeing on the most appropriate systems to implement. A key PAR methodology in implementation is experimentation, especially on-farm, farmer-managed trials, with the following objectives: a) to improve experiential learning, b) to improve modification and dissemination of technologies to local farmers, c) to increase awareness among farming communities and d) to facilitate farmer-to-farmer extension and training.

Results show that the emphasis on improving the farmers' inherent capacity for experimentation is an important element in sustainable agricultural projects. Equipping farmers to select sustainable management options from a 'basket of CA principles and technologies' and developing capacity to experiment with and adapt these technologies, were found to be the key to the success of PAR projects. It was furthermore found that the intensive and prolonged interaction of farmers with project staff (especially researchers) was clearly important for blending indigenous and scientific knowledge and building experimentation skills.

PAR can have a major positive effect in developing local CA systems. By engaging farmers in a long enough period of experimentation, there is an emergence of innovation, self-learning and self organization, which are critical ingredients for adaptive management and sustainability. Furthermore, PAR links up (integrates) various system elements and stakeholders and thereby serves as a platform for social learning and local institution building. Finally, the principles and process of experiential and adult learning play a fundamental role in changing farmers' interest, paradigms and behaviour, which are key indicators of emerging sustainability.

Adoption of Conservation Agriculture in Kazakhstan

M. Karabayev and M. Suleimenov

*International Maize and Wheat Improvement Center, CIMMYT-Kazakhstan,
P.O. Box 1446, Astana, 010000, Kazakhstan*

First conservation tillage methods were developed in North Kazakhstan back in 1960s. Farming systems were based on grain production in cereal fallow rotations with sweep soil tillage. Currently many components of this system are reviewed to increase the efficiency and sustainability of the soil. Long term experiments showed the opportunity to decrease the tillage and minimum tillage became generally adopted practice by the end of the 20th century. There is great potential shift to direct seeding at certain soil-climatic conditions. No-till is already adopted on over 10% of cropland area in north Kazakhstan. Raised bed planting has been showing positive results in irrigated agriculture in the south but it is not adopted by practice because of lack of equipment in the market. In regard to rotations the opportunities of crop diversification and replacement of tilled summer fallow with cereal and oil crops are studied. In production conditions, the decrease of summer fallow area takes place at a slow rate.

Industrial activities have often regrettably caused serious consequences for the environment, which now threatens normal life on Earth. Degradation, desertification, pollution, salinity, wind and water erosion and loss of soil fertility constitute a long but still incomplete list of the problems facing the humanity today. Sustainable use of natural resources, rehabilitation of land fertility, while improving quality and increasing productivity of plant industry should become integral parts of national policy and a basis of sustainable economic development of every country and region of the world.

Kazakhstan is characterized by a rich diversity of climatic conditions and soil types. The existing plant production systems in terms of grain crops include the following:

- Rainfed agriculture dominated by spring grain crops (north and center of the country);
- Rainfed agriculture dominated by winter grain crops (south and southeast);
- Irrigated agriculture (south and southeast).

The largest part of the country where the grain crops primarily spring wheat are produced, is located in semiarid steppes. The climate of Kazakhstan is sharply continental, and a large part of the territory is affected by wind erosion. The concern about drought and salinity is growing. Soil fertility has decreased dramatically throughout the region. Soil organic matter content in the topsoil reduced significantly, and weed infestation of cereal fields has increased. Water deficiency and insufficient soil moisture levels remain among the major problems of the national agriculture. It becomes increasingly clear that in the existing conditions the improvements in plant production should be achieved through implementation of the agricultural production system based on conservation and sustainable use of water, soil, energy and other natural resources and the whole environment. Today, such system is the key to survival of farmers producing agricultural crops, and, in particular, wheat, which is the major export commodity of Kazakhstan.

Currently at former virgin lands, which were developed 50 years ago, many constituents of crop production have been revised. These practices were formalized in conditions of socialist system at newly developed lands. In this interval of time the soils turned from nitrogen rich soils to nitrogen poor soils. This factor changed many trends regarding soil tillage and crop rotations. From the other side the shift to commercial farming forced to review a lot of issues concerning resource conservation. The process of reformation and free enterprise led to the situation where large farms (which produce and market grain) control the main areas of arable lands.

In this article we will consider the topic of soil tillage and crop diversification. Within long period of time in scientific institutions of North Kazakhstan the soil tillage was examined. There was made the main conclusion: the soil can not be tilled with moldboard plow instead of this sweep tillage was suggested (Baraev, 1998). In result of examination of the depth of sweep tillage in crop rotation they came into conclusion that it's necessary to rotate deep and shallow tillage annually. In 1980-s appeared that deep fall tillage had an advantage in moisture accumulation at intensive snow trapping.

Climate and Soils

The steppes of northern Kazakhstan are representative of the vast Eurasian grasslands spreading from the foothills of the southern Ural Mountains in the west to the foothills of the Altai Mountains in the east (Gilmanov *et al.*, 2000). In general there is a gradient in annual precipitation from approximately 350mm in the northern and northwestern steppes to 200mm or less in the southern and south-eastern steppes. Some precipitation can be expected in all months, with approximately one third of annual precipitation falling as winter snow. July is the wettest month, although drought periods in July are also common. The soils of the region are Chernozems and Kastanozems (chestnut soils), with Chernozems predominating in the wetter, north and north-western regions and becoming increasingly lighter in the lower rainfall areas. The common chernozem soils have approximately 5-6% SOM (1 million ha), the southern black chernozems have approximately 3.5-4% O.M. (1.5 million ha) and the dark chestnut soils approx. 3.0% O.M.

Results reported in this paper are from the Kazakh Research Institute of Grain Farming, (KRIGF) near the town of Shortandy, about 40 km NNW of Astana (51°40' N, 71°00'E, 367 m a.s.l.). The SOM levels of the natural steppe at the KRIGF are approximately 3.5%. Mean annual temperature at Shortandy is 1.6°C, and mean annual rainfall 323mm.

In the experiment at Shortandy Research Institute on south black soil the influence of three variants of main soil tillage: traditional deep conservation tillage at 22-25 cm depth with sweep in the fall, reduced tillage in the fall at 12-14 cm depth and minimum tillage with no-tillage in the fall) in a four-year crop rotation in combination with the fertilizers: 15 t/ha P₂O₅ and 30 kg N/ha were tested (Suleimenov *et al.*, 2006). In all treatments seedbed preparation was done with early spring harrowing and sowing with cultivator-drills. A long-term crop rotation study in Shortandy included 5yr data (2003-2007) on comparative study of four year rotation fallow-wheat-wheat-barley (control) with continuous cropping.

On-farm trials were conducted during 2003-2004 at four farms located indifferent soil zones: farm Darin on chestnut soil (OM 2-2.5%), farm Surayev on dark chestnut soil (OM 3.1-3.5%), farm Dostyk on south chernozem (OM 3.6-3.9%) and farm Cherezdanov on common chernozem soil (OM 3.8-4.2%). In these trials no-till was compared with traditional conservation tillage. No-till treatment consisted of sowing spring wheat with chisel openers while traditional tillage included fall tillage with blades, early spring harrowing, seedbed preparation with disks and sowing with cultivator-drills. The tillage treatments were compared on fallow land and on stubble land.

Raisedbed planting of winter wheat under irrigation with three seed rates was compared with traditional sowing with double disk drills during 2002-2004 in southeast Kazakhstan under umbrella of GTZ supported CIMMYT project on Seed Production Improvement.

Results and Discussion

Tillage

Four years data showed that the advantage had the variants with deep tillage with moldboard plow in fallow field. This was explained with the fact that such type of tillage improved nutritious order of the soil, as after many years of sweep tillage the fertility differentiation of tilled layer took place, and movement of top layer down gave positive effect. Besides, intensive tillage allowed mobilizing nitrate from soil organic matter more active.

The continuous shallow tillage in the fall, used during 3 years period, resulted in significant yield reduction by 7% comparing to the variant of rotation deep and shallow tillage. Stubble left without fall tillage decreased the yield by 9% at the third year after deep tillage in summer fallow. The same reduction of the yield on stubble without fall tillage happened at deep moldboard tillage (12%). This can be explained with the soil compaction. In the variants of conventional tillage system bulk density of the soil with stubble is 1.01–1.17 g/cm³, and in the variant without tillage the weight increases up to 1.13–1.25 g/cm³. As a result this worsens the penetration of melt waters. Without fall tillage increased weed infestation of soils. Besides, fall tillage of the soil favors to better nitrate supply.

Economical assessment of tillage systems showed that total expenses on 1 ha of rotation area do not differ at tillage systems except shallow tillage in fallow and without tillage on stubble. At minimum tillage system the highest economy of resources appeared on fuel. Eventually the most efficient appeared the variant of deep tillage with moldboard plow in summer fallow in combination with the following no-till on stubble.

In another experiment the influence of three variants of soil tillage in four-year crop rotation in combination with the fertilizers: 15 t/ha P_2O_5 and 30 kg/ha N was examined (Suleimenov et al., 2006). In this trial, the deposits of moisture before the seeding of spring wheat in the variant without fall tillage were 108 mm comparing to 119-126 mm in the system of deep and shallow tillage in the fall. This means that the necessity of fall tillage for better water conservation using melt waters was confirmed in the experiment. The runoff of snowmelt water occurs in many years because soil during cold winter is frozen to depth of below one meter.

Analysis of nitrate content in soil layer of 0-40 cm before the seeding of spring wheat showed that reduction of nitrate content appeared at mini-till comparing to conventional or reduced till from 8.2 to 3.8 mg per 100 gm of the soil.

Decrease of soil moisture and deterioration of nitrogen supply led to yield reduction of wheat. In first crop after the fallow the difference between minimum till and reduced till was not significant, and conventional tillage reduced the yield of wheat. At the same time, significant yield reduction appeared at mini-till on stubble, besides greater reduction of yield appeared at non fertilized land. At the second and third years after the fallow the yield reduction at mini-till comparing to reduced tillage was at fertilized land 8-17% and non-fertilized 17-20% respectively. Need to note, that in these experiments we did not speak about no-till, but about mini-till (when you eliminate tillage in the fall but do not refuse of tillage totally).

In 2000, CIMMYT and FAO jointly with scientists and farmers of Kazakhstan, initiated activities on introduction of zero/minimum tillage and direct sowing (leaving crop residue in the field, shredding and broadcasting of straw), furrow irrigation and raised bed planting of wheat, as well as diversified crop rotations.

Under the non-irrigated conditions these technologies can significantly increase soil fertility through more efficient control of wind and water erosion, increase of moisture retention and organic matter content in soil. Standing crop residue helps retaining snow, whereas shredded and broadcasted straw improves soil structure and quality through biological degradation. All these processes facilitate water accumulation in soil, which is the most important factor for sustainable wheat production in rainfed areas of Kazakhstan. These technologies also allow reducing the number of tillage operations (down to zero tillage, when seeds are sown into untilled soil with direct sowing planters) thus reducing production costs. That is why they have potential to become part of the low-cost agriculture system which is currently adopted by the country's farmers. Moreover, these technologies help farmers sow on time, which is very important for grain yields in the region.

Examination of direct seeders in FAO and SIMMIT projects showed, that the usage of direct seeding method at four farms proved yield advantage of new technology comparing to conventional systems at all farms as on fallow and on stubble (Karabaev et al., 2005).

In 2004, on average at four farms on fallow land, no-till as compared with control gave 1.49 and 1.35 t/ha^{-1} respectively. The largest difference in favor of no-till was obtained on the farm Dostyk where weather conditions in that year were much better than in other locations. The difference in favor of no-till amounted to 0.46 t/ha^{-1} or 25%. The comparison of two tillage treatments on stubble land was conducted in 2003 and 2004. On average of two years yield advantage in favor of no-till amounted to 0.07 t/ha^{-1} or 6.5%.

The decrease of labor cost by 41.9% for wheat production on fallows at no-till, decrease of fuel cost by 71.9%, and explicit cost by 5.5% were fixed in these production experiments. On stubble land, this difference was 28.7% and 54.6% respectively, explicit costs were the same.

In the south Kazakhstan, other efficient technologies for irrigated agriculture are furrow irrigation and raised bed wheat planting: they increase water use efficiency, facilitate uniform water distribution in the field, enhance water-air soil regime, etc. A combination of raised bed planting and furrow irrigation with zero tillage, i.e. growing crops on the permanent beds and furrows, appears to be particularly efficient.

On average in three years (2002-2004), raised bed planting of winter wheat Almalay with seed rate of 1.5 million seeds ha^{-1} as compared to traditional sowing with double disk drills and seed rate of 5 million seeds ha^{-1} provided grain yields 5.89 and 4.73 t/ha^{-1} respectively.

The results obtained clearly demonstrated the advantages of this technology, including tillage cost reduction, better residue management, weed control, improved irrigation conditions, reduced seed rate, improved chemical, physical and biological properties of soil, especially in the untilled surface part (bed). If the distance between beds is acceptable for other crops in the rotation, use of permanent beds can significantly reduce the time between harvesting the previous crop and sowing the next one.

Crop Rotations

Regarding rotations, the main conclusion of the Institute of Grain Production was the following: in dry conditions of North Kazakhstan rotations should be short duration with summer fallow. Particularly, they recommended four and five years crop rotations, besides one field with black fallow, which occupy 20-25% of rotation area (Baraev, 1998). The doubt of necessity of cereal fallows firstly was expressed in 1988 (Suleimenov, 1988). Our works showed that when using appropriate methods of crop management there is no need for black soils to summer fallow, besides one can sow spring wheat continuously for a long time at one area without yield reduction (Suleimenov and Akshalov, 2005). But this doesn't mean that we are for single crop – spring wheat. In this article we show you the data of comparison of cereal fallows rotations with no-fallow rotations at 2003–2007 (Kiyas et al., 2008). One of the very popular crop rotation is “fallow – wheat – wheat – barley”. In this rotation in 1988 the fallow was changed into oat and pea, afterwards we received two rotations with annual cropping. In average during 5 years period the yield of grain from 1 ha of seeding area in control was 2.05 t/ha, but the grain yield from total area was only 1.53 t/ha, because 25% of the area was under the fallow. In these years average grain yield from 1 ha of total rotation area in the variant of replacing fallow by dry pea was 1.77 t/ha, that means by 16% more. But the highest yield was achieved from grain rotation with oat instead of summer fallow – 2.10 t/ha or by 37% more. It's not easy to calculate economic efficiency, as in the local market the pea is feed grain, it means that it's cheaper than wheat, while in the world market pea costs more than wheat in one and a half time. Oat also is considered as feed grain, but it could be grown as edible crop. But the main thing is that the shift of clean summer fallow to grain crops stops soil erosion, and the shift of fallow to grain legumes crops strengthen the sustainability of the soil and reduce the need in nitrogen fertilizers.

Besides pea, such alternative crops as chickpea and lentil were examined and gave positive results. Good potential also show millet, sunflower, canola, buckwheat, rye, sweet clover and grain maize.

Many scientists and experts from Kazakhstan and Siberia often refer to Canada experience, leaving large areas under summer fallow, although in Canada large summer fallow areas located only in dry steppe zones, and in black soil canola and grain legume crops pushed out fallow (Larni et al., 2004).

Conclusions

Conservation tillage studies started in north Kazakhstan since 1954 after a Soviet Union Conference on Tillage which approved suggested by agronomist T. Maltsev from Kurgan Province of West Siberia so called non-moldboard tillage method. In north Kazakhstan, Canadian Noble blades for tillage and hoe drills for sowing type conservation tillage equipment were tested and adopted. In 1963, a decision of Central Committee of Communist Party was passed on Measures to control wind erosion in the steppes of north Kazakhstan and west Siberia. According to this decision, two large manufactures were established in Astana, Kazakhstan to produce soil conservation equipment to supply all farms in steppe belt all across Kazakhstan, Russia and Ukraine. During 1970s conservation tillage was widely adopted in north Kazakhstan and west Siberia regions covering area of over 25 million hectares. In the 1980s the conservation tillage practices were spread to Europe part of Soviet Union but its adoption was not as wide as it occurred in Asia. Major difference in attitude to a new tillage method was explained by the fact that trials didn't show grain yield advantage and in some regions even yield reduction was observed.

Since 1990s, in north Kazakhstan practices great shifts have been occurred regarding tillage systems and rotations. For various reasons number of tillage decreased, they almost do not prepare early spring water conservation, reduced the number of pre-seeding cultivations. Seeding planters for no-till of John Deer, Bourgaou, Horsh-Agrosoyuz and other are used for seeding at the area more than one million hectare. This means that minimum tillage is already intensively used and the territory is constantly enlarged. No-till areas might be enlarged improving the methods of crop production.

Conservation agriculture including no-till and minimum tillage (just one tillage operation) is progressively increasing and reached 7.7 million hectares in Kazakhstan. The largest adoption of CA is noted in Kostanai province. Total area under no-till farming amounted to 1,192,000 ha in northern Kazakhstan. There is no data on adoption of no-till farming practices in other regions of Kazakhstan. This area is not large and might be of the order of 100,000 ha. The leading province in adopting no-till is North Kazakhstan Province followed by Kostanai.

The adoption of no-till farming practices has been moving at rather high rate thanks to several factors. During last five years, in northern Kazakhstan large investors representing grain handling and exporting companies came to agriculture and bought rights to use land for agricultural production. These companies presently control huge

areas of former state farms. They organized vertically integrated enterprises including grain production, handling, storing, processing and marketing both grain and flour. These companies have resources to buy modern large tractors, combines, planters and sprayers.

The highest rate of adoption is observed in zones of common black soils as compared to zone of chestnut soils. This can be explained by four reasons. First, farms on chestnut soils have more problems with soil compaction and farmers tend to do tillage to improve water permeability. Second, grain yields on common black soils are higher and provide better returns which have been used for more investment into new machinery. Third, adoption of new technologies started in the North Kazakhstan and Kostanai provinces earlier and mindset in general is not a big problem for farmers in these provinces. Fourth, suppliers of modern equipment such as John Deere have been establishing more of their dealers and service offices in North Kazakhstan province.

The government policy has been promoting investment into buying modern machinery through leasing mechanism financing these operations. Government of Kazakhstan supports no-till farming and willing to promote further increase of adoption area. There are good perspectives of further increase of area under no-till and mindset seems to be not a big obstacle in northern Kazakhstan.

Last few years were favorable for grain producers in Kazakhstan in terms of weather and in terms of marketing conditions especially 2007 with record grain production and record high grain prices in the world market. Many companies used the obtained revenues for investing into buying modern machinery. Large companies are investing into no-till farming first of all because they see advantages in saving labor and fuel, and benefits from timeliness of field operations.

Challenges include first of all management of weeds and plant diseases. Also crop residue management is another problem. There are also details of cultural practices of different crops which are important for ensuring high crop yields with high quality.

Summer fallows areas are being slowly decreased; they are replaced as a rule with grain crops. Siberian farmer V. Shneider (2002) became a pioneer in using no-fallow rotation at steppe. He successfully produces crops at black soils in Omsk region. The area is over 100 thousand hectares. He shifted fallows to wheat, sunflower, grain maize and canola.

And in Kazakhstan areas, where alternative crops planted, are enlarged. The most rapid enlargement occurred at areas under oil crops: sunflower and canola. Besides they enlarge the territories where pea and chickpea are sown. One of the most limiting factors is inability to enter into the world market and the lack of modern seeding machinery, equipment for spraying, harvesting and processing, especially in the south.

But nevertheless last trends in science and practice show that large grain companies, which control enormous areas of the soil, are ready for rush shifts and to reach the modern level of production of competitive agricultural products on the basis of soil conservation technologies.

Future Thrusts

Despite the progress of zero tillage and soil conservation technologies in the country, in the nearest future Kazakhstan and international organizations should join their efforts to address the following objectives in the field of agricultural science and production:

- Weed control (infestation management) remains one of the major tasks of conservation management, which need to be addressed through further scientific research. It is important to develop efficient methods to combat weeds, especially for the early stages of introduction of zero tillage technologies. Selection of herbicide types, identification of efficient combinations, concentrations and application schedule depending on the weed species present is the main objective of this research. The research is expected to provide recommendations on the most efficient and cost-effective measures to combat weeds under zero tillage. Experience shows that after a while zero tillage helps reducing the weed infestation level significantly.
- Development and introduction of economically viable crop rotations and diversification of production are very important pre-requisites for successful implementation of the zero-tillage conservation technologies in Kazakhstan. Besides obvious economic advantages, the introduction of diversified crop rotations under zero technologies will significantly reduce weed infestation level and plant vulnerability to diseases as well as improve rotation of nutritious elements in soil. Introduction of legumes into crop rotation will increase nitrogen

content in soil. While introducing crop diversification, just as much attention should be paid to the issues of processing and marketing of the newly introduced crops.

- There is a need for more thorough research on application of mineral fertilizers and balance and dynamics of mineral nutrients' content in soil under zero tillage technologies for production of wheat and other agricultural crops. At the same time, it is important to remember that application of fertilizers is important not only to ensure high yield of grain, but also to gain biomass to remain in the field, which is an important part of zero technologies.
- An important component of the strategy for promotion of zero tillage technologies for soil conservation is building scientific and technical capacity, teaching new technologies and agricultural methodologies to the specialists and farmers, conducting various training courses and programs for personnel, drawing from international experience, providing consulting services and field days led by highly-qualified specialists and building public awareness of the modern agricultural technologies.

References

- Barayev, A. 1988. Soil conservation practice. Selected works. Moscow, Agropromizdat publ. (Rus.)
- Gilmanov, T.G., Johnson, D.S., Saliendra, N.Z., Akshalov, K. and Wylie, B.K. 2004. Gross Primary Productivity of the True Steppe in Central Asia in Relation to NDVI: Scaling Up CO₂ Fluxes. *Environmental Management* Vol. 33, Supplement 1, p. S492–S508
- Karabayev M., I. Vasko, M. Matyushkov, A. Bektemirov, A. Kenzhebekov, T. Bakhman, T. Friedrich, L. Makus, A. Morgounov, A. Darinov, M. Sagimbayev, B. Surayev, B. Cherezdanov, A. Rodionov and P. Wall. 2005. No-till technologies for grain crop growing in northern Kazakhstan. Almaty, Interligal publ., 64 p. (Rus.)
- Larney F., H. Yanzen, E. Smith and D. Anderson. 2004. Dryland agriculture on the Canadian Prairies: Current Issues and Future Challenges. In: *Challenges and Strategies for Dryland Agriculture*. S. Rao and J. Rayan (eds.), CSSA Special Publication, Madison, Wisconsin, USA, 2004, p. 113–139.
- Suleimenov, M. 1988. On theory and practice of crop rotations in northern Kazakhstan. *J. Zemledeliye*, #9:12-18.
- Suleimenov, M. and K. Akshalov. 2005. Crop rotations with no fallow in the steppes of Northern Kazakhstan. *J. Agricultural science. Moscow*. #8:2-9.
- Suleimenov, M., Z. Kaskarbayev, A. Kenzhebekov, V. Skoblikov, E. Chirkov. 2006. Zero tillage and Crop Diversification in Northern Kazakhstan. In: *Proceedings of the 4th Conference on No-till in Conservation Agriculture*, Dnipropetrovsk, 27-30 September 2006, Corporation Agrosoyuz, Dnipropetrovsk, Ukraine, p. 213-217.
- Schnider, V. 2002. Large grain farm in Siberia. *J. Economics of Agriculture of Russia*. #11:12-16.

Uncertified Organic Farming – Holistic Paradigm Imperative for Mass-scale Sustainable Agriculture

Bharat Mansata

*Vision Acres-Van Vadi, Village Vare, District Raigad, Maharashtra;
Earthcare Books and Resources Centre, Kolkata
(Email: bharatmansata@gmail.com))*

India has an acknowledged ten millennia history of farming. [1] For about 9,950 years, most farmers in this sub-continent practised 'Conservation Agriculture', the sustainability of which was time-tested. Such agriculture, based on indigenous knowledge, was mass-scale. It was organic; and of course, it was uncertified.

We cannot reverse history, but we can learn valuable lessons from it. In particular, it is vital we take a fresh look at the underlying native knowledge and farming practices that have proven their sustainability over many centuries. Understanding relevant aspects of the socio-cultural and economic milieu that helped agriculture remain sustainable is important too.

Many have paid glowing tribute to the great wealth of traditional agriculture in India. British agricultural scientist, JA Voelcker, wrote – for example – in his 'Report on Indian Agriculture' (1891): "It is wonderful how much is known of rotation, and the system of mixed crops, and of fallowing ... Nowhere would one find better instances of knowledge of soils and their capabilities, as well as the exact time to sow and reap as one would in Indian agriculture; and this is not at its best alone, but at its ordinary level. Certain it is that I at least have never seen a more perfect picture of careful cultivation ..." [2]

Half a century later, Sir Albert Howard, the well-known author of 'An Agricultural Testament', 1940, [3] wrote that he regarded the Indian peasant farmers as his professors. In more recent times, Dr. Winin Pereira's valuable treatise, 'Tending the Earth – Traditional, Sustainable Agriculture in India', 1993, provides a wealth of information and analysis on the subject. [4]

Fortunately, there are still many practising organic farmers in India today, from whom much can be learned and disseminated to other farmers. Outstanding among these are veterans like Bhaskar Save, who has inspired a whole new generation of organic farmers in India. His farm, Kalpavruksha – near village Dehri in southernmost coastal Gujarat – is a veritable food forest. It is highly productive at minimal cost, and a net *supplier* of water, fertility and energy to the eco-system of the region, rather than a net consumer!

Pondering on the grand mystery of creation in Nature, Save quotes from the Upanishads:

Om Pumamadaha Purnamidam
Purnat Purnamudachyate
Purnasya Purnamadaya
Purnamewa Vashishyate
"This creation is whole and complete.
From the whole emerge creations,
Each whole and complete.
Take the whole from the whole,
But the whole yet remains,
Undiminished, complete"

Comparing industrial systems with those of Nature, Save points out, "Industry cannot create anew. It merely transforms raw materials sourced from Nature. Only Nature is truly creative and self-regenerating – through synergy with the fresh daily inflow of the sun's energy." He adds, "A child has a right to its mother's milk. But if farmers (using chemicals) begin to draw on Mother Earth's blood and flesh as well, how can they expect her continuing sustenance?"

In 2006, Bhaskar Save sent a widely circulated and much acclaimed Open Letter to MS Swaminathan, chairman of the National Commission on Farmers, stating: "I am an 84-year old natural/organic farmer with over six decades

of personal experience in growing a wide range of food crops... I say with conviction that only by organic farming in harmony with Nature, can India provide abundant wholesome food and meet every basic need of all – to live in health, dignity and peace...” [5]

Save's Open Letter was accompanied by 6 annexures, including a detailed elaboration of his principles of farming in harmony with Nature. Another annexure related an old example of a 6 crop integral system – of cotton, 2 native millets, and 3 edible pulse legumes – which provided farmers in low rainfall regions with continuity of diverse yield round the year, without *any* irrigation or external inputs.

Mr Swaminathan replied to Save's letter, stating: “I have long admired your work and am grateful to you for the detailed suggestions ... valuable comments and recommendations. We shall take them into consideration in our final report.” [6]

There are other remarkable organic farmers like Vasant and Karuna Futane in Amravati District, Maharashtra; Dhirendra & Smita Soneji in Narmada District, Gujarat; and many more in various parts of the country. Such farmers typically retain important aspects found in our traditional, self-sufficient agriculture, that actually provided a higher aggregate yield of diverse, useful produce and organic matter than the chemical-industrial, mono-cultural systems.

A number of present-day organic farmers in India have made significant adaptations and innovations of their own. With the steadily worsening agricultural scenario in this country, these experienced, successful farmers are like shining lighthouses or beacons, offering a new direction of hope to those feeling lost.

While Indian agriculture had suffered under British rule, it steadily improved after independence. India's first Minister of Agriculture, KM Munshi, adopted a policy of regenerating the ecological foundations of farm productivity, based on a bottom-up, decentralised and participatory strategy. [7] He called for the healing or restoration of the hydrological (water) and nutritional (fertility) cycles in every Indian village. As a result, the nation's agricultural productivity received a significant boost in the first two Plan periods post independence.

But from the 1960s, organic farming steadily declined in India, as the Government pushed the 'Green Revolution' with much determination and a generous basket of incentives and support. In more recent years, however, this once seductive 'modern technology' has plainly left farmers and farmlands writhing in India, as in many other parts of the world.

In extreme distress, over 200,000 Indian farmers committed suicide in the past decade. There is unabated spiralling of farm input costs; and extensive degradation/depletion of natural resources, including soil and groundwater, vital for agriculture. Systemic toxicity levels, pestilence and diseases have greatly increased. Farm produce prices remain un-remunerative, with the government's minimum support prices falling far short of production costs. And agricultural yields have not just plateaued, but are declining in many parts.

According to the National Sample Survey, per capita food grains consumption has fallen to levels lower than the 1939-44 famines! UNDP, UNICEF & World Food Programme state that almost half the children in India are malnourished, and 20% of the country's population goes hungry. But ironically, media reports indicate that India aims to plant 35 million acres (140,000 sq km) to bio-fuel cash-crops like *Jatropha* [8] – to grow food for cars rather than people!

Amid this alarming situation, India's National Commission on Farmers recently bemoaned that 40% of India's agricultural families would like to leave farming. This forebodes a potential quarter billion economic and ecological refugees streaming into India's slums in quest of any available work to earn their living! Without doubt, such a situation will be ever more unsustainable – both economically and ecologically. It will likely become a fertile breeding ground of rampant and uncontrollable social unrest.

The global IAASTD report (International Assessment of Agricultural Knowledge, Science and Technology for Development) is testimony that planetary consciousness is finally waking to the stark reality that chemical-intensive industrial agriculture has been disastrous at multiple levels. The 2,500 page IAASTD Report – prepared over 4 years by more than four hundred experts and a near thousand researchers and reviewers, and endorsed by 60 nations – recommends that small-scale farmers and agro-ecological methods are the way forward, with indigenous knowledge playing an important role.

The IAASTD emphasises a bottom-up rather than top-down approach. It looks upon farmers as the future custodians and managers of environment and ecosystem services; and it adds that the primary beneficiaries in agriculture should be the farmers; not the processors, intermediaries and corporate agri-commodity traders and retailers.

The IAASTD Report points out too that GM crops (now aggressively promoted by agri-business corporations like Monsanto) are surely not an answer to hunger and poverty. They will heighten the farmers' vulnerability through increased dependence on expensive, externally purchased inputs. Most importantly, the GM crops are fraught with grave, poorly tested hazards and long-term risks to health and the environment; and they threaten inevitable (and virtually irreversible) genetic contamination and erosion of biodiversity essential for the future of agriculture.

On September 25, 2008 the President of the General Assembly of the United Nations produced a report stating: "The essential purpose of food, which is to nourish people, has been subordinated to the economic aims of a handful of multinational corporations that monopolize all aspects of food production, from seeds to major distribution chains, and they have been the prime beneficiaries of the world crisis. Research conducted by the UN Environment Programme suggests that organic, small-scale farming can deliver the increased yields which were thought to be the preserve of industrial farming, without the environmental and social damage which that form of agriculture brings with it. An analysis of 114 projects in 24 African countries found that yields had more than doubled where organic, or near-organic practices had been used."

It is increasingly evident that the path to sanity, sustainability and social justice demands an integrated, holistic strategy of organic mixed cropping suited to local conditions and needs. This must necessarily draw on indigenous knowledge and wisdom; and it must be combined with a mass-participatory campaign to regenerate our natural resources – of soil, ground water, biodiversity and forest/tree cover.

While organic certification may play a limited role in fetching higher produce prices for some farmers, making agriculture more remunerative for them, this option has little relevance for most small farmers who largely consume their produce within their own family, selling or sharing any small surpluses of diverse, perishable produce within their local community or village. Such small and marginal farmers, with land holdings of less than 2 hectares, constitute almost 80% of all Indian farmers. [9] Unless an alternative, suitable paradigm of sustainability with equity addresses their needs as well, the future of conservation agriculture may well be a repeat story of token measures – 'too little, too late'!

The certification of organic produce is essentially a marketing strategy to procure a higher value from a minority of conscious consumers – often in distant places – who can afford it. (Product labelling should actually be required of hazardous industrial junk-foods, not safe foods!) In countries that are poor and ill-equipped, the expensive certification process currently followed, invites corruption; and inevitably, there will be unethical trade-offs in the 'buying and selling' of certificates, which only a small section of farmers may be able to afford. Rather, 'farmer-consumer organic cooperatives', mediated by local or regional/state organic farming associations, may be a better option than impersonal certification of allegedly organic produce from anonymous suppliers.

Any undue emphasis on certification effectively marginalises organic farming into a niche. While such a niche may grow from tiny to small, or not-so-small, the narrow certification corridor can certainly have no pretence of moving agriculture in general to a level of mass-scale sustainability, essential for addressing the burning challenges of our time.

Another limitation, almost inherent in large-scale, market-oriented, certified organic farming – such as large, cash-cropping estates with mechanised operations – is that such agriculture cannot hope to be truly sustainable, even if one ignores considerations of equity. This is because commercial farming focuses on convenience of functioning for maximising short-term profit. It thus tends to be mono-cultural, or near mono-cultural, growing only such crop/s which are most profitable, and thereby missing out on the synergies that are possible with more diversified, poly-cultural systems. (Nature abhors monoculture!)

Further, large-scale commercial organic agriculture, with its higher purchasing power, also tends to monopolise the organic matter available in the region, thereby depriving other neighbouring farmers and lands of such soil-regenerating matter. It is for this reason that the well-known Japanese natural farmer, the late Masanobu Fukuoka, termed such agriculture 'Hinayana Farming'; *hinayana* meaning 'small vehicle', helpful only to a few, as against 'Mahayana' – a vehicle spacious enough to carry many, indeed all! [10]

To reach out to the large masses of both food growers and consumers with long-term viability in mind, it is imperative that the costs incurred by farmers be brought down, without reducing *aggregate* yields, so that sufficient food – varied and wholesome – is universally affordable and accessible. Regenerating our natural resources – of soil, ground water, biodiversity, vegetative cover and organic matter – on which sustainable agriculture fundamentally depends, will be crucial for this. India thus needs to nurture socio-ecological zones rather than Special Economic Zones that encroach unsustainably on agricultural lands and livelihoods.

It is also important that both food and farming inputs be sourced as locally as possible. Ideally, the consumption of food produce should be within a 100 mile radius of its source, with only low-volume, high value items of surplus (in excess of local demand) sold outside the region. This is required to keep distribution costs low, as well as to minimize energy inefficiencies and related ecological hazards, including climate change.

The IAASTD Report estimates that almost 31% of total greenhouse gas (GHG) emission annually is attributable to agricultural and land use related practices, including: crop and livestock husbandries, deforestation, transportation of food, farm inputs, agro-industrial raw materials, etc. A revised calculation of Mae-Wan Ho, (ISIS, 2008) indicates that organic sustainable agriculture and localized food systems would reduce 17.3% of energy use; and mitigate 32.1% of global greenhouse emission responsible for potentially catastrophic climate change. The largest contributions in such mitigation of climate change, would be through carbon sequestration by organically managed soils, and reduced transportation of inputs and produce through localization of food systems. [11]

The challenge is thus nothing short of evolving, and implementing on the ground, an inclusive, holistic paradigm of integrated agro-ecology to address the impending multiple crises – of food, fresh water, fuel, extinction of species, health problems, climate change, unemployment, social unrest and violence – that are simmering ominously all over our planet. As the IAASTD Report bluntly points out, radical changes are demanded – “Business as usual is *not* an option!”

For those particularly interested in the agricultural practices followed and recommended by seasoned conservation farmers like Bhaskar Save, here is a sampling of a few nuggets of indigenous wisdom:

- Barely 10-15% of the crop plant, consisting of edible seeds or fruit, is the due of the farmer (for consumption or sale); the balance 85-90% is the due of the soil, and must go back to the soil, either directly as mulch, or indirectly via the dung of farm animals. If this is followed, no external fertility inputs would be needed.
- Establishing complete ground cover of vegetation, through suitable inter-cropping, creates a favourable micro-climate for the regeneration of soil life, which in turn recycles nutrients and maintains soil porosity, enhancing both aeration and moisture absorption, vital for healthy plant growth. Groundwater recharge of rain is augmented. Evaporation loss and soil erosion are effectively checked. Aggregate yields increase.
- Conservative irrigation maintains both dampness and aeration in the soil, aiding healthy plant growth. Excess irrigation expels soil aeration, and may cause insidious salinization, especially in poorly drained soils and dry climates.
- Bio-diverse poly-cultures of healthy, organically grown crops have a high resistance to pest attack, and reduced vulnerability to climatic vagaries; natural processes of biological control help to check any build-up of pest rampancy.
- Restoring at least 30% ground cover of mixed, indigenous trees and forests is the core task of ecological water harvesting – the key to restoring the natural abundance of groundwater. Diverse, useful produce may also be obtained, apart from increased biomass availability to regenerate soil fertility. The loss of soil through erosion is greatly checked.

It can thus be seen that poly-cultural organic farmers, particularly those who integrate trees and perennials, provide not just food, but vital ecological services as well – including bio-diversity regeneration, groundwater recharge, augmentation of soil and fertility, incremental net harvesting (rather than consumption) of energy, and mitigation of climate change. The economic value of such services may significantly outweigh the monetary return from the sale of produce, particularly in a context of stable, affordable pricing of food for common citizens. Consequently, there is wisdom in compensating organic, agro-ecological farmers for such services, rather than pursuing far more expensive, and much less efficient technological ‘solutions’ and mega-projects.

Considering that the Indian government currently provides a massive annual subsidy to the tune of Rs 119,000 crore (or thereabouts) to support inefficient, inequitable and ecologically damaging (and hence, unsustainable)

chemical-industrial agriculture, it is high time that it began to encourage and proactively support more beneficial and deserving agro-ecological methods instead. This would call for a progressive phasing out of old subsidies, perhaps over a pre-announced period of 4-5 years, and correspondingly diverting the funds that are saved towards sustainable organic methods and natural regeneration.

Bhaskar Save's 3rd Open Letter, dated 9th October, 2006, to the National Commission on Farmers, summarises a number of suggestions by him towards formulating a new agricultural policy for India. [12] Similarly, the 'Civil Society and Farmers' Representation' (2007) outlines a holistic agricultural agenda for the nation, offering a host of ecological, economic, social and health benefits [13]. Without doubt, the rationale for adopting such a national agenda with highest priority is compelling. On how soon we act on this, depends our chances of averting calamity of gravest proportions, and retrieving a sane future for ourselves, our children, and generations to come. Without firm foundations that recover food sovereignty and security, mere economic glitter is sure to fade like a mirage. We need to urgently learn from the Cuban story post 1990. [14]

References

1. Report of India's 'National Commission on Farmers', 2006.
2. Voelcker JA, 'Report on the Improvement of Indian Agriculture', 1891, Agricole reprint 1986, pg 11
3. Albert Howard, 'An Agricultural Testament', first published in 1940, London; Indian edition - Earthcare Books, Kolkata, 2007
4. Winin Pereira, 'Tending the Earth – Traditional Sustainable Agriculture in India', Earthcare Books, 1993
5. 'The Great Agricultural Challenge', Bhaskar Save's Open Letters (with 6 annexures) to MS Swaminathan, National Commission on Farmers; transcribed by Bharat Mansata, Earthcare Books, 2008
6. Ibid
7. Vandana Shiva, 'The Violence of the Green Revolution', 1989
8. John Vidal, 'The Looming Food Crisis', Guardian, London, August 29, 2007
9. Civil Society and Farmers' Representation, 'Holistic Ecological Agriculture Agenda for India', 2007, reproduced in 'The Great Agricultural Challenge' (op cit), pages 101 to 114
10. Masanobu Fukuoka, 'The Natural Way of Farming' (pages 93 to 97), first published in 1985, Japan Publications, Tokyo; Indian Edition – Bookventure, 1993
11. Prof RN Basu, Chairman, West Bengal State Agriculture Commission, 'Indian Agriculture at the Crossroads', published in 'The Agriculturist' (pages 32 to 49), Kolkata, December 2008, Golden Jubilee Number of the Agricultural Society of India
12. 'The Great Agricultural Challenge, op cit
13. Civil Society and Farmers' Representation, 2007, op cit
14. Bharat Mansata, 'Organic Revolution', The Agricultural Transformation of Cuba since 1990, Earthcare Books, 2008

Theme 2: Institutional Innovations and Policies

Session 2.2: Integrated Approach for Technology Development and Dissemination

Adoption of Conservation Agriculture Technologies: Constraints and Opportunities

Theodor Friedrich* and Amir Kassam

*Plant Production and Protection Division, Food and Agriculture Organization of the United Nations,
Viale delle Terme di Caracalla, 00153 Rome, Italy
(*Email: Theodor.Friedrich@fao.org)*

Conservation Agriculture in its different local adaptations is practiced for more than 3 decades and has reached nearly every part of the world. Wherever it has been adopted it has proven the benefits usually claimed in its favour. Therefore the question arises: if CA is so good, why is it not spreading like wildfire? The simple answer to this is that the answer is not that simple. Equal to many other good and proven technologies, adoption of conservation agriculture needs a primer before it starts moving on its own. A number of constraints are between the theory and a full scale adoption.

These constraints come in different categories viz., intellectual (knowledge), social, financial, technical, infrastructural and political. These constraints are meeting actually a number of opportunities which are facilitating change in crisis and emergencies, such as the soaring food prices, make people more receptive for change; increasing environmental concerns and pressures regarding the sustainability of production processes, which increasingly put agriculture under pressure; rising input and energy costs urging for improved input use efficiency; challenges of climate change for which CA holds promising options. The challenges and opportunities will be discussed in the paper and options to overcome challenges and to harness opportunities be presented.

Key words: Conservation Agriculture, Technology Adoption

Conservation Agriculture (CA) is, to those who know it, the best bet for a sustainable and productive agriculture. People refer to CA as a win-win agricultural production system and it is successfully applied on more than 100 million hectares in so many different agro-ecosystems and cropping systems that the reason and justification for soil tillage should become weaker and weaker. Already in the 1940s Edward Faulkner in his revolutionary “Ploughman’s Folly” stated that ‘no one has ever advanced a scientific reason for ploughing’. Wherever CA has been adopted it has proven its benefits. The cases where CA did not perform as expected can usually be related to mistakes or shortcuts in the management of the system, but not to any inherent failures in the system. Yet the question arises: if CA is so good, why is it not spreading like wildfire? The simple answer is that the answer is not that simple. CA is knowledge intensive and a complex system to learn. It cannot be reduced to a simple standard technology and especially for pioneers and early adopters there are many hurdles in the way before the full benefits of CA can be reaped. This explains, why in all cases where CA has been or is currently in a process of successful adoption, this process follows an S-curve with a slow to very slow start, leading then into exponential growth, and slowing down towards a plateau level, which is most likely above 90% adoption. Since so far only about 6-7 % of the world cropland is farmed under conservation agriculture it can be postulated that in most countries CA is introduced as an “unknown” new concept and that neither the knowledge nor the other elements of an enabling environment for the adoption of CA in the country exist. This is the condition, which presents most of the constraints to adoption. Only in very few occasions, as was the case with the southern parts of Brazil in the 1970s, the problems with conventional tillage-based farming practices become so severe that spontaneous adoption occurs despite these constraints. In that case it was the uncontrollable water erosion combined with extremely poor profit margins for farmers. Obviously the reasons to change from one cropping system to another vary according to location, but in most cases erosion problems, climatic problems (drought) and unfavourable profit margins are the most important motivations for farmers to adopt CA.

As the adoption advances, the constraints decline, explaining the exponential uptake after some years. The duration of this slow early adoption before it turns into the exponential growth can be influenced mainly through supportive policies for services and related regulations.

Constraints to CA Adoption

Farmers in a country or region, where CA is not practiced, face a number of problems which make adoption difficult. These problems are of diverse nature, such as intellectual, social, biophysical and technical, financial,

infrastructural and policy. Most farmers are facing several of these problems, if not all, at the same time to the effect that only very few bold pioneer farmers adopt CA. Farmers are not in the position to start with a blank sheet and to weigh objectively the merits and disadvantages of CA against conventional tillage farming. In all cases CA is the new unknown concept, while the default condition for more than 90% of the world's farmers is the conventional tillage-based practice which has worked for them so far.

Intellectual Constraints to Adoption

New technologies that lead to immediate fast adoption often show obvious advantages resulting in fast acceptance and enthusiasm. In many cases this enthusiasm cools down, once the new technology is known and the downsides become visible. With CA it is just the opposite way: it contradicts so much of the knowledge a farmer has learned and been told that the benefits offered by CA are not obvious in the beginning. However, once the step-wise adoption begins, CA improves its performance over time. The more experience producers have with CA, the more convinced and positive is their opinion about it. The less practical experience people have with CA, the more critical and negative is their attitude towards it. A study carried out with European and American no-till farmers and agricultural experts came to similar conclusions. It was found that the experts, mostly without practical experience in CA, anticipated many problems for its adoption. In their perception actually the problems exceeded the benefits leading to an overall negative attitude. Farmers, however, who were actually practicing CA and had experience with the system, had an overall positive perception with the benefits clearly dominating and the problems being manageable (Tebrügge and Böhrnsen 2000).

CA has actually two intellectual barriers to overcome: the first is that CA concept and principals are counterintuitive and contradict the common tillage-based farming experience, which has worked for generations and which often has created cultural values and rural traditions; the second is the lack of experiential knowledge about CA and the mechanism to acquire it.

Soil tillage, and particularly the plough, has in most countries become part of the culture of crop production. Ploughing, cultivation and tillage are often synonyms for growing a crop. Cropland is called "arable" land which is Latin for "ploughable" land. The plough has been part of the very early developments of agriculture and has the character of a brand symbol for what is 'correct'. It is therefore difficult for people to accept that all of a sudden the plough is dangerous and that a crop can grow without tilling the land. Overcoming this "mental compaction" is often much more difficult than actually physically starting with no-till farming (Landers 2001). Unless a person has seen it happen, it is very difficult to imagine a soil becoming softer and better structured without being tilled.

The second intellectual impediment to adoption is simply the lack of sufficient experiential knowledge about it at all and the means of acquiring it. Globally some 7% of the agricultural land is under CA. The adoption is concentrated in some few countries, eventually reaching adoption levels beyond 50%, while in the rest of the world the adoption is at levels below 2%. This explains that most people have never seen a CA system in practice. Since it is also not yet represented in any labels or certification schemes or has any direct relevance to consumers, CA hardly appears in the media. CA is also not included in university curricula even in good agricultural universities. This explains that, despite having an adoption level more than twice that of organic farming, the public knowledge about CA is much lower than about organic farming. Even most agricultural professionals and many farmers have never heard about CA, and if they have, they have only vague ideas. Permanent no-tillage farming and CA are often simply not known and therefore not on the screen as an option for farmers.

For actual adoption of CA the farmer would not only need to know about CA elements in general, she/he would need to know the details on how to implement CA elements under the specific conditions of an individual farm. This knowledge is generally not available as a standard technology package off-the-shelf. Worse, CA is a complex and management intensive farming concept in which crop management has to be planned ahead and is mostly proactive and not reactive, as in the standard tillage-based systems. Problems of soil compaction or uneven surface in tillage-based systems are corrected with tillage, in no-till systems they have to be prevented from occurring from the start. Weed and pest management in conventional tillage systems is often based on chemical or mechanical control as response to the incidence, while in CA the incidence of weeds and other pests is reduced by forward planning of crop rotations. This increased complexity requires a degree of experience and knowledge, which has to be acquired and learned. For early adopters this learning process and experiential knowledge has therefore involved a lot of trial and error until sufficient local experience and knowledge is accumulated to make the adoption easier. However, the solutions to these practical problems are best developed by the farmers themselves and not by scientists. Usually farmer's own adaptive "research and development" process leads to quicker and more applicable

results than the so called 'Green Revolution' approach of leaving the development of a standard technology package "ready for adoption" to the scientific community.

To effectively cope with the diverse agro-ecological and socio-economic conditions of farming environments when considering system level alternatives and changes, *flexible* approaches to on-farm testing and dissemination are required. This is particularly so when knowledge-intensive, integrated practices involving the simultaneous management of several elements are being introduced as is the case with CA, and the elements concerned cannot be reduced to standardised technology package intended for wide applicability (Stoop *et al.* 2008). The same accounts for other complex and management intensive concepts, such as integrated pest management (IPM), which has been successfully introduced by FAO through a network of Farmer Field Schools (FFS) first in Asia. (van den Berg and Jiggins, 2007) and more recently in Africa. Another more recent example is the System of Rice Intensification (SRI) with similar levels of complexity and need for local adaptation paired with the problem of being counterintuitive (Stoop *et al.* 2008).

Thus, a relatively large variation in the implementation and performance of CA practices in farmers' fields is an obvious and logical consequence of this dissemination approach, partly also because the new balances and equilibria as well as full benefits that such practices are expected to offer take time to establish. Therefore, economic assessments and adoption studies based on aggregated results over relatively short periods of time will further contribute to biased and/or pre-mature, generalised conclusions with regards to production potentials, agronomic feasibility and future prospects.

Social Constraints to Adoption

Farming communities in the developing regions are mostly conservative and risk averse. Any farmer doing something fundamentally different from the others will therefore risk being excluded from the community. Only very strong and individually minded characters would take that step, which leads to social isolation and sometimes even to mocking. Even if those individuals have visible success, the aversion created in the community and the peer pressure can result in other farmers not following. The pressure can be so bad that the community gets jealous of the success and instead of also adopting it, it leads to boycott including using 'black magic' and placing bad spells on the fields. For adoption of CA it is therefore not enough to find any progressive farmer who will prove the concept to work, but the farmer must have a socially important role, and be respected and integrated in the community. Ideally the community should be involved from the very beginning to avoid this kind of antagonism.

Other problems can be traditional land tenure systems, where there is no individual ownership of land, which lowers the incentives of farmers to invest in the long term improvement of soil health and productivity. Also communal grazing rights, which often include the right to graze on crop residues or cover crops after the harvest of the main crop, create conflicts which make it difficult for the uptake of CA practices. These problems can be real impediments to the adoption of CA and conflicts arising, for example, from alternative uses of crop residues as mulch or animal feed cannot be solved by orders or directives. Even physical protective structures such as fences might not be the optimal solution, if they work against the traditional social values of the respective cultures. Much more important in the process is that the entire community first understands the issues and the changes and benefits involved in adopting CA and jointly looks for solutions.

Biophysical and Technical Constraints to Adoption

Although the concept of CA is universally applicable, this does not mean that the techniques and practices for every condition are readily available. In most cases the actual CA practice has to be developed locally, depending on the specific farming situation and agro-ecological conditions. Especially the crop rotations, selections of cover crops, issues of integration of crop and livestock have to be discovered and decided upon by the farmers in each location. A diversity of problems arises, very often around weed management, residue management, equipment handling and settings, planting parameters like timing and depth, which all have to be discovered new. This creates the problem that extension agents and advisors in the beginning, when CA is newly introduced in a region, cannot give specific advice on practices, but have to develop these practices together with the farmers. On the other side such an approach, if correctly applied, is much quicker and more sustainable than the development of specific practices by scientists, since it uses the immense pool of experience and innovation potential of the farmers' community. In this way some cover crops have been developed from weeds, or practices such as growing paddy rice or potatoes under no-till in CA have been developed by farmers without the scientists even thinking of proposing such innovations.

Another technical constraint is the simple unavailability of certain technologies or inputs, apart from the financial or other constraints. In many countries where farmers start with CA there are no seeds available for cover crops. Also the availability of equipment, especially no-till direct seeding equipment, often is a problem. By now there are technologies available for most situations, somewhere in the world. However, in a specific location farmers might not be aware of these technologies or they simply have no way to access them. This is where usually external support such as knowledge sharing or eventually even the introduction of specific technologies, such as direct seeding equipment, is required.

Financial Constraints to Adoption

Although the profitability of CA is usually higher than for conventional farming practice there are still financial hurdles to adoption, depending of the availability of capital to invest into this change of production system. These constraints exist at all farm size levels, though obviously to different degrees and for different purposes. Changing a production system to CA is a long term investment. In many cases the rationale for the change is the degradation of the natural resources, especially of soil and water, as a result of the previous tillage-based agriculture. In order to start with CA and to successfully create favourable conditions for the soil life and health to return, some initial investment into the land might be necessary, such as breaking existing compactions by ripping, correction of soil pH or extreme nutrient deficiencies, levelling and shaping of the soil surface for the cropping system foreseen under CA. Especially for small subsistence farmers the capital for this kind of investment is not available. In addition to this, the farmer needs new equipment, while most of the existing equipment is becoming obsolete and will most likely not find an attractive second hand market for.. The larger the farmer, the more important is this hurdle, since a no-till seed drill for example is considerably more expensive than a conventional one. This conflict between the potential improved profit margin on one side and the very concrete and actual investment requirements on the other side often leads to the fact that farmers decide not to change to CA, even though they are convinced about the benefits.

The provision of credit facilities for these cases is one solution, but sometimes also the availability of contractor services or technical advice on how to adapt and modify existing equipment as a low cost intermediate solution to start can help. The modification of existing equipment has, for example in Brazil and in Kazakhstan, provided an entry point for some farmers to start with CA and then, after benefiting from the higher profitability, making the investment into proper equipment at a later stage. Especially for small farmers the home made solutions for simple CA farm tools are an important element for CA adoption in Paraguay (Lange and Meza, 2004).

Infrastructural Constraints to Adoption

As with any agricultural production system, CA also requires certain exogenous inputs to achieve intensive production levels. CA is capable of improving the soil and crop growth conditions for production and the efficiency of the natural resource and input use, but it is not a 'perpetual motion' process which would allow crop intensification from endogenous resources. If CA is therefore meant to sustainably intensify agricultural production, a suitable market and service infrastructure must be in place to provide inputs and to allow the processing and marketing of the produce. Without any external inputs, CA systems will still perform better than conventional tillage-based methods, but this will be at a much reduced level. Some of the inputs like the types of fertilizers will differ only marginally from the requirements of conventional tillage-based farming. Other inputs, however, such as herbicides, seeds for cover- and rotational crops and especially equipment for direct seeding, planting and residue management are often completely different to the traditionally used ones and have to be introduced to the markets. This requires not only a good input supply infrastructure, but also a proactive attitude of the supply sector, such as dealers and manufacturers. Otherwise a chicken-and-egg situation is created where the supply sector does not offer certain inputs because there is no market for them, but the farmers are also not demanding the items because they are not being offered. This deadlock often requires some external intervention mostly in stimulating the demand, but also in assisting the supply sector in making inputs commercially available. This includes, besides the collaboration with the farming sector, a close collaboration with the commercial input supply sector and some supportive policies.

Policy Constraints to Adoption

Adoption of CA can take place spontaneously, but it usually takes a very long time until it reaches significant levels. Adequate policies can shorten the adoption process considerably, mainly by removing the constraints

mentioned previously. This can be through information and training campaigns, suitable legislations and regulatory frameworks, research and development, incentive and credit programmes. However, in most cases policy makers are also not aware about CA and many of the actually existing policies work against the adoption of CA. Typical examples are commodity related subsidies, which reduce the incentives of farmers to apply diversified crop rotations, mandatory prescription for soil tillage by law, or the lack of coordination between different sectors in the government. There are cases where countries have legislation in place which supports CA as part of the programme for sustainable agriculture. If those countries, within the same Ministry of Agriculture, have then also a programme to modernize and mechanize agriculture, it usually happens that the first items introduced under such a mechanization programme are tractors with ploughs or disk harrows. This does not only give the wrong signal, but it works directly against the introduction and promotion of CA, while at the same time an opportunity is missed to introduce the tractors with no-till seeders instead of the plough, helping in this way to overcome this technology constraint. Countries, with their own agricultural machinery manufacturing sector, also often apply high import taxes on agricultural machinery to protect their own industry. This industry often has no suitable equipment for CA available in the short term, but due to the high import taxes the importation of equipment from abroad is made impossible to the farmers who wish to adopt CA. In other cases the import tax for raw material might be so high that the local manufacturing of CA equipment becomes unfeasible. In all those cases regulations have to be revised even beyond the influence of the Ministry of Agriculture, which often proves very difficult. Policymakers and legislators must be made aware of CA and its ramifications to avoid such contradictory policies.

Where farmers do not only farm their own land, but rent land from others, there are additional problems with the introduction of CA: the building up of soil organic matter under CA is an investment into soil fertility and carbon stocks, which so far is not recognized by policy makers, but increasingly acknowledged by other farmers. Farmers who still plough know that by ploughing up these lands the mineralization of the organic matter acts as a source of plant nutrients, allowing them to “mine” these lands with reduced fertilizer costs. This allows them to pay higher rent for CA land than the CA farmer is able to do. Such cases can be observed in “developing” African countries as well as in “developed” European ones. To avoid this some policy instruments are required to hold the land owner responsible for maintaining the soil fertility and the carbon stock in the soil, which in absence of agricultural carbon markets is difficult to achieve.

Opportunities for CA Adoption

Fortunately, besides the constraints to adoption, there are many opportunities which facilitate the change to CA. The higher the pressure on farmers and the bigger the problems for them to carry on with their business, the easier it is to introduce a change. Farmers that are still complacent with their situation are reluctant to change.

Crisis and Emergencies

The crisis of the soaring food prices in 2007/08 has brought the importance of food as a global policy issue to the attention of everyone. Food security has been newly discussed and countries have begun to revisit their food self-sufficiency policies. Also, other emergencies, in particular those related to natural disasters such as floods and droughts are mobilizing relief funds. There is an increasing awareness that these relief funds should not only be used to replace the losses, but also be used as an investment into the rehabilitation towards more resilient agricultural production systems. In this way more and more FAO emergency rehabilitation projects are introducing CA practices into their operations with growing success, particularly in Southern and Eastern Africa and in the DPR Korea. There is obviously a problem in this, since ideally the introduction of CA should be accompanied over several years to achieve uptake and sustainability, while emergency projects are only of short duration of maximum one year. However, even if farmers would revert back to conventional tillage farming after the intervention they would not have lost, but gained some new insights. In reality there is a growing awareness about CA in many of these countries in crisis so that besides the emergency intervention the respective Ministries of Agriculture can carry on promoting CA practices. On the other side the frequency of natural disasters seems to increase and in most countries the emergency rehabilitation projects return year after year following similar events. This allows in practice the support of CA programmes over a longer time period and positive developments have been seen in this way. Obviously the project implementation has to make sure that the capacity building component is well enough established to allow for long term sustainability. This makes this kind of emergency projects more complex than the usual input distribution ones.

Increasing Environmental Concerns

Increasing environmental concerns regarding the sustainability of modern farming is putting agriculture under pressure to reform. Regulations regarding soil conservation or water quality, as for example the new EU Water Framework Directive, make it difficult for conventional tillage-based farmers to comply with the new maximum residue levels in ground or surface waters. If those threshold values would be consequently followed up, farmers would have to revert to no-till farming, which significantly reduces the water contamination levels with chemical substances from agricultural soils (Bassi 2000, Saturnino and Landers 2002). In the past the consumer interest was very much focussed on food safety resulting in growing markets for organic food. More recently the focus seems to shift to environmental issues, including biodiversity and water resources, and consumers start to become concerned with the environmental footprint of agricultural production and its sustainability. While recognizing that production levels have to increase and cannot go down, agricultural production will have to be combined increasingly with the delivery of environmental services to become sustainable and acceptable. This is a major opportunity for CA, since it is so far the best available concept for combining high intensive production with long term sustainability of the environment and the resource base. Accordingly, the reform of the UN Food and Agriculture Organization in 2008 came to the formulation of new strategic goals, with the first one being “Sustainable Intensification of Crop Production”, facilitating the promotion of CA as a fundamental element in support of this strategic goal (FAO 2008a).

Rising Input and Energy Costs

The increasing costs of agricultural inputs, namely fuel and nitrogen fertilizer, both closely linked to energy costs, are the strongest direct arguments for farmers to reduce or do away with their tillage practices. However, most farmers will realize that reducing the tillage alone will not bring the desired effects and might not even work out in the long term. If correctly advised they will adopt other elements to make no-till farming sustainable, and ending up in CA-based cropping systems. While the adoption of no-till will reduce more than anything else the fuel costs for tillage, it might lead to other problems and even to increased requirements for nitrogen fertilizer and other agrochemicals. The combination with crop rotations and mulch cover however has a positive effect such that the input use becomes more efficient and optimised. Yields increase without additional inputs and in the long term even with significantly reduced inputs (Saturnino and Landers 2002). In most of the cases of CA adoption the immediate impact has been that of a reduction in production costs resulting in increased farm income, even if the yield levels would not increase or even decline in the beginning (Hickmann 2006, Lange 2005). The full adoption of CA will result in an overall reduction of the energy inputs in the system (Doets *et al.* 2000) which should be reflected in the energy costs.

Challenges of Climate Change

Climate change is an increasing challenge for agriculture. For conservation agriculture, however, it is also an opportunity, since it can respond to climate change in two ways, harnessing policy support for the further up-scaling of CA.

As a no-tillage cropping system CA holds opportunities for climate change mitigation through carbon sequestration in the soil. By reducing the mineralization of soil organic matter and hence the losses of carbon dioxide from soils through no-tillage, and by adding additional organic matter with soil residues and providing a balanced C-N ratio with crop rotations including legumes, CA contains the essential elements needed for a crop production protocol to qualify for carbon sequestration in agricultural soils. In addition the emissions from fuel are also reduced under CA. If some other complementary practices are applied, avoiding soil compactions for example with controlled traffic systems and avoiding anaerobic conditions in soils through adequate water, irrigation and drainage management, also the nitrous oxide and methane emissions can be reduced compared to conventional tillage-based agricultural practices. In this way CA can contribute to mitigating climate change. This can be harnessed with payment schemes for environmental services, such as carbon markets or emission reduction payments, which could help to promote the adoption of CA.

At the same time CA systems serve for climate change adaptation and as such should be part of national climate change adaptation plans since CA, being resilient to drought stress, reduces the yield variability over time (Tebrügge 2000) thus improving food security. The increased soil organic matter facilitates increased and better

water storage in the soil. The mulch cover and the minimum soil disturbance reduces water losses from the soil and the better rooting system of the crops facilitates access to soil water from deeper soil horizons resulting in an overall water saving of about 30 % compared to conventional tillage-based systems (Bot and Benites 2005). This together helps crops to survive drought spells. In addition, run-off losses of excess surface water are avoided through far better infiltration rates of water into the soil, providing a replenishment of the groundwater aquifers and a more steady flow of rivers and wells even in the dryer months of the year. The increased infiltration capacity of soils under CA also helps to reduce the surface runoff and associated soil erosion as well as the flooding created by the water downstream in watersheds. No-tilled soils with an intact vertical macro pore structure and a good mulch cover can withstand even heavy tropical rainstorms of over 100 mm per hour, with a significantly reduced amount of surface runoff (Saturnino and Landers 2002). This can be instrumental for the reduction of flood risks as a climate change adaptation strategy (DBU 2002).

Concluding Remarks

Despite the obvious productivity, economic, environmental and social advantages and benefits of CA, adoption does not happen spontaneously. There are good reasons for individual farmers not to adopt CA in her/his specific farm situation. The origin of the hurdles ranges from intellectual, social, financial, biophysical and technical, infrastructural to policy issues. Knowing the respective bottlenecks and problems allows developing strategies to overcome them. Crisis and emergency situations, which seem to become more frequent under a climate change scenario, and the political pressures for more sustainable use of natural resources and protection of the environment on the one hand and for improving and eventually reaching food security on the other provide opportunities to harness these pressures for supporting the adoption and spread of CA and for helping to overcome the existing hurdles to adoption. In this way, the increasing challenges faced around the world, from the recent sudden global crisis caused by soaring food prices, high energy and input costs, increasing environmental concerns to issues of climate change facilitate the justification for policy makers to introduce supportive policies and institutional services, even including direct payments to farmers for environmental services from agricultural land use, which could be linked to the introduction of sustainable farming methods such as CA. In this way the actual global challenges are providing at the same time opportunities to accelerate the adoption process of CA and to shorten the initial slow uptake phase.

A diverse group of international stakeholders, interested in accelerating the mainstreaming of CA, recommended at a meeting held at FAO in July 2008 the creation of a global cluster or network of interconnected *Communities of Practices (CoPs)* (FAO 2008b). They proposed the formation of a small interim Facilitating Group, coordinated by FAO, to oversee the creation of a global network of CoPs, to firm up the agenda for action and to manage related tasks. A Listserve has been established to serve as a communication platform to facilitate the operations of this international network of CA-CoPs.

References

- Bassi, L. 2000. *Impactos sociais, econômicos e ambientais na Microbacia Hidrográfica do Lajeado São José*, Chapecó, SC; EPAGRI, Documentos No 203, 50 pp
- Bot, A. and Benites, J. 2005. *The importance of soil organic matter, Key to drought-resistant soil and sustained food production*. FAO Soils Bulletin 80, FAO, Rome
- DBU, 2002. *Innovativer Ansatz eines vorbeugenden Hochwasserschutzes durch dezentrale Maßnahmen im Bereich der Siedlungswasserwirtschaft sowie der Landwirtschaft im Einzugsgebiet der Lausitzer Neiße*. Project report DBU-project AZ 15877, Deutsche Bundesstiftung Umwelt (German Federal Environment Foundation), Osnabrück
- Doets, C.E.M., Best, G. and Friedrich, T. 2000. *Energy and Conservation Agriculture*. Occasional Paper, FAO SDR Energy Program, Rome
- FAO, 2008a. *Report of the Conference Committee on Follow-up to the Independent External Evaluation of FAO (CoC-IEE), Immediate Plan of Action*. FAO Conference, Thirtyfifth special session, FAO Rome, 18-22 November 2008
- FAO, 2008b. *Investing in Sustainable Agricultural Intensification: The Role of Conservation Agriculture – A Framework for Action*’ FAO Rome, August 2008 (available at www.fao.org/ag/ca/).
- Hickmann, S. 2006. *Conservation Agriculture in Northern Kazakhstan and Mongolia*. Agricultural and Food Engineering Working Document 4, FAO, Rome

- Landers, J. 2001. *Zero tillage development in tropical Brazil – the story of a successful NGO activity*. FAO Agricultural Services Bulletin **147**, Rome, Italy
- Lange, D. and Meza, M. 2004. *You Can Do It! Innovative homemade equipment by/for smallholder farmers in Conservation Agriculture*. FAO/GTZ/MAG-Paraguay, Asunción, Paraguay
- Lange, D. 2005. *Economics and Evolution of Smallholdings' Conservation Agriculture in Paraguay, mid-term experiences*. FAO-GTZ, Asunción/Paraguay, ISBN: 99925-3-389-7
- Saturnino, H. M. and Landers, J. N. 2002. *The Environment and Zero Tillage*. APDC-FAO, Brasilia, Brazil UDC 504:631/635, CDD 631.521, 144 p.
- Stoop, W.A., Adam, A. and Kassam, A.H. 2008. *Comparing rice production systems: a challenge for agronomic research and for the dissemination of knowledge-intensive farming practices*. Submitted to *Agricultural Water Management*.
- Tebrügge, F. 2000. *Bodenbearbeitung: Langfristige Auswirkungen ausgewählter Systeme*. AGRARfinanz 7, S. 6-7
- Tebrügge, F. and Böhrnsen, A. 2000. *Direktsaat -Beurteilung durch Landwirte und Experten in der EU und Nebraska*. Landtechnik 55, 1, S. 17-19
- Van den Berg, H. and Jiggins, J. 2007. *Investing in farmers – The impacts of Farmer Field Schools in relation to integrated pest management*. World Development, 35, 663-686.

Institutional Innovations for Participatory Approaches for Conservation Agriculture in Africa

Pascal G. Kaumbutho

KENDAT, P.O. Box 2859-00200, Nairobi, Kenya

(Email: KENDAT@Africaonline.co.ke)

The rate of adoption of Conservation Agriculture (CA) practices in Africa needs to be accelerated in order to acquire mainstream (government) development attention and support. This is achievable through support to integrated processes that must engage smallholder farmers directly and at their level in three-pronged and parallel journeys: i) from isolated to group farming ii) from labour-intensive to labour-saving operations iii) from subsistence to market-led business farming. To achieve these, farmers must be engaged, with empowerment and business development support to fight food insecurity and poverty. The new and intensified livelihoods approaches must tap into the abundant social capital in emancipation schemes that allow farmers to define and rank their development challenges as much as their participatory roles, towards wealth creation. Agricultural mechanization systems across the entire CA value-chains which tap into traditional renewable power sources such as animal and solar power are needed. New ways in supportive exploitation of social, human, physical and financial capital by smallholders need to be modelled and demonstrated for wider adoption. Overall, faster and effective CA gains that have revolutionized agricultural development elsewhere in the world are possible for Africa as well. However major paradigm shifts are needed in setting win-win goals and defining how supply side institutional members (government, research, input suppliers, NGO, finance etc.) engage with farmers across the entire value chains.

It took Latin American countries like Brazil, Argentina and Paraguay an average of about 18 years to arrive at what can be described as mass (or exponential) adoption of conservation agriculture (CA) practices. While CA adoption is expanding at unknown rates in Africa's farmlands, no country can claim to have reached mass adoption rates. A country like Zambia has managed to get the national agricultural policy to embrace CA but the impact in terms of improved productivity and food security remains highly elusive.

This is mostly because unlike, for example, seed and fertiliser that are said to have made a difference to Malawi's agriculture, CA is a concept and not a single practice or technique. CA requires wholesome development interventions that cut across development sectors, livelihood components in terms of natural, human, social, physical and financial capitals. Indeed development interventions must be seen and acted upon across the entire value-chains, from seeding to markets.

It is this holistic and inclusive approach to CA interventions that remains absent in Africa. CA is about farming while allowing nature to have a say. Without the disturbance of man, nature makes real and in a sustained sense, the interaction between humans, animals and plants - on living soil. Unfortunately in institutional and human relations that determine how development systems are run, nature's harmony is not maintained. This is why scientists continue to work in ways far removed from farmers who they are meant to serve. This is why in Africa's governments the agricultural ministry is often separated from the livestock, water and forestry ones, as much as wildlife is separated from fisheries etc. Often agriculture will be seen in terms of crop production in subsistence farming, rather than in the light of farming for food security and wealth creation. Value-chain approaches are lost, with distinct separation between say: agriculture, information, transport and industry.

In such development scenarios the called-for inclusive and complementary roles across development sectors that would support rapid advancement of CA are lost. To break from this situation farmer organizational and institutional innovations are needed. There are recent institutional as well as operational CA development models that have arisen in recent times. As if by well timed evolution the much needed farmer organizational structures (Farmer Field Schools, Community Parliaments etc.) and new institutional engagement models led by advances in ICT and other infrastructural aspects have become real. At the same time, specialised equipment using renewable energy and applicable to smallholder farming schemes have become available for those that know where to look.

These are great opportunities for an African agricultural revolution. Models of these new approaches need to be demonstrated in intensive business-oriented schemes among large and smallholder farmers. Through these a real difference for Africa's development can be felt and adopted by governments and other mainstream operators in the private sector.

Background

Fast advancement in Conservation Agriculture has been brought to the limelight with felt urgency due to the precarious situation of global warming and climate change. CA is one of few existing, widely accessible, readily applicable and relatively inexpensive ways of effectively curtailing climate change. CA effectively converts rain water to soil water and captures and stores carbon in soils and plants with an overall effect of cooling the planet. CA has got the gross benefits of enriching organic carbon in agricultural soils, terminating mono-cropping and creating the crop-based eco-abundance needed by humans, animals and plants, and providing permanent soil cover. CA commences journeys back to the good old days of rich ecosystems and soils with capacity for co-benefits that support all other life. Today CA benefits are well documented and they point confidently towards increased agricultural production, resilience in the face of climate change and enhanced rural livelihoods that curtail urban migration, more so in the continents of the South.

Complementary Approaches to CA Advancement

There are many practices that have been tried eco-management and protection. All these are brought together in complementary ways by applying the knowledge-intensive CA. For a conservation agriculture system, the priority is placed on the biological conservation measures though combined where necessary, for example on steep slopes with physical conservation measures. Biological measures aim to improve vegetation cover in order to promote soil protection, and to improve soil structure for erosion control. This is true, no matter the agro-ecological zone.

Agronomic measures such as early planting, mulching, green manure, organic and inorganic fertilisers, mixed-cropping and crop rotations can be effectively combined with moisture conservation measures such as tied ridging and reduced tillage. On steep slopes there is also a need for soil and water conservation through grass strips, trash-lines, agro-forestry and gully reclamation where necessary.

CA now challenges us to combine a number of practices according to topography and the farming system. In fact such approaches which must climax on reduced tillage practice were applied traditionally by farmers of yesterday. They always knew the advantages of mixing selected crops, and even crops and livestock which complemented one another, over and above natural competition characteristics of living beings.

The advent of introducing commercial crops brought about the concepts of mono-cropping and the good old plough for heavy soil manipulation, all to the detriment of living soils, flora and fauna. For Kenya and elsewhere in Africa, the same commercial farming approaches broke the glue that had kept smallholder farmers close to one another. They did so by building cooperative movements which unfortunately focused on commodity availability and mass-marketing, while ignoring the importance of smallholder empowerment through village-level social structure and the requisite entrepreneurship building. This is now an important ingredient of what the face of the new, integrated and revolutionary conservation agriculture engagement must entail.

From Conventional to Conservation Agriculture with a Human Face

Smallholder farmers are able to relate closely to the need to change mind-sets. Their minds would normally be bogged in decades of traditional conventional farming practices but if they are helped to think systematically and with much exclusivity, they are able to enjoy the journey from conventional to conservation agriculture. Indeed they need to understand that they are in a journey with various possible pitfalls. When it is the case of smallholder farmers this journey must engage them effectively and with a livelihoods perspective.

The motivation and exciting part however comes from the business empowerment angle. This has indeed become the new thing in the 10-year experience of KENDAT working with smallholder farmers. The journey begins with farmers admitting that much damage has taken place on their eco-systems. Once they admit this they are able to journey with an attitude of repairing the damage while making business out of it. Labour savings and higher productivity in this case appear to come as bonuses.

Box 1 shows the steps of the typical journey. What must not be forgotten is the social fabric-building which must be maintained to glue own activities as well as that with partners, be they from supply or demand side of the divide.

**Box 1: The journey from Conventional to Conservation Agriculture
(Old KENDAT Approach)**

- STOP yourself, your neighbours and everyone from burning the bush, crop or weed residues, grasses, or any other types of vegetation. The material can be better used on your farm.
- Note that soils with low fertility or degradation must be improved with some special cover crop species, mainly legumes for periods, 1-3 years long. When resources are available, have your soil tested for its chemical content and acidity and apply selected fertilizers and/or lime.
- Plant more trees that fix nitrogen or produce plenty of biomass and place emphasis on foresting your land in every possible way. If you have any idle sections of the farm, plant a nitrogen fixing cover crop on them without having to till the soil.
- Reorganise your farm and graze your animals in a controlled manner. Rotate plot layout including paddocks and eliminate any soil compaction using proper tools like animal drawn subsoiler and crops with strong taproots.
- If you have terraces plant on them live material such as vetiver grass, napier, lemon grass, pigeon pea, gliricidia sepium, tephrosia vogelli, and other strong-rooted crops.
- In all cases, plan for the whole farm but start the techniques in small areas, and gradually introduce the conservation system to larger areas as you learn what is good for your ecology and positive results are achieved.
- Plant with reduced tillage techniques and progress to no-tillage. If you are in a humid area, or have aggressive weeds like couch, herbicides will help until you establish an appropriate and soil covering crop association.
- In the first few years there will be a huge weed seed pool in your fields. You may initially need to use herbicides to control these high populations. To weed, use a herbicide or simply slash the weeds and lay them to suppress further growth. Gradually phase out herbicides by investing in cover-crop seed to suppress weeds.
- Try and establish a soil cover with native or improved exotic cover crop species (mainly legumes or plant cocktails). Preferably start in areas with less difficult weed infestations (few perennial species).
- Practice crop rotations, changing crop sequences or intercropping with cover crops (e.g. mucuna, lablab or pigeon pea intercropped with maize). This will decrease the occurrence of pests, diseases and weeds protect your soil.
- When you harvest, use appropriate mulch management. You can sow through the mulch with a direct seeder, or use the economical hand jab planter.
- If all you have is a hoe, push aside the trash, to expose only the planting holes you make. At all costs leave the crop residues on the soil surface even if you have to share the smaller portion with your animals. Once your CA system is established your animals will have plenty to eat!

Issues Influencing CA Adoption: Preconditions for True and Sustained Change

Although there is much potential for the adoption of CA systems on Africa's farms, there are many external influences that may hinder the anticipated and fast adoption process. CA facilitators and venture leaders need to create real opportunity to convince communities, local and national leaders to appreciate the quick gains derivable from CA approaches. Events such as field-days, farmer to farmer visits, community debates about development etc. will help bring about the much needed and eventual infrastructural and industrial support. As farmers get organised and more productive they will increasingly have a say and need central or project support for access to inputs, service infrastructure, equipment, markets etc. Conscious effort towards capacity and opportunity to make demands will need to be organised. The KENDAT experiences in CA adoption venture, including the necessary components and ingredients for true and fast yet sustained change from conventional to conservation agriculture are presented below:

Getting Farmers together in an Inclusive Manner

Farmer Field Schools

Africa has great wealth in social capital. Africans spend much time and resources in cultural and other social events which are conducted with greatest levels of commitment and joy. These energies need to be tapped for activities that bring about business farming. Farmer Field Schools (FFS) are a newly found way of engaging smallholder farmers in efforts that help close the gap between research and its beneficiaries. Used adequately FFS are able to shape the agenda for extension as much as research services. This is because of the empowerment nature of the approach. FFS has beat the previous research and extension models by bringing farmers to the centre and recognizing them as knowledgeable experts with first hand experience that beats all other players in terms of sustainable problem solving.

Farmer Field School (FFS) are platforms and “schools without walls” for improving decision making capacity of farming communities and stimulating local innovation for sustainable agriculture. FFS offers community-based, non-formal education to groups of 15-30 farmers through self-discovery and participatory learning principles. The schools bring together farmers who live in the same village or catchment, sharing the same ecological settings and socio-economic and political situations to solve own problems together. FFS provides opportunity for learning by doing. FFS engages experts according to the problem solving needs of farmers.

Food Security Field Schools (FSFS) are broader and move a step further from agricultural into a community study and support group that addresses the multi-faceted aspects of food security, including measures to raise production, reduce risks, mitigate the effects of disease, water and energy shortages hence the building of development safety nets that are necessary for farmer-centred development. Over the last four years FFS have advanced to levels where they are contributing to value chain advancement by representatives of various FFS forming umbrella groups which venture into group acquisition of inputs as well as marketing structures.

3.1.2 Community Parliaments

By assisting Common Interest Groups (like shown for this example from Mwea in Kirinyaga District of Kenya) to send two representatives each, to a Community Parliament (CP) sitting once a month, they are able to define their development needs and priorities. The identified priority development and growth issues are structurally addressed under ‘Ministries’, whose competitively appointed leaders call in the necessary help and support for maximum knowledge and information build-up. Against this, solution pathways and targets with agreed implementation timelines are set.

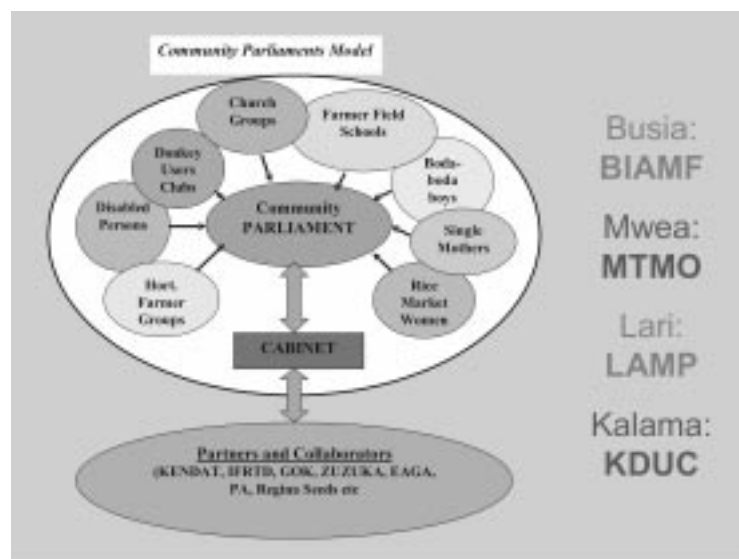


Chart 1. Community Parliaments - Emancipation Model for bringing together Common Interest Groups (CIGs) to form a unified body with a common vision and agenda

The parliament quickly grows to a voice loaded force in rural development, a body to influence development agenda and make demands on supply-side actors from all sectors, no matter how foreign. Other development supporters soon see the CPs as dependable channels through which to pass development plans and resources. CP leaders soon find themselves in Local Authorities Transfer Fund (LATF) Committees where they help determine allocations of resources, building on pre-defined CP development agenda. Over time CPs grow many new development initiatives centred around business build-up to reach further and wider aspects and scope of own as much as supporters' and government's development agenda. Using network marketing expansion models where each CIG group member is supported and rewarded to expand the sphere of influence and numbers of interest groups, millions of farmer level trainers and development promoters can be brought on board in two to three years. If such a network is backed by newly found technological practices like CA, new motivation for farming will arise, even among the desperately poor. If CA is backed by innovative agricultural mechanization initiatives that make more power available per unit of smallholders farm land, a sure journey out of poverty will gain momentum. Only with more appropriate power (direct seeders, Zamwipes, solar driers, donkeys etc.) will farmers seed in no-till farms, add value to produce and explore markets using traditional and modernized means of transport.

3.1.3 Mechanizing CA Systems

This paper gives special attention to agricultural mechanization for CA systems. Rapid CA advancement is not possible without adequate levels of use of inputs in "modern farming". These inputs are such as primary plant seed as well as cover-crop seeds and fertiliser but the equipment needed are what make the true revolution of CA for Africa's agriculture.

Box 2. Today's definition of agricultural mechanization

Agricultural mechanization needs a new look in 21st Century Africa. Agricultural mechanization is the application of mechanical technology and increased power to agriculture, largely as a means to enhance the productivity of human labour and often to achieve results well beyond the capacity of human labour. Tractors of various types, animal and human power are important, as are electric motors, solar power and other methods of energy conversion. Mechanization also includes irrigation pumps, food processing, transportation, communication and related technologies. Mechanization is not an "all or nothing" process. Levels and types of improved mechanical technologies need to be appropriate, meaning: compatible with local, agronomic, socio-economic and industrial conditions.

Table 1 shows the pathetic situation of Africa's Agriculture. In terms of cereal yields, the rest of the world is ahead of Africa and this is reflected also in figures for fertilizer consumption and investment in inputs such as irrigation and machinery. Table 1 compares African countries with nine other developing countries. Egypt and Mauritius are singled out as being unlike the rest of Africa. Over the continent as a whole, 21 countries failed to reach 1 tonne per hectare, others achieved yields of between 1 tonne and 1.5 tonnes, four harvested between 1.5 and 2 tonnes. Only one (South Africa) reached 2.3 tonnes in 2000 although 3.3 tonnes was achieved there in 2002. Cereals are not the only product of African agriculture but these are most important and they are important because agricultural mechanization impacts especially on cereal production.

Table 1 illustrates what must be considered when it comes to CA advancement. It makes real the fact that agricultural productivity is not the product of a single factor but a combination of factors including an adequate level of investment in infrastructure (particularly irrigation), plant nutrition (fertilizer) and mechanization.

As farmers venture into CA they find that they need adequate exposure and training in the use of no-till direct seeders, specialised weeders, chemical applicators, post-harvest processing equipment and energy applications, transport and marketing infrastructure including ICT support. Mechanization is therefore one of the necessary inputs towards CA systems of sustained development and growth. One of the major reasons for disappointing performance and low contribution for mechanization has been the fragmented approach to mechanization issues. Strategic national and regional plans would bring about the critical mass that is needed to make machinery contractual services viable, hence fertile ground for entrepreneurship (Limbrej and Makungu 2007).

Smallholder farming in our region has not received persistent support with machinery and equipment for reduced drudgery and operational efficiency. Recently more appropriate equipment has become available, though much of this is still on a trial basis. Farmers need access to a reasonable range of small tools and equipment which requires

Table 1. Cereal Yields Compared with Basic Inputs

Country or Group	Cereal Yield (kg/ha)	Fertilizer Use (kg/ha)	Irrigation % of Arable land	Tractors per 100 ha
Africa (minus - Egypt & Mauritius)	1040	13	5	28
Egypt	7041	446	100	263
Mauritius	5193	304	20	35
Bangladesh	2786	174	54	7
Brazil	2660	120	4	137
China	4879	352	48	89
India	2293	104	33	141
Korea Rep.	6400	432	47	1239
Pakistan	2255	138	81	149
Philippines	2420	131	15	20
Thailand	2442	104	27	144
Viet Nam	3995	317	34	247

Source: World Bank, World Development Indicators

investment in developing manufacture and supply mechanisms. The best equipment for any farmer will always be that which is accessible if not already available, is manageable and serviceable close to the farmstead.

3.1.4 Millennium Information Centres

Another business empowerment institution that KENDAT has found to be most useful is what has come to be called the Millennium Information Centre (MIC). The MIC answers to the fact that one of the major shortcomings in knowledge-intensive CA value-chain advancement is in access to information by farmers. Indeed supply side and demand side need to meet and interact in an ongoing sense, at a level acceptable and close enough to smallholder farmers.

The MIC is a tele- and techno-centre. It is a technology end-users approved, supported & sustained business centre where farmers, rural and peri-urban transporters and other rural business persons congregate. Such persons will be from interest groups represented at community parliaments coming for information, training and referral services as well as parliamentary and special-interest or committee meetings on a regular basis. The centre is wireless online with a wide range of information about crops, seed and inputs and agricultural equipment. Also included are information on health and administration issues (e-government soft and hard information booklets and application forms).

Private sector and NGO operators including government agencies fund the operations through programme support and by renting space to display their products in a place where contact with farmers is no longer only at field days and public meetings but on a daily and regular basis. Programme staff is able to help farmers search for information regarding new crop varieties and inputs (sources and prices), diseases and pests on CD-ROMs and other media, from daily market to weather information. Farmer plans are effectively managed and their demands addressed in a monitored and measurable sense. The centre grows into a club and expands rapidly to other localities in the areas of operation. Under innovative operation farmers own equity and manage such units with drastic growth in business. It is this value-chain contribution to business farming that will bring about rapid CA advancement.

The NEW KENDAT Way of Doing Business with Farmers

New Models for CA Value-Chains

After a decade of CA advancement work, working closely with smallholder and large-scale farmers, KENDAT and partners believe they have found the best approach to helping CA adoption be propagated more rapidly within and across nations. The strategy is one of modelling good practice for mainstream actors including government and the private sector to provide business-led umbrella support. The argument is that CA will not develop rapidly until and unless programmes adopt business farming with a value chain approach. It is no longer about promoting CA but

modelling it as per varying ecological, social and economic conditions prevailing at each farming system. Market-orientation and farming higher value crops are the essential starting points to determine the necessary institutional streamlining that will lead to food security and wealth creation.

Features of Value-chain Business Models in the Agri-food Sector

In recent times farming higher value crops for market is getting aggressively globalized. Local food systems are suffering from poor market and distribution systems. Until these are addressed, CA advancement and the prosperity of its farmers will remain elusive. Business farming is built on consumer assurance, high standards for food quality and safety, availability, adequate pricing and branding. Business etiquette is determined by supply chain management where recent issues concern standards hence preferred suppliers, cutting out middlemen, traceability, economies of scale and logistical support shape capacity to regulate.

The challenges to current business models are in that the necessary market modernization and restructuring has hardly delivered growth and equity across rich and poor nations. Where business models exist, they have been transferred from urbanized areas and countries without due regard for populations that are entirely agriculture – dependent. The classic model is not working for the majority of producers or consumers raising issues of costs of organizing supply, reliability of volatile markets and consumer willingness to pay.

Where smallholder farmers are involved business performance is limited by cost of conducting business transactions. Institutional innovation needs to overcome

- dispersion of producers,
- diseconomies of scale,
- poor access to information, technology and finance,
- inconsistent volume and quality,
- lack of traceability and
- management of risk.

Agrifood markets are in an unprecedented state of flux, with domestic markets undergoing rapid but uneven modernization. Market modernization offers increased economic opportunities for producers, small and medium-sized enterprises (SMEs), and other actors in the value chain, but there are also risks of local producers and domestic businesses being bypassed, or failing to meet costly market entry requirements which favour the better-resourced.

Vorley and Lundy, 2008

This is indeed why KENDAT is promoting the concept of Millennium Information Centres as described below.

According to Vorley and Lundy (2008) there are three types of production models:

- 1) *Producer-driven*: where producers themselves are seeking a market; larger farmers are seeking extra supply volume, or processors, exporters or retailers are seeking to ensure supply.
- 2) *Buyer-Driven*: where traders and other traditional market actors, NGOs and other support agencies organize production.
- 3) *Intermediary*: where national and local governments are seeking regional development

Overall there is no single “golden” business model and which one is adopted depends on the prevailing livelihoods and institutional arrangements. Operational risks are in time demands and expenses, possible paternalism and dependency on particular partners who may demand exclusivity. As an NGO, the KENDAT preferred business model is one of a doubly specialized intermediary with a business oriented as well as development motivated working scheme across all value chain components.

Essential Ingredients for Rapid CA Value-Chain Advancement

Programme Partnerships

Rapid progression in CA advancement requires that programmes are set out to model how participatory engagement of resource poor farmers in carefully selected enterprises and input schemes including mechanization

can bring about drastic advances in market oriented agricultural growth and development. The programmes however must be led by ventures under newly tested options and institutional models across CA value chains. Farmers need the technical and management skills needed to intensify and commercialize their farming enterprises, to prove to themselves that the higher investments in agriculture are mandatory but definitely worthwhile. They need to prove that based on the generated profits derived, the investments will become attractive necessities for them, their governments, private sector and other development supporters.

On the basis of agreed strategies, innovative research and training programmes need to be set in motion, cascading to farming communities from the partnership farming sites and supporting key institutions through new and innovative education and extension services. Farmers need to advance into taking charge through support by existing or upcoming agro-industries, of which they will be part and parcel. In this process FFS, CP and MIC structures are seen as the prime institutional additions to provide the necessary learning and exchange alliances.

Essential Components for CA Value-chains

Essential and strategic programme components for CA value-chain advancement are shown in Chart 2.

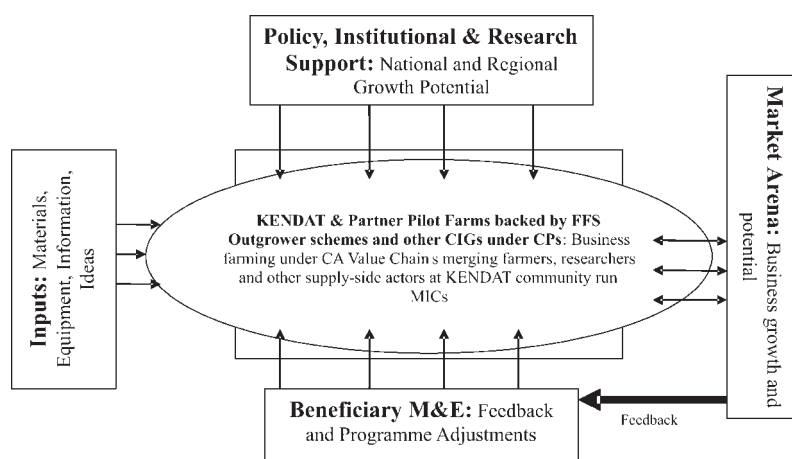


Chart 2. Essential components for rapid advancement of CA-Value Chain business models

The essential CA Value-Chain programme components flow from the left to the right, - from crop establishment to marketing. The Operational programme components sought and the project thrusts that guide the implementation as well as the delivery procedure are shown. At the core are KENDAT & Partner Pilot Farms backed by FFS and other Common Interest Groups (CIGs) Outgrower schemes. Operations are guided by Community Parliaments (CPs). Operations for these are managed at the Millennium Information Centres (MICs). The MICs are established such that their operationalization is guided by farmers, based on development goals and activities prioritization that will meet their identified and analyzed needs.

Overall and out of necessity, rural Kenyans and Africans in general are observing clearly changing trends in local climate across the range of environments, from humid to semi-arid and arid. Many are already adapting to climate change with or without external support. For communities dependent on natural resources, adaptation involves a mix of technical solutions (such as different crops or planting patterns) and institutional solutions (such as new means of sharing information). Local adaptations include responses to specific trends (such as growing shorter season crop), but also building of capacity and resilience - say through investments or savings clubs and diversified agriculture, to cope with uncertainties. Supporting the most local initiatives and institutions is the most effective way to support climate change adaptation.

Adapted from: Springing back: climate resilience at Africa's grassroots Sonja Vermuelen (IIED), Krystel Dossou (OFEDI), Duncan Macqueen (IIED) Dominic Walubengo (Forest Action Network), and Everhart Nangoma (EU)

The dynamic system is established to ensure that operations will eventually receive mainstream support hence the Policy, Institutional and Research Support umbrella (Upper end of Chart 1). There are established and viable links with suppliers according to arising farm business, information and new learnings, hence Inputs at the left-end of Chart 1.

On the right end of the Chart is the Market Arena whose transaction outputs determine the viability of the ongoing and new business ventures. As long as the market scene is active and deriving credible business profits, all parties will benefit. Business and overall feedback will flow back into the value chain activities to provide the necessary system dynamism and M&E adjustments (see bottom end of Chart 1). This will be in accordance with the progress felt by all participating beneficiaries who will learn from the M&E reports and take in New Opportunities which will be known from activities of the market arena, sending business (status and needed adjustments) feedback information through the bottom end of Chart 1.

KENDAT Model Farms

Chart 3 shows a typical model of how KENDAT and partners are coming together to advance CA through business farming. Such farms are being opened in 6 zones across agro-ecological zones across the country. The business is being conducted with external collaborative support with institutions and equipment suppliers from Uganda, Tanzania, South Africa and Brazil. India and other partner countries in Asia are well advanced in this kind of approach to farmer engagement but not necessarily in CA farming systems. Partners are being pursued from this region that has much to offer in all aspects.

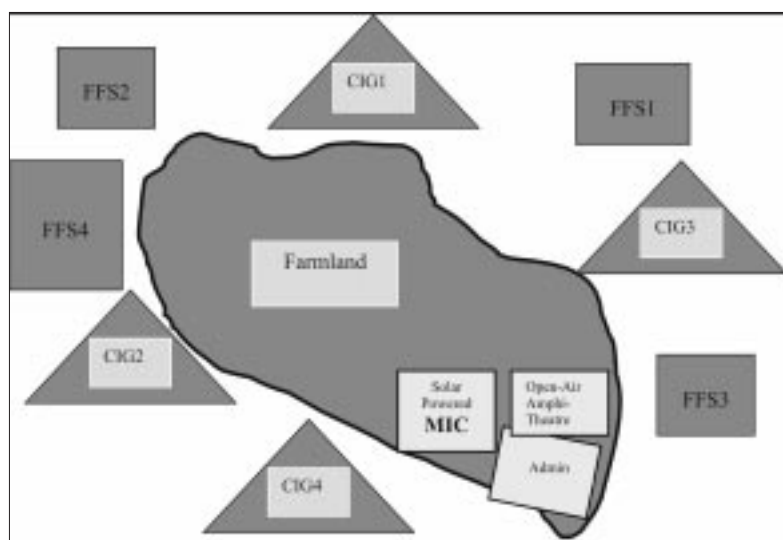


Chart 3. 10-20 hectares KENDAT partnership managed land (own, contributed or hired) surrounded by outgrowers in FFS and other CIGs. Farm is planned to have MIC, administration facilities for farming and marketing and an amphitheatre for meetings, training etc. Eventually the farm will have classroom and accommodation facilities for groups among other amenities. Other partnership amenities may be for equipment storage yards and those associated with sponsored special programmes for youth, researchers, private sector installations, those associated with livelihood matters, e.g. facilities to demonstrate how the elderly can be taken care of in an urbanizing world, among numerous other innovative amenities.

It is foreseen that KENDAT partnership farms will advance to being centres for advancing vibrant mechanization, value addition and marketing operations and other business schemes. Eventually farmers may build agricultural input and processed product outlets more or less like the upcoming farmer-run supermarkets of India. For the case of India, it is not unusual for a farmer to deliver produce to a market he owns and to find facilities where they can have a blood-pressure check-up as their truck is being offloaded! Chart 4 shows the multiplicity of activities that can take place at such a venue.

Key Deliverables of the New KENDAT Programme

In summary, over the 5 years the programme will have indicative impact, measurable by the following contributions and observable through drastic changes in enterprise choice, behaviour, operations, social relations and development contributory roles, institutional support and general wealth creation among others:

- empowered farmers equipped with knowledge and capacity for business learnings and etiquette as demonstrated by significant increase in upcoming male and female commercially active farmers and rural agricultural entrepreneurs.



Chart 4. Base of pyramid model (Adopted from Vorley and Lundy, 2008)

- improvements to mechanization patterns and applications across the value chain, including irrigation and special applications like weeding, chemical application, hay baling, threshing, shelling, food processing , transport services etc.
- a major increase in the power types (solar, wind, bio-diesel etc.) and applications available to agriculture, whether manual, animal powered or motorized backed by locally based maintenance and repair services.
- stronger networks for agricultural mechanization supply among other inputs and technical and industrial support for advanced business earning and spare-part and other back-up services ;
- a major increase in land under cultivation with parallel increases in crop yields and support harvest and post-harvest services;
- growth in the agricultural sector with environmental protection and long term improvements to soil and moisture conservation as well as market networks and information hence a major increase in farm produce marketed;
- an increase in value added to raw materials and employment created in rural communities as indicated by a significant and measurable increase in cash flows and general sense of well-being among participating rural communities;
- development of a viable agricultural value chain, well supported by inputs including equipment provided by supplier networks in partnerships that have research and market backing to farmers.

References

- Kaumbutho, P., E. Murithi and G. Murithi 2006. Supporting Innovation - Changing lives: Inventory of Research Into Use Programme (RIUP) and Process. KENDAT P.O. Box 2859-00200. Nairobi.
- Biamah E.K., F.N. Gichuki and P.G. Kaumbutho. 1993. Tillage Methods and Soil and Water Conservation in
- Bishop-Sambrook, C. 2005. Contribution of Farm Power to Smallholder livelihoods in sub-Saharan Africa. FAO, 2005.
- Bolliger, A, Magid, J., Amado, T.J.C., Neto, F.S., Ribeiro, M.F. S., Calegari, A., Ralisch, R. and Neergaard A. 2007. *Taking Stock of the Brazilian "Zero-Till Revolution: A Review of Landmark Research and Farmers' Practice*. Plant Nutrition and Soil Fertility Laboratory, Department of Agricultural Sciences, The Royal Veterinary and Agricultural University, Thorvaldsensvej 40, DK-1871 Frederiksberg C, Copenhagen, Denmark
- BOLLIGER, A.; MAGID, J.; AMADO, T.J.C.; SKÓRA NETO, F.; SANTOS RIBEIRO, M. F.; CALEGARI, A.; RALISCH, R.; AND NEERGAARD, A. (2006). Taking Stock of the Brazilian "Zero Till Revolution": A Review of Landmark Research and Farmers' Practice . REVIEW ARTICLE. ADVANCES IN AGRONOMY. Vol. 91, Pages 47-110.
- Braun, Arnoud R., J. Jiggins, N. Röling, H. van den Berg and P. Snijders, 2006. A Global Survey and Review of Farmer Field School Experiences. Final Report. Report prepared for ILRI. Endelee, Wageningen, The Netherlands. 91 p.
- Brenndorfer, B.; Kennedy, L.; Oswin Bateman, C.O.; Trim, D.S.; Mrema, G.C.. 1985. Soalr dryers: Ther role in post-harvest processing. Commonwealth Science Council. London UK. 337p. ISBN 0850922828
- CALEGARI, A. (2002). The spread and benefits of no-till agriculture in Paraná State, Brazil. In "Agroecological innovations: Increasing food production with participatory development". Edited by Norman Uphoff, Pages 187-202, London, Earthscan, 2002.

- Chavez-Tafur, J., K. Hamson, A. Ingevall & R. Thijssen, 2007. *Learning from experience: a manual for organizing, analysing and documenting field-based information*. Amersfoort, Netherlands: ILEA center for Information on Low External Input and Sustainable Agriculture (www.leisa.info)
- Comprehensive Africa Agriculture Development Programme, 2002. New Partnership For Africa's Development, 2002. NEPAD South Africa*
- Kaumbutho P.G., M Sishekanu, G. Gebresenbet and E.K. Biamah 1996 *Tillage Effect on Soil and Water Conservation Properties of a Hard Setting Soil in a Semi-Arid Environment*. Paper presented at the 9th International Conference of the International Soil Conservation Organization (ISCO) Bonn. Germany 23-30th August 1996
- Kaumbutho P.G. and R. Krause. 1996. *Agricultural Mechanization as a Worthwhile Input Towards Enhanced Crop Production*. Invited Paper. Proceedings of the 3rd International Conference on Domestication Production and Utilization of New Crops. International Centre for Under-utilized Crops. University of Southampton. UK. June 1996.
- Duveskog, D., 2006. Theoretical Perspectives of the Learning Process in Farmer Field Schools. With reference to East African experiences. Working Paper, December 2006. 38 p.
- Gebresenbet G. and P.G. Kaumbutho. 1997. Comparative analysis of the field performances of a reversible animal-drawn prototype and conventional mouldboard ploughs. *Journal of Soil and Tillage Research* 40(1997) 169-183
- Hilhorst, T. and F. Muchena (eds), 2000. *Nutrients on the move: soil fertility dynamics in African farming systems*. London: International Institute for Environment and Development. ISBN 1 8 99825 56 8
- IDS Institute of Development Studies. 2006. The power of Labelling in development practice. IDS Policy Briefing. Issue 28 April 2006. Institute of Development Studies at the University of Sussex. Brighton BN1 9RE UK
- IIRR and ACT. 2005. *Conservation Agriculture: A manual for farmers and extension workers in Africa*. International Institute for Rural Reconstruction. Nairobi. Africa conservation Tillage Network, Harare. ISBN 9966-9705-9-2 (*Key Experience Contributor to a Ground Breaking Manual*)
- Jones, P 2004. The increasing importance of donkeys. In T.E. Simalenga & A.B.D. Joubert (eds) 2004. *Animal traction in development: issues, challenges and the way forward*. pp30-39. Workshop Proceedings South African Network of Animal Traction (SANAT), University of Fort Hare, South Africa. ISBN 1-86810-046-4
- Kanali C.L. P.G. Kaumbutho, C.M. Maende and J. Kamau 1997. The use of soils compaction levels in the selection field-safe sugarcane transport vehicles. *Journal of Terramechanics Vol 34 No.2, pp 127-140. 1997.*
- Kaumbutho P and Josef Kienzle eds. 2007. *Conservation Agriculture as practiced in Kenya: two case studies*. Nairobi. Africa Conservation Tillage Network, and Food and Agriculture Organisation of the United Nations. ISBN: 9966-7219-0-8
- Vanlauwe, B., F. Kanampiu, G.D. Odhiambo, H. De Groote, L. Wadhams, Z.R. Khan. 2008. Integrated management of *Striga hermonthica*, stemborers, and declining soil fertility in western Kenya. *Field Crops Research (In press)*.
- Gurney, A.L., D. Grimanelli, F. K. Kanampiu, D. Hoisington, J.D. Scholes and M.C. Press. 2003. Novel sources of resistance to *Striga hermonthica* in *Tripsacum dactyloides*, a wild relative of maize. *New Phytologist* 160:557-568.
- Rutto, E., H. De Groote, Bernard Vanlauwe, Fred Kanampiu, George Odhiambo and Zeyaur Khan. 2005. Farmers' Perceptions and Evaluation of Integrated Approaches to Combat Striga, Stemborer and Soil Fertility Problems in Western Kenya: Preliminary Results 2003. Paper presented at the 7th African Crop Science Conference, Entebbe, Uganda, 5-9 December 2005.
- Kaumbutho P. G and Smith D .G. 2003. *Crop-Livestock Integration in Conservation Agriculture: The Case of Smallholder Farmers in Africa* Paper presented at the 2nd World Congress on Conservation Agriculture. Iguassu Falls Brazil. August, 2003.
- Kaumbutho P.G. 1994. *Principles of Costing Mechanized Agricultural Operations and Their Application to the Kenyan Sugar Industry*. Lecture Paper presented to the Workshop of the Kenya Society of Sugar and Sugarcane Technologists. Kisumu, Kenya. 1994.
- Kaumbutho P.G. 1997. *Donkey power utilization within the broader context of agricultural mechanization in Kenya*. Paper presented at the ATNESA workshop on Donkey Utilization and Management. Debre Zeit, Ethiopia. May 1997.
- Kaumbutho P.G. and T.E. Simalenga (editors) 1999. *Conservation Tillage with Animal Traction*. A Resource Book of Animal Traction Network for Eastern and Southern Africa (ATNESA). Harare. Zimbabwe.
- Kaumbutho P.G., G. Gebresenbet and T.E Simalenga. 1998. *Overview of conservation tillage practices in East and Southern Africa*. In: Kaumbutho P.G. and T.E. Simalenga (editors) 1999. *Conservation Tillage with Animal Traction*. A resource book of Animal Traction Network for Eastern and Southern Africa (ATNESA). Harare. Zimbabwe.
- Kaumbutho PG, A. Pearson and T.M Simalenga (editors) 2000. *Empowering Farmers with Animal Traction*. A Resource Book of Animal Traction Network for Eastern and Southern Africa (ATNESA). Harare. Zimbabwe ISBN No 0-907146-10-4

- Limbrey, L. and Makungu P. 2007. Agricultural mechanization in Africa – Time for a New Look. Commissioned Paper prepared for the Joint FAO/UNIDO Agricultural Mechanization Expert Group Meeting held in Vienna, Austria. 29-30th November, 2007
- Marinda, P. (2006): Effects of gender inequality in resource ownership and access on household welfare and food security in Kenya: A case study of West Pokot district. Published by Peter Lang Europäischer Verlag der Wissenschaften in the 'Development Economics and Policy Series': Frankfurt.
- Mrema G.C. and Odigboh E.U. 1993. Agricultural development and Mechanization in Africa: Policy perspective. In NAMA Newsletter Vol 1. No.3 page 11-50.
- Njenga P., P.G. Kaumbutho and J. Maganya. 1999 *Intermediate Means Of Transport In East Africa: An overview of Initiatives, Opportunities and Constraints*: A Keynote paper presented at the Sub-Saharan Africa IMT Initiative; Regional Experts Meeting. June 1999. UNEP Gigiri Nairobi.
- PRUDENCIO, Y. C.; KAUMBUTHO, P. G.; CALEGARI, A.; AND BWALYA, M. (2004), CD-Room. Conservation Agriculture For Sustainable Land Management, Food Security and Improved Livelihood in Africa. Extension & Training Manual. Publication of the Soil Fertility Initiative (World Bank/AFR/ESSD), and the Africa Conservation Tillage Initiative (ACT).
- Rockstrom, J., P. Kaumbutho, P. Mwalley and M. Temesgen. 2001. *Conservation farming among smallholder farmers in E. Africa: Adapting and adopting innovative land management options*. In Garcia-Torres, L, Benites, J., and Martine-Vilela, A. (eds) "Conservation Agriculture, A Worldwide Challenge", Proceedings of the First World Congress on Conservation Agriculture, Madrid, 1-5 October, 2001. Vol I. Keynote Presentations pp 363-374 ISBN 84-932237-1-9
- Shetto R. M. and Kaumbutho P. G. 2007. *Agricultural Mechanization in East Africa*. Paper presented at the FAO/UNIDO Expert Group Meeting on "Agricultural Mechanization in Africa - Time for a New Look" 29-30th November, 2007 Vienna, Austria.
- Sims B.G., Kienzle, J., Cuevas R. and Wall G. 2007. Addressing the challenges facing agricultural mechanization input supply and farm product processing. Proceedings of an FAO workshop held at the CIGR World Congress on Agricultural Engineering. Bonn, Germany, 5-6 September 2006. ISBN 978-92-5-105784-1
- Starkey P.H. and P.G. Kaumbutho (editors) 1999. *Meeting the Challenges of Animal Traction*. A Resource Book of Animal Traction Network for Eastern and Southern Africa (ATNESA). Harare. Zimbabwe. Intermediate Technology Publications 326p ISBN 1-85339-483-1
- Vorley B. and Lundy M 2008. Business models that are inclusive of small farmers and SMEs. Paper presented at the Global Agro-Industrial Forum (GAIF) New Delhi India, 8-11 April 2008.

Development, Integration and Dissemination of Resource Conservation Options through Community Watershed Approach

Suhas P. Wani^{1*}, T.K. Sreedevi¹, P.K. Joshi² and B. Venkateswarlu³

¹International Crops Research Institute for the Semi-Arid Tropics, Patancheru, 502 324, Andhra Pradesh, India

²National Centre for Agricultural Economics and Policy Research (NCAP), DPS Marg, Pusa, New Delhi 110 012, India

³Central Research Institute for Dryland Agriculture, Santosh Nagar, Hyderabad, 500 059, Andhra Pradesh, India
(*Email: s.wani@cgiar.org)

Dryland areas in the tropics are hot spots of poverty as well as severe land degradation and water scarcity. In order to achieve the food security for millions of rural poor, it is critical to enhance the productivity of rainfed agriculture through conservation of natural resources such as water and land. The Comprehensive Assessment of Water for Food and Water for Life has demonstrated that potential of rainfed agriculture of doubling the productivity can be harnessed by adopting integrated approach through watershed management. Assessment of watershed impacts in India revealed that watershed approach can be applied in all rainfed areas with suitable modifications of interventions or economically beneficial and rainfed agriculture can be upgraded by enhancing the effectiveness of 68% of the watershed projects which are performing below average. The new paradigm for unlocking the potential of rainfed agriculture is by adopting community watershed management approach as a business model through convergence and linking of farmers to the markets, efficient use of conserved natural resources for enhancing the productivity by adopting IG-NRM approach and improving community participation through capacity building and ensuring tangible economic benefits. Capacity building has been identified as a weakest link for scaling-up the watershed programs and national strategy for quality capacity building measures through consortium of quality service providers with suitable quality indicators is recommended. Conservation agriculture can be operationalized through watershed approach for improving the livelihoods of rural poor by unlocking the potential of rainfed agriculture.

Key words: Community Watershed, Resource conservation, Rainfed agriculture, integrated approach, Livelihood, scaling-up.

To meet the millennium development goal of halving the number of poor people by 2015 and achieve food security for the ever growing population along with increasing incomes in the world with the prevailing status of available natural resources *viz*: land and water and the associated impacts of global warming is a challenging task. Sixty per cent of the food insecure people in the world live in South Asia and sub-Saharan Africa. Recently completed Comprehensive Assessment of Water for Food and Water for Life revealed that it is possible to produce required food – but it is probable that today's food production and environmental trends, if continued, will lead to crises in many parts of the world (Molden, 2007). The assessment has also indicated that the world's available land and water resources can satisfy future demands by taking appropriate steps.

The comprehensive assessment has also highlighted the importance of rainfed agriculture (Molden, 2007, Rockstrom et al; 2007) that varies regionally (95% in sub-Saharan Africa, 60% in South Asia, and 90% in Latin America) but produces most food for poor communities in developing countries. Despite large strides made in improving productivity and environmental conditions in many developing countries, a great number of poor families in Africa and Asia still face poverty, hunger, food insecurity and malnutrition, where rainfed agriculture is the main agricultural activity. These problems are exacerbated by adverse biophysical growing conditions and the poor socioeconomic infrastructure in many areas in the semi arid tropics (SAT). The importance of rainfed sources of food weighs disproportionately on women, given that approximately 70% of the world's poor are women (WHO, 2000). Agriculture plays a key role for economic development (World Bank, 2005) and poverty reduction (Irz and Roe, 2000), with evidence indicating that every 1% increase in agricultural yields translates to 0.6 to 1.2% decrease in the percentage of absolute poor (Thirtle *et al.*, 2002). Agriculture will continue to be the backbone of economies in Africa and South Asia in the foreseeable future. Substantial gains in land, water and labour productivity as well as better management of natural resources are essential to reverse the downward spiral of poverty and environmental degradation. Renewed effort and innovative R&D strategies are needed to address these challenges in rainfed areas.

Rainfed Agriculture in Need of Natural Resource Conservation Technologies

An insight into the inventories of natural resources in rainfed regions shows a grim picture of water scarcity, fragile environments, drought and land degradation due to soil erosion by wind and water, low rainwater use efficiency

(35-45%), high population pressure, poverty, low investments in water use efficiency (WUE) measures, poor infrastructure and inappropriate policies (Wani *et al.*, 2003b; Rockström *et al.*, 2007). Drought and land degradation are interlinked with poverty, hunger and water stress (Falkenmark, 1986) and the “hot spot” of malnourished countries in the world hosted in semiarid and dry subhumid hydroclimates in the world (Figure1), i.e. savannahs and steppe ecosystems, where rainfed agriculture is the dominating source of food, and where water constitutes a key limiting factor to crop growth (SEI, 2005). The global assessment showed that 57% of the total area of drylands occurring in two major Asian countries namely China (178.9 million ha) and India (108.6 million ha) are degraded (UNEP, 1997). To break this unholy nexus between drought (water scarcity), poverty and land degradation to meet the MDG of halving the number of food insecure poor by 2015 resource conservation technologies need to be urgently developed and scaled-up through appropriate dissemination.

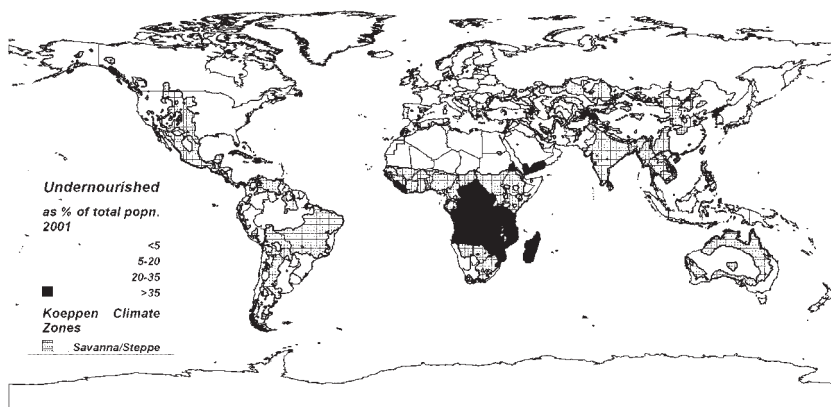


Figure 1. The prevalence of undernourished in developing countries (as percentage of population 2001/2002 (UNStat, 2005), together with the distribution of semiarid and dry subhumid hydroclimates in the world, i.e. savannah and steppe agro-ecosystems. These regions are dominated by sedentary farming subject to the world’s highest rainfall variability and occurrence of dry spells and droughts

Conservation agriculture¹ systems are one of the most important strategies to enhance soil productivity and moisture conservation. Non-inversion systems, where conventional ploughs are abandoned in favour of ripping, sub-soiling and no-tillage systems using direct planting techniques, combined with mulch management, builds organic matter and improves soil structure. Conservation agriculture is practised on approximately 40% of rainfed agriculture in USA, and has generated an agricultural revolution in several countries in Latin America (Derpsch, 1998, 2005; Landers *et al.*, 2001). Large-scale adoption of conservation agriculture systems is experienced among small-scale rainfed and irrigated farmers cultivating rice and wheat on the Indo-Gangetic plains in Asia (Hobbs *et al.*, 2002).

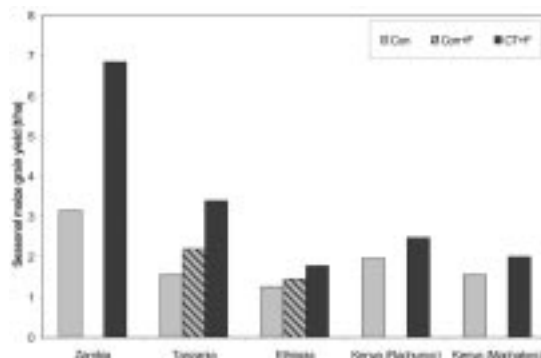
Conservation agriculture is of key importance in efforts of upgrading rainfed agriculture through conservation soil and water among the world’s resource-poor farmers. It reduces traction requirements (by tractors, or animal draught power), which saves money and is strategic from a gender perspective, as it generally gives women, particularly in female-headed households, a chance to carry out timely and effective tillage. A challenge is to find alternative strategies to manage weeds, particularly in poor farm households where herbicides are not an option. Furthermore, conservation agriculture can be strengthened in watershed areas. Conservation agriculture is a particularly important soil and water management strategy in hot tropical regions subject to water constraints. Soil inversion (using ploughs) in hot tropical environments leads to rapid oxidation of organic matter and increased soil erosion, which can be avoided using conservation agriculture practices.

Converting from ploughing to conservation agriculture using sub-soiling and ripping has resulted in major improvements in yield and water productivity in parts of semiarid to dry subhumid East Africa, with a doubling of

¹Conservation agriculture, often defined as conservation tillage or conservation farming, includes tillage systems with no-inversion of soil, i.e. without conventional ploughing, and range from no-tillage to minimum tillage and tillage systems aimed at opening the soil for rainfall capture without inversion. These systems include crop rotations and a mulch cover, which according to the convention should allow at least an average 30% cover of the soil throughout the year. For many farming systems in arid, semiarid and dry subhumid tropical regions a permanent mulch cover is difficult to sustain. Despite this difficulty, conservation agriculture systems, often adopted as a strategy for in-situ water harvesting, show much promise, even though difficulties with weed management is a more prominent challenge than when securing a mulch cover. The Comprehensive Assessment has chosen to adopt a wide definition of conservation agriculture focussed on non-inversion tillage for improvement of soil and water management (including sub-soiling, ripping, pitting and no-till systems).

Box 1. Conservation agriculture options in East Africa – a strategy for water and soil productivity improvement

On-farm participatory trials on innovative conservation agriculture in semiarid to dry subhumid Ethiopia, Kenya, Tanzania and Zambia indicate large potentials to substantially improve yields and rainwater productivity of staple food crops, through conservation agriculture. Conservation agriculture involves the abandoning of soil inversion through conventional ploughing (generally mouldboard or disc ploughing), in favour of tillage systems with no turning and with minimum disturbance of the soil. Trials were carried out with farmers during 1999-2003, where yields increased significantly in all countries (see figure below). The conservation agriculture systems maximized rainfall infiltration into the soil, through ripping and sub-soiling. Draught animal traction requirements were reduced drastically (with at least 50%) and limited soil fertilization resources (manure and fertilizer) were applied along permanently ripped planting lines.



Maize yield improvements from conservation agricultural in on-farm trials in Eastern and Southern African countries. A conventional mouldboard ploughing system (Con) is compared with conventional ploughing with added fertilization (Con+F) and conservation agriculture using ripper and sub-soilers combined with fertilizer (CT+F).

Box 2. Efficient use of *in-situ* water harvesting techniques in arid regions

Water harvesting systems using small micro-basins are used to support plants and trees in arid and semiarid environments. Small basins (*Negarim*) have supported almond trees for over 17 years in the Muwaqqar area of Jordan where the mean annual rainfall is 125 mm. The system has proved sustainable over a period of several years of drought (Oweis and Taimeh, 1996).

In the Mehassah area of the Syrian steppe, with an average annual rainfall of 120 mm, the survival rate of rainfed shrubs is less than 10%, while those that were grown in micro-catchments had a survival rate of over 90%. Shrub survival rate can be improved between 70 and 90% with the introduction of water harvesting interventions (semicircular bunds). In northwest Egypt, with an average annual rainfall of 130 mm, small water harvesting basins with 200 m² watersheds support olive trees, and harvesting rainwater from greenhouse roofs can provide about 50% of the water required by vegetables grown inside the greenhouse (Somme *et al.*, 2004).

yields in good years, due to increased capture of rainwater (Box 1). Further increases in grain yield were achieved by applying manure. Compared to irrigation, these kinds of interventions can be implemented on all agricultural lands. Moreover, Eastern and Southern Africa shows a large potential to reduce labour needs and improve yields in small-holder rainfed agriculture with the adoption of conservation agriculture practices (Box 1). Yield improvements range from 20 to 120%, with rainwater productivity improving at 10-40%. *In-situ* water harvesting options also include techniques to concentrate runoff to plants, such as terracing, bunds, ridges, khadins and micro-basins. The productivity of rain in arid environments can be substantially increased with appropriate water harvesting techniques, which concentrate runoff to plants and trees (Box 2).

Rainfed Agriculture – A Large Untapped Potential

Although agricultural production has kept us the space with the increasing global population during the past 40 years large regional variation as well as the large difference between irrigated and rain-fed agriculture exists. In developing countries rainfed grain yields are on average 1.5 t/ha, compared to 3.1 t/ha for irrigated yields (Rosegrant *et al.*, 2002), and increase in production from rainfed agriculture has mainly originated from land expansion.

In view of the historic regional difference in development of yields there exists a vast potential for raised yields in rainfed agriculture, particularly in sub-Saharan Africa and South Asia. In tropical regions, particularly in the

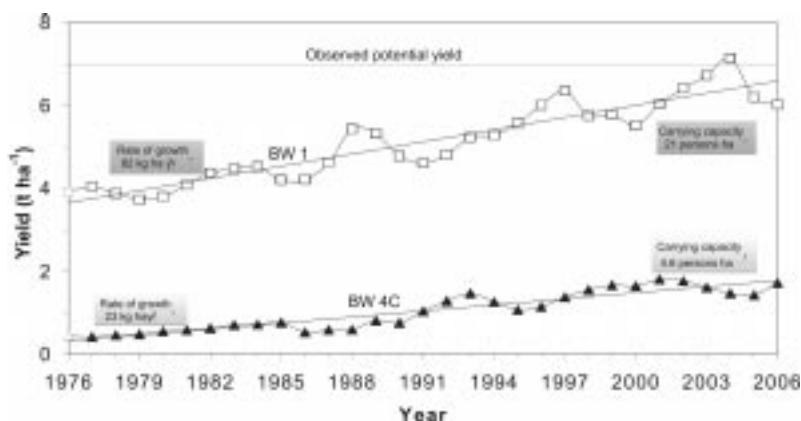


Figure 2. Three-year moving average of sorghum and pigeonpea grain yield under improved and traditional management in a deep Vertisol catchment at Patancheru, India

subhumid and humid zones, agricultural yields in commercial rainfed agriculture exceed 5-6 t/ha (Falkenmark and Rockström, 2000; Wani *et al.*, 2003a, 2003b). At the same time, the dry subhumid and semiarid regions have experienced the lowest yields and the weakest yield improvements per unit land. Here, yields oscillate between 0.5 to 2 t/ha, with an average of 1 t/ha in sub-Saharan Africa, and 1-1.5 t/ha in South Asia, Central Asia and West Asia and North Africa (CWANA) for rainfed agriculture (Falkenmark and Rockström, 2000; Wani *et al.*, 2003a, 2003b).

Evidence from a long-term experiment at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India since 1976, demonstrated the cycle of persistent yield increase through improved land, water and nutrient management in rainfed agriculture. Improved systems of sorghum/pigeonpea intercrops produced higher mean grain yields (5.1 t/ha) compared to 1.1 t/ha, average yield of sole sorghum in the traditional (farmers') post-rainy system where crops are grown on stored soil moisture (Figure 2). The annual gain in grain yield in the improved system was 82 kg/ha/yr compared with 23 kg/ha/yr in the traditional system. The large yield gap between attainable yield and farmers' practice as well as between the attainable yield of 5.1 t/ha and potential yield of 7 t/ha shows that a large potential of rainfed agriculture remains to be tapped. Moreover, the improved management system is still continuing to provide increase in productivity as well as improving soil quality (physical, chemical and biological parameters) along with increased carbon sequestration of 330 kg C per ha per year (Wani *et al.*, 2003a).

Yield gap analyses carried out by Comprehensive Assessment, for major rainfed crops in semiarid regions in Asia and Africa and rainfed wheat in WANA, reveal large yield gaps with farmers' yields being a factor 2 to 4 times lower than achievable yields for major rainfed crops (Singh *et al.*, 2009). Figure 3 illustrates examples of observed yield gaps in various countries in Africa, Asia and the Middle East and the historic trends present a growing yield gap between farmers' practices and farming systems that benefit from management advances (Wani *et al.*, 2003b).

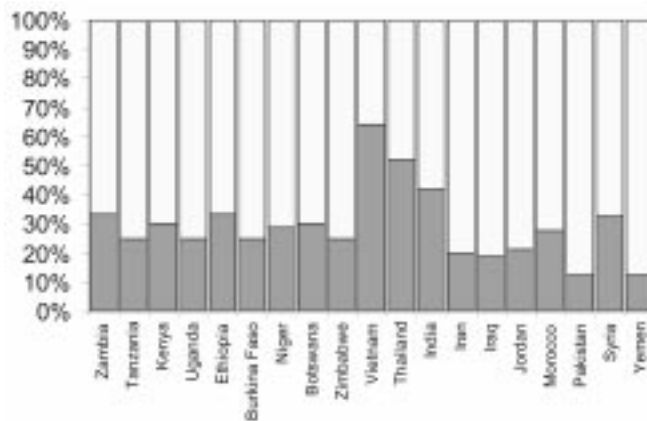


Figure 3. Examples of observed yield gap (for major grains) between farmers' yields and achievable yields (100% denotes achievable yield level, and columns actual observed yield levels). (Source: Derived from Rockstrom *et al.*, 2007)

The difference is largely explained by inappropriate soil, water and crop management options used at the farm level, combined with persistent land degradation. The vast potential of rainfed agriculture needs to be unlocked through knowledge-based natural resource conserving technologies for increasing the productivity and income to achieve food security in the developing world.

The Challenges of Out-scaling in Investments and Policies

Recent reviews of rain-fed agriculture listed the challenges of out-scaling in investments and policies (Ryan and Spencer, 2001, Rockström *et al.*, 2007, Wani *et al.*; 2009, Sreedevi and Wani; 2009). Investments in agricultural research in savannah agroecosystems in the past have generated highly disappointing results (Seckler and Amarasinghe, 2004). A reason for this is the lack of holistic approach as over the past 50 years at farm level has mainly been on crop, soil, or water research. It is only in the past 10-15 years that science and technology development has focused more strongly on water management in rainfed agriculture (on water harvesting and supplemental irrigation in rainfed systems), and on tillage research focused in more explicit terms on water conservation (conservation tillage systems) at the farm scale (Rockström *et al.*, 2007).

Upgrading rainfed agriculture requires that technologies (indigenous or improved) are strongly adapted to local biophysical and socio-cultural conditions accompanied with institutional and behavioural changes (Harris *et al.*, 1991; van Duivenbooden *et al.*, 2000). Adoption of conservation agriculture in several parts of the world was driven by crises, e.g. in USA, as a response to the Dust Bowl in the 1930s, in part of Latin America as a response to an agrarian yield crisis and in Zambia, as a response to droughts. Increased emphasis on watershed management in India is largely to cope with droughts in drought-prone areas, i.e. drylands in India after severe droughts in early 1980s. In rainfed areas the challenges are for many knowledge intensive extension effort along with the widespread limitations of the capacity of local institutions engaged in agricultural development and extension to promote management of rainwater.

New Paradigm in Rainfed Agriculture

For sustaining the economic growth and needed food security we need to have knowledge-based holistic approach converging necessary aspects of natural resource conservation, their efficient use, production functions, income enhancement avenues through value chain and enabling policies coupled with capacity building measures and much needed investments in rainfed areas.

Integrated Genetic and Natural Resource Management (IGNRM)

Traditionally, crop improvement and NRM are two sides of the same coin but were seen as distinct but complementary disciplines. ICRISAT is deliberately blurring these boundaries to create the new paradigm of IGNRM (Twomlow *et al.*, 2006). In essence, plant breeders, NRM and social scientists must integrate their work with that of private and public sector change agents to develop flexible cropping systems that can respond to rapid changes in market opportunities and climatic conditions. Crucially the IGNRM approach looks at various components of the rural economy is participatory, with farmers closely involved in technology development, testing and dissemination. Rather than pursuing a single correct answer, we need to look for multiple solutions tailored to the requirements of contrasting environments and diverse sets of households. In the rainfed areas for improving livelihoods the approach has to be business approach through marketable surplus production through diversified farming systems with necessary market linkages and institutional arrangements.

In much of agricultural research, the multidisciplinary team approach has often run into difficulties in achieving impact because of the perceived disciplinary hierarchy. In Asia the IGNRM approach in Community Watershed Consortium pursues integration of the knowledge and products of the various research disciplines into useful extensions messages for development workers that can sustain increased yields and promote income-generating and sustainable crop and livestock production options for a range of climatic and edaphic conditions (Wani *et al.*, 2006a).

Community Watershed as Growth Engine for Development of Dryland Areas

Watershed, as an entry point should lead to exploring multiple livelihood interventions (Wani *et al.*, 2006a, 2006b, 2008b). The overall objective of the whole approach being poverty elimination through sustainable development, the new community watershed management model fits into the framework as a tool to assist in sustainable rural livelihoods. Watershed management is the integration of technologies within the natural boundaries of a drainage

area for optimum development of land, water and plant resources to meet the basic needs of the people and livestock in a sustainable manner through value addition and market linkages.

ICRISAT and the national agricultural research systems (NARSs) in Asia have developed in partnership an innovative and up-scalable consortium model for managing watersheds holistically. In this approach, rainwater management is used as an entry point activity starting with *in-situ* conservation of rainwater and converging the benefits of stored rainwater into increased productivity by using improved crops, cultivars, suitable nutrient and pest management practices and land and water management practices. Conservation of soil and water resources fuel the crop yield increases, diversification and income enhancements. ICRISAT's consortium model for community watershed management espouses the principles of collective action, convergence, cooperation and capacity building (4 Cs) with technical backstopping by a consortium of institutions to address the issues of equity, efficiency, economics and environment (4Es) (Wani *et al.*, 2006a).

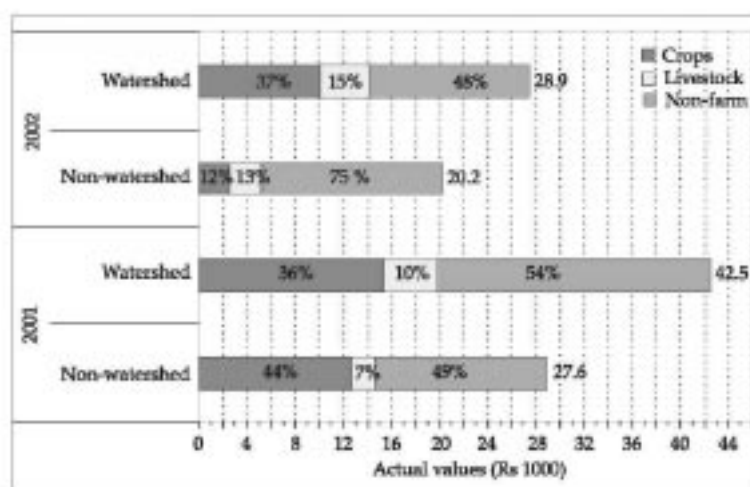


Figure 4. Effect of integrated watershed management on flow of household net income (Source: ICRISAT Data - Adarsha Watershed, Andhra Pradesh, India)

Table 1. The effect of integrated watershed interventions on alternative sources of household income (Rs 1000).

Year	Village group ^a	Statistics income	Crop income	Livestock income	Off-farm income	Household income
2001 (average year)	Non-project	Mean income	12.7	1.9	14.3	28.9
		Share of total income (%)	44.0	6.6	49.5	100.0
	Watershed project	Mean income	15.4	4.4	22.7	42.5
		Share of total income (%)	36.2	10.4	53.4	100.0
2002 (drought year)	Non-project	Mean income	2.5	2.7	15.0	20.2
		Share of total income (%)	12.2	13.3	74.5	100.0
	Watershed project	Mean income	10.1	4.0	13.4	27.6
		Share of total income (%)	36.7	14.6	48.7	100.0

^a The sample size is n = 60 smallholder farmers in each group (ICRISAT data).

The IGNRM approach in the community watersheds has enabled communities not only to harness the benefits of watershed management i.e. conservation of natural resources, but also achieve much of the potential from improved varieties from a wider range of crops through efficient and sustainable use of the conserved natural resources. The households' incomes and overall productivity have more than doubled throughout selected benchmark sites in Asia (Figure 4 and Table 1). The benefits not only accrue to landholding households, but also to the landless marginalized groups through the creation of greater employment opportunities.

The Common Features of the Watershed Development Model

Government agencies, development thinkers, donors, researchers and NGOs have gradually learnt from each other, (though some are ahead of the field and others deficient in some aspect or other, principally in people

participation or in the science). But generally, nowadays the better models have some or all of the following features in common (Wani *et al.*, 2008a).

- participation of villagers as individuals, as groups or as a whole, increasing their confidence, enabling their empowerment and their ability to plan for the future and for self-determination
- Capturing the power of group action in the village, between villages and from federations, e.g. capturing economies of scale by collective marketing
- Construction of basic infrastructure with contributions in cash or labour from the community
- Better farming techniques, notably the improved management of soil, water, diversifying the farming system and integrating the joint management of communal areas and forest
- Involvement of the landless, often in providing services
- Arrangements for the provision of basic services and infrastructure
- Establishment of village institutions and links with the outside world
- Improved relationships between men and women
- Employment and income generation by enterprise development in predominantly but not exclusively agricultural-related activities.

And sometimes:

- The fusion of research and development (R&D) by capturing the extraordinary power of participatory technology development, including varietal selection with direct links to germplasm collections
- Complete avoidance of corruption so that trust is built and all the benefits pass to the community
- Reduction in distressed migration

Recent Additions to the Watershed Model

- The pragmatic use of scientific knowledge as the entry point rather than money, dole-out of completed by tangible economic benefit from low-cost interventions that generate rapid and substantial returns at low level of risk.
- A broad-based approach to income generation, involving private sector associated with scientific advances and markets; for instance, in the remediation of micro-nutrient deficiencies; in the marketing of medicinal and aromatic plants; with premium payments paid by industrial processors for aflatoxin-free maize and groundnut etc.
- Using new science methodologies to improve performance like remote sensing for monitoring and feedback to farmers, yield gap analysis and rapid assessment of the fertility status of the watershed.
- Building productive partnerships and alliances in a consortium for research and technical backstopping, with the members brought together from the planning stage.
- A concern to create resilience in the watershed and its community to climate change and to events of post-programme intervention.

Where best applied, the model has led to profound farming system changes, improved food self-sufficiency, expanded employment and commerce and enhanced incomes. Where indifferently executed the approach has led, as we shall see in what follows. There is indeed something here analogous to the 'yield gap' exhibited between research station and farmers' yields. Much of the difference can be captured by implementing agencies 'catching up' with best practice. The more recent linking of natural resource science with the private sector, markets and with peoples broader livelihoods in consultation with them, is transforming the dynamic and success rate of development efforts (Wani *et al.*, 2008a).

Broad Overall Conclusions about Watershed Performance and Impact from the Comprehensive Assessment

The watershed approach is a paradigm that works in all rainfed circumstances, has delivered important benefits and impacts and needs to be implemented on a large scale. The difference in result between indifferent and best

watershed practice is in part because the watershed approach has been rapidly evolving and the assessment looked at a field in which the goal posts have repeatedly been moved. In part, it is due to deficiencies in execution.

To consolidate and build upon the foundation already laid and universally gain the impact that is possible, the government should undertake some difficult tasks, most noticeably introducing a new 'mind set' or different form of approach that accepts the following (Wani *et al.*, 2008a):

- Watershed development is not just a means to increase production or to conserve soil and water but an opportunity for the fully integrated and sustained development of human and natural resources.
- The approach is valid across various rainfall regimes over vast tracts of India and can contribute in large measure to the simultaneous achievement of government's production environmental and social goals.
- Sustainability and better social impact and equity are very important issues with pro-poor interventions not as a spin-off or after-thought but planned and integrated with the whole.
- There are vast opportunities to reduce costs and increase output by improving the appropriateness and extent of technology.
- There is obvious value in converging Government schemes in the interest of impact and sustainability, rather than a spread of activity; this is particularly important in the case of water and schemes aimed to reach the poor.

Watersheds should be seen as a business model. This calls for a shift in approach from subsidized activities to knowledge-based entry points and from subsistence to gaining tangible economic benefits for the population of the watershed at large. This is being done by productivity enhancement, diversification to high-value enterprises, income-generating activities, market links, public-private partnerships, micro-entrepreneurship and a broad-based community involvement.

Moving forward requires that a lack of capacity to effectively implement programmes be addressed. Implementing agencies need to expand and broaden their capacities and skills; while communities need to strengthen their institutions and their skills. This will require a longer implementation period of seven to eight years with more time spent in preparation and in post-intervention support. It also requires additional funds and more flexibility in using budgets and the engagement of specialist service providers (Wani *et al.*, 2008a).

One of the weakest aspects lies in the generation and dissemination of technology. A big improvement is needed in making appropriate technology and information accessible to the watershed community. The remedy lies in devising technology for the drier and wetter parts of the rainfed area, more participatory development research and in forming consortia, and employing agencies to provide specialist technical backstopping.

There is a crucial need to improve monitoring and evaluation and the feedback of the information obtained to constantly improve performance. Only a few key indicators need to be monitored in all watersheds. At one or two representative watersheds in each district, a broad range of technical and socioeconomic parameters should be measured to provide a scientific benchmark and a better economic valuation of impact than is currently possible (Wani *et al.*, 2008a).

Operationalizing Community Watershed as Growth Engine

Community watershed development programmes are used as growth engines for sustainable development of rainfed areas (Wani *et al.*, 2003b, 2006b, 2008b). However, the major challenge is scaling-up to large areas as successful watersheds remained few and unreplicated (Kerr *et al.*, 2002; Joshi *et al.*, 2005). Recently ICRISAT has developed and evaluated an integrated consortium approach for sustainable development of community watersheds with technical backstopping and convergence (Wani *et al.*, 2002, 2003b). Most farming problems require the IGSRM approach that is participatory, with farmers closely involved in technology development, testing and dissemination. The adoption of this new paradigm in rainfed agriculture has shown that with proper management of natural resources the systems productivity can be enhanced and poverty can be reduced without causing further degradation of natural resource base (Wani *et al.*, 2008b; Rockström *et al.*, 2007). The scaling-up of these innovations with technical support from ICRISAT-led consortium has been attempted in Andhra Pradesh, India through Andhra Pradesh Rural Livelihoods Programme (APRLP) supported by the Department for International Development (DFID), UK; in Karnataka, (India), Sujala watershed programme supported by the World Bank; in three districts of Madhya

Pradesh and Rajasthan with the support from Sir Dorabji Tata Trust (SDTT), Mumbai, India; and four countries in Asia (India, Thailand, Vietnam and China) with the support of Asian Development Bank (ADB), Philippines (Wani et al. 2008b, Sreedevi and Wani 2009).

Knowledge-based Entry Point –widespread Micronutrient Deficiencies in SAT Soils

In the watershed programs to build the rapport with the communities an entry point activity (EPA) is undertaken at the beginning of the program. In the traditional watershed programs generally the EPAs covered some common intervention such as construction of classroom, a meeting place, putting a hand pump for drinking water, etc to benefit the community. However, such EPAs did not serve the purpose of building the rapport with the communities and no quality participation was achieved. ICRISAT consortium team identified the drivers of collective action (Sreedevi et al. 2004) and developed knowledge-based EPA to enhance community participation. The main objective was to use knowledge as capacity building measure to benefit the large number of farmers to get tangible economic benefits during the first season. (Dixit et al, 2007). Analysis of soil samples, introduction of seeds of stress-tolerant and high yielding cultivar in the watershed, which can benefit large number of farmers, were selected as the EPAs. ICRISAT-led consortium has assessed 11000 soil samples from the farmers' fields in different states of India (Andhra Pradesh, Karnataka, Kerala, Rajasthan, Madhya Pradesh, Gujarat and Tamil Nadu) and observed widespread deficiencies of sulphur (S), zinc (Zn) and boron (B) along with total nitrogen (N) and phosphorus (P) (Table 2a, Table 2b) (Sahrawat *et al.*, 2007). For rapport building, knowledge-based EPA for example, the results of the soil analysis were presented in the *gram sabhas* and the importance of soil analysis and nutrient deficiencies in crop production were discussed. A large number of farmers were convinced about the importance of balanced nutrition in crop production and came forward as volunteers to evaluate the INM options.

Convergence and Collective Action

Convergence of actors and their actions at watershed level is needed to harness the synergies and to maximize the benefits through efficient and sustainable use of natural resources to benefit small and marginal farmers through increased productivity per unit of resource. We have missed out large benefits of watershed programmes due to compartmental approach and there is an urgent need to bring in convergence, as the benefits are manifold and its win-win for all the stakeholders including line departments involved in improving rural livelihoods.

Table 2a. Percentage of farmers' fields deficient in soil nutrients in different states of India^(a).

State	No. of farmers' fields	OC (%)	AvP (ppm)	K (ppm)	S (ppm)	B (ppm)	Zn (ppm)
Andhra Pradesh	1927	84	39	12	87	88	81
Karnataka	1260	58	49	18	85	76	72
Madhya Pradesh	73	9	86	1	96	65	93
Rajasthan	179	22	40	9	64	43	24
Gujarat	82	12	60	10	46	100	82
Tamil Nadu	119	57	51	24	71	89	61
Kerala	28	11	21	7	96	100	18

^(a) OC = Organic Carbon; AvP = Available phosphorus

Table 2b. Percentage of farmers' fields deficient in soil nutrients in different states of Karnataka, India^(a).

State	No. of farmers' fields	OC (%)	AvP (ppm)	K (ppm)	S (ppm)	B (ppm)	Zn (ppm)
Dharwad district	1129	31	53	1	79	39	44
Haveri district	1532	55	42	5	85	46	60
Chitradurga Dist	1489	76	54	15	86	64	80
Madhgi Dist	987	81	67	30	93	91	51
Tumkur Dist	2054	75	64	35	92	92	50
Kolar Dist	2161	81	31	34	85	87	32
Chickballapur Dist	2257	78	37	34	80	80	52

^(a) OC = Organic Carbon; AvP = Available phosphorus

New institutional mechanisms are also needed at district, state, and national level to converge various watershed programmes implemented by several ministries and development agencies to enhance the impact and efficiency by overcoming duplicity and confusion. In 2005, the National Commission on Farmers recommended a holistic integrated watershed management approach, with focus on rainwater harvesting and improving soil health for sustainable development of drought-prone rainfed areas (Government of India, 2005). Recently, Government of India has established National Rain-fed Areas Authority (NRAA) with the mandate to converge various programmes for integrated development of rainfed agriculture in the country and have released Common Watershed Guidelines (Government of India, 2008). Recently, Department of Land Resources, Ministry of Rural Development has merged all its watershed programs in to Integrated Watershed Development Program (IWDP). Similarly, national rural employment guarantee act (NREGA) programs are trying to converge watershed activities. These are welcome developments, however, it is just a beginning and lot more still needs to be done to provide institutional and policy support for development of rainfed areas. Thus, it has become increasingly clear that water management for rainfed agriculture requires a landscape perspective, and involves cross-scale interactions from farm household scale to watershed/catchment scale.

Enhancing partnerships and institutional innovations through the consortium approach was the major impetus for harnessing community watershed's potential to reduce households' poverty. The underlying element of the consortium approach adapted in ICRISAT-led community watersheds is engaging a range of actors with the locales as the primary implementing unit. This created the venue for receiving technical support and building the capacity of members like women for the management of conservation and livelihood development activities. Incorporating knowledge-based entry point in the approach led to the facilitation of rapport and at the same time enabled the community to take rational decisions for their own development. As demonstrated by ICRISAT, the strongest merit of consortium approach is in the area of capacity building where farm households are not the sole beneficiaries and researchers, development workers and students of various disciplines are also trained, and policymakers from the NARSs sensitized on the entire gamut of community watershed activities. Private-public partnership has provided the means for increased investments not only for enhancing productivity but also for building institutions as engines for people-led NRM. From another aspect, the consortium approach has contributed to scaling through the nucleus-satellite scheme and building productive alliances for further research and technical backstopping. A balanced R&D programme in community watersheds has encouraged scientific debate and at the same time promoted development through tangible economic benefits.

Capacity Building

ICRISAT-led consortium's comprehensive assessment of watershed programs in India identified the poor capacity building as the weakest link for scaling-up the program and enhancing the impacts as watershed development is knowledge intensive and inherently slow. It has recommended strengthening of capacity building strategies at different levels from community level to national level. Capacity building of different stakeholders from farmers up to policy makers in various aspects of holistic watershed management is needed and it should be through a consortium of quality service providing training institutions. As a forward looking step it has also suggested quality management systems and certification system for the service providers. Establishment of Model watersheds as sites of learning in each district for hands on training for the stakeholders and also for monitoring detailed impacts are recommended (Wani et al, 2008a). Empowerment of different stakeholders through capacity building in participatory integrated watershed management could be facilitated for scaling-up the benefits from the nucleus and satellite watersheds in the target regions (Figure 5).

ICT-enabled Farmer-centred Learning Systems for Knowledge Exchange

It is increasingly realized that facilitation of knowledge flows is a key in fostering new rural livelihood opportunities using modern information and communication technologies (ICTs). The concept adapted is one of intelligent intermediation for facilitation of flows of information and knowledge. The community centre managed by the PIAs functions as a Rural Information Hub connecting participating villages (or groups of villages, as the case may be) and also with other Internet connected websites. It is operated or managed by a rural group (women or youth SHGs) identified by the village watershed council through a consultative process. The activities on this module are planned to adopt a hub-and-spokes model for information dissemination among the participants and stakeholders. The electronic network across select nuclear watersheds enables sharing of experience and best practices.

Knowledge Transfer within the Institution

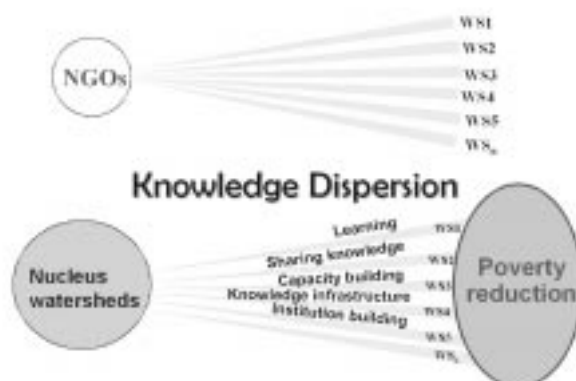


Figure 5. Knowledge transfer within the institution and the region (WS = Watershed).

Forward Looking Approach to Manage High Risk and Impacts of Climate Change

Rainfed agriculture is a risky business due to high spatial and temporal variability of rainfall. Rainfall is concentrated in short rainy seasons (approximately 3 to 5 months), with few intensive rainfall events, which are unreliable in temporal distribution, manifested by high deviations from the mean rainfall (coefficients of variation of rainfall as high as 40% in semiarid regions) (Wani *et al.*, 2004). In fact, even if water is not always the key-limiting factor for yield increase, rainfall is the only truly random production factor in the agricultural system. This is manifested through high rainfall variability causing recurrent flooding, droughts and dry spells.

Established but incomplete evidence suggests that the high risk for water related yield loss makes farmers avert risk, which in turn determines farmers' perceptions on investments in other production factors (such as labour, improved seed and fertilizers) (Wani *et al.* 2006a & b). Temporal and spatial variability of climate, especially rainfall, is a major constraint to yield improvements, competitiveness and commercialization of rainfed crop, tree crops and livestock systems in most of the tropics. Management options should therefore start by focussing on reducing rainfall induced risks.

Evidence is emerging that climate change is making the variability more intense with increased frequency of extreme events such as drought, floods and hurricanes (IPCC, 2001). A recent study assessing rainfed cereal potential under different climate change scenarios, with varying total rainfall amounts concluded that it is difficult to estimate the degree of regional impact. But most scenarios resulted in losses of rainfed production potential in the most vulnerable developing countries. In these countries, the loss of production area was estimated at 10-20%, with an approximate potential of 1-3 billion people affected in 2080 (IIASA, 2002). In particular, sub-Saharan Africa is estimated to lose 12% of the cultivation potential mostly projected in the Sudan-Sahelian zone which is already subject to high climatic variability and adverse crop conditions. Because of the risk associated with climate variability, small-holder farmers are generally and rationally keen to start by reducing risk of crop failure due to dry spells and drought before they consider investments in soil fertility, improved crop varieties, and other yield enhancing inputs (Hilhost and Muchena, 2000).

Conjunctive Use of Water: Discard Artificial Divide between Irrigated and Rainfed Agriculture

Adopt integrated water resource management approach in the watersheds by discarding the artificial divide between rainfed and irrigated agriculture. There is an urgent need to have sustainable water (rain-, ground- and surface-water) use policies to ensure sustainable development. In the absence of suitable policies and mechanisms for sustainable use of groundwater resources benefits of watershed programmes can easily be undone in short period with overexploitation of the augmented water resources (Sreedevi *et al.* 2006). Cultivation of water inefficient crops like rice and sugarcane need to be controlled using groundwater in watersheds through suitable incentive mechanisms for rainfed irrigated crops and policy to stop cultivation of high water requiring crops (Wani *et al.* 2008a).

Business Model

Watersheds should be developed as business model through public-private partnership using principles of market-led diversification using high-value crops, value chain approach and livelihood approach rather than only soil and water conservation approach. Strengths of rainfed areas using available water resources efficiently through involvement of private entrepreneurs and value addition can be harnessed by linking small and marginal farmers to markets through public-private partnership business model for watershed management.

Multiple Benefits and Impacts of the Community Watershed Development

Through the use of new science tools [i.e. remote sensing, geographical information systems (GIS) and simulation modelling] along with an understanding of the entire food production-utilization system (i.e. food quality and market) and genuine involvement of stakeholders, ICRISAT-led watersheds effected remarkable impacts on SAT resource-poor farm households.

Reducing rural poverty in the watershed communities is evident in the transformation of their economies. The ICRISAT model ensured improved productivity with the adoption of cost-efficient water harvesting structures (WHS) as an entry point for improving livelihoods. Crop intensification and diversification with high-value crops is one leading example that allowed households to achieve production of basic staples and surplus for modest incomes. The model has provision for improving the capacity of farm households through training and networking and for alleviating livelihood and enhanced participation especially of the most vulnerable groups like women and the landless.

Building on social capital made the huge difference in addressing rural poverty of watershed communities. This is evident in the case of Kothapally watershed in Andhra Pradesh, India. Today, it is a prosperous village on the path of long-term sustainability and has become a beacon for science-led rural development. In 2001, the average village income from agriculture, livestock and non-farming sources was US\$ 945 compared with the neighbouring non-watershed village income of US\$ 613 (Figure 4). The villagers proudly professed: “*We did not face any difficulty for water even during the drought year of 2002. When surrounding villages had no drinking water, our wells had sufficient water.*”

Crop Livestock integration is another facet harnessed for poverty reduction. The Lucheba watershed, Guizhou province of southern China has transformed its economy through modest injection of capital-allied contributions of labour and finance, to create basic infrastructures like access to roads and drinking water supply. With technical support from the consortium, the farming system was intensified from rice and rape seed to tending livestock (pig raising) and growing horticultural crops (fruit trees like *Ziziphus*; vegetables like beans, peas and sweetpotato) and groundnuts. In forage production, wild buckwheat was specifically important as an alley crop as it was a good forage grass for pigs. This cropping technology was also effective in controlling erosion and increasing farm income in sloping lands. This holds true in many watersheds of India where the improvement in fodder production has intensified livestock activities like breed improvement (artificial insemination and natural means) and livestock centre/health camp establishment (Wani et al., 2006b). In Tad Fa and Wang Chai watersheds in Thailand, there was a 45% increase in farm income within three years. Farmers earned an average net income of US\$ 1195 per cropping season. A complete turnaround in livelihood system of farm households was inevitable in ICRISAT-led watersheds (Wani et al. 2008b).

Increasing crop productivity is a common objective in all the watershed programmes; and the enhanced crop productivity is achieved after the implementation of soil and water conservation practices along with appropriate crop and nutrient management. For example, the implementation of improved crop management technology in the benchmark watersheds of Andhra Pradesh increased the maize yield by 2.5 times (Table 3) and sorghum yield by threefold (Wani et al., 2006b & 2008b). Overall, in the 65 community watersheds (each measuring approximately 500 ha), implementing best-bet practices resulted in significant yield advantages in sorghum (35-270%), maize (30-174%), pearl millet (72-242%), groundnut (28-179%), sole pigeonpea (97-204%) and intercropped pigeonpea (40-110%). In Thanh Ha watershed of Vietnam, yields of soybean, groundnut and mung bean increased by threefold to fourfold (2.8–3.5 t/ha) as compared with baseline yields (0.5 to 1.0 t/ha), reducing the yield gap between potential farmers' yields. A reduction in nitrogen fertilizer (90–120 kg urea per ha) by 38% increased maize yield by 18%. In Tad Fa watershed of northeastern Thailand, maize yield increased by 27-34% with improved crop management.

Table 3. Crop yields in Adarsha watershed Kothapally during 1999-2007.

Crop	1998	Yield (kg/ha)									SE±
	base-line yield	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	Ave-rage yields	
Sole maize	1500	3250	3750	3300	3480	3920	3420	3920	3635	3640	283.3
Improved intercropped maize	-	2700	2790	2800	3083	3129	2950	3360	3180	3030	263.0
Traditional intercropped maize	-	700	1600	1600	1800	1950	2025	2275	2150	1785	115.6
Improved intercropped pigeonpea	-	640	940	800	720	950	680	925	970	860	120.3
Traditional intercropped pigeonpea	190	200	180	-	-	-	-	-	-	190	-
Improved Sole sorghum	-	3050	3170	2600	2425	2290	2325	2250	2085	2530	164.0
Traditional sole sorghum	1070	1070	1010	940	910	952	1025	1083	995	1000	120.7
Intercropped sorghum	-	1770	1940	2200	-	2110	1980	1960	1850	1970	206.0

Improving water availability in the watersheds was attributed to efficient management of rainwater and *in-situ* conservation, establishment of WHS and improved groundwater levels. Findings in most of the watershed sites reveal that open wells located near WHS have significantly higher water levels compared to those away from the WHS. Even after the rainy season, the water level in wells nearer to WHS sustained good groundwater yield. In the various watersheds of India like Lalatora (in Madhya Pradesh), treated area registered a groundwater level rise by 7.3 m. At Bundi, Rajasthan, the average rise was 5.7 m and the irrigated area increased from 207 ha to 343 ha. In Kothapally watershed in Andhra Pradesh, the groundwater level rise was 4.2 m in open wells. With such improvement in groundwater availability, the supply of clean drinking water was guaranteed. In Lucheba watershed in China, a drinking water project, which constitutes a water storage tank and pipelines to farm households, was a joint effort of the community and the watershed project. This solved the drinking water problem for 62 households and more than 300 livestock. Earlier every farmer's household used to spend 2-3 hours per day fetching drinking water. This was the main motivation for the excellent farmers' participation in the project. On the other hand, collective pumping out of well water established efficient water distribution system and enabled farmers' group to earn more income by growing watermelon with reduced drudgery as women had to carry water on the head from a long distance. Pumping of water from the river as a means to irrigate watermelon has provided maximum income for households in Thanh Ha watershed (in Vietnam) (Wani *et al.*, 2006b).

Supplemental irrigation can play a very important role in reducing the risk of crop failures and in optimizing the productivity in the SAT. In these regions, there is good potential for delivering excess rainwater to storage structures or groundwater because even under improved systems, there is loss of 12-30% of the rainfall as runoff. Striking results were recorded from supplemental irrigation on crop yields in ICRISAT benchmark watersheds in Madhya Pradesh. On-farm studies made during 2000-03 post-rainy seasons, showed that chickpea yield (1.25 t/ha) increased by 127% over the control yield (0.55 t/ha); and groundnut pod yield (1.3 t/ha) increased by 59% over the control yield (0.82 t/ha) by application of two supplemental irrigations of 40 mm (Pathak *et al.*, 2009).

Sustaining development and protecting the environment are the two-pronged achievements of the watersheds. The effectiveness of improved watershed technologies was evident in reducing runoff volume, peak runoff rate and soil loss and improving groundwater recharge. This is particularly significant in Tad Fa watershed where interventions such as contour cultivation at mid-slopes, vegetative bunds planted with *Vetiver*, fruit trees grown on steep slopes and relay cropping with rice bean reduced seasonal runoff to less than half (194 mm) and soil loss less than 1/7th (4.21 t/ha) as compared to the conventional system (473 mm runoff and soil loss 31.2 t/ha). This holds true with peak runoff rate where the reduction is approximately one-third (Table 4).

Large number of fields (80-100%) in the SAT were found severely deficient in zinc, boron and sulphur as well as nitrogen and phosphorus. Amendment of soils with the deficient micro- and secondary nutrients increased crop yields by 30 to 70%, resulting in overall increase in water and nutrient use efficiency. Introduction of integrated pest management (IPM) and improved cropping systems decreased the use of pesticides worth US\$ 44 to 66 per ha. Crop rotation using legumes in Wang Chai watershed (Thailand) substantially reduced nitrogen requirement for rainfed sugarcane. The IPM practices, which brought into use local knowledge using insect traps of molasses, light traps and tobacco waste, led to extensive vegetable production in Xiaoxingcun (China) and Wang Chai (Thailand) watersheds.

Table 4. Seasonal rainfall, runoff and soil loss from different benchmark watersheds in India and Thailand.

Watershed	Seasonal rainfall (mm)	Runoff (mm)		Soil loss (t/ha)	
		Treated	Untreated	Treated	Untreated
Tad Fa (Khon Kaen, NE Thailand)	1284	169	364	4.21	31.2
Kothapally (Andhra Pradesh, India)	743	44	67	0.82	1.9
Ringnodia (Madhya Pradesh, India)	764	21	66	0.75	2.2
Lalatora (Madhya Pradesh, India)	1046	70	273	0.63	3.2

Improved land and water management practices along with integrated nutrient management comprising application of inorganic fertilizers and organic amendments (such as crop residues, vermicompost, farm manures and *Gliciridia* loppings) as well as crop diversification with legumes not only enhanced productivity but also improved soil quality. Increased carbon sequestration of 7.4 t/ha in 24 years was observed with improved management options in a long-term watershed experiment at ICRISAT (Wani *et al.* 2003a). Normalized difference vegetation index (NDVI) estimation from the satellite images showed that within four years, vegetation cover could increase by 35% in Kothapally. The IGCRM options in the watersheds reduced loss of NO₃-N in runoff water (8 vs 14 kg nitrogen per ha). Reduced runoff and erosion reduced risk of downstream flooding and siltation of water bodies that directly improved environmental quality in the watersheds (Pathak *et al.*, 2005; Sahrawat *et al.*, 2005; Wani *et al.*, 2005).

Conserving biodiversity in the watersheds was engendered through participatory NRM. The index of surface percentage of crops (ISPC), crop agro-biodiversity factor (CAF), and surface variability of main crops changed as a result of integrated watershed management interventions. Pronounced agro-biodiversity impacts were observed in Kothapally watershed where farmers now grow 22 crops in a season with a remarkable shift in cropping pattern from cotton (200 ha in 1998 to 100 ha in 2002) to a maize/pigeonpea intercrop system (40 ha in 1998 to 180 ha in 2002), thereby changing the CAF from 0.41 in 1998 to 0.73 in 2002. In Thanh Ha, Vietnam the CAF changed from 0.25 in 1998 to 0.6 in 2002 with the introduction of legumes. Similarly, rehabilitation of the common property resource land in Bundi watershed through the collective action of the community ensured the availability of fodder for all the households and income of US\$ 1670 per yr for the SHG through sale of grass to the surrounding villages. Aboveground diversity of plants (54 plant species belonging to 35 families) as well as belowground diversity of microorganisms (21 bacterial isolates, 31 fungal species and 1.6 times higher biomass C) was evident in rehabilitated CPR as compared to the degraded CPR land (9 plant species, 18 bacterial isolates and 20 fungal isolates of which 75% belong to *Aspergillus* genus) (Wani *et al.*, 2005)

Conclusions

Sustainable rural development through conservation of land and water resources gives plausible solution for alleviating rural poverty and improving the livelihoods of rural poor through watershed approach. In an effective convergence mode for improving the rural livelihoods in the target districts, with watersheds as the operational units, a holistic integrated systems approach by drawing attention on the past experiences, existing opportunities and skills, and supported partnerships can enable change and improve the livelihoods of rural poor. The rationale behind convergence through watersheds has been that these watersheds help in “cross learning” and drawing wide range of experiences from different sectors. A significant conclusion is that there should be a balance between attending to needs and priorities of rural livelihoods and enhancing positive directions of change by building effective and sustainable partnerships along with the capacity building of the stakeholders. Based on the experience and performance of the existing integrated community watersheds in different socioeconomic environments, appropriate exit strategies, which include proper sequencing of interventions, building up of financial, technical and organizational capacity of local communities to internalize and sustain interventions, and the requirement for any minimal external technical and organizational support need to be identified.

Acknowledgements

We acknowledge the help of number of community based organizations in different watersheds who undertook PR&D. Financial support provided by the Government of India, Asian Development Bank (ADB), Manila, The Philippines, DFID, through APRLP (Andhra Pradesh Rural Livelihood Project), Sir Dorabji Tata Trust, Mumbai and World Bank supported Sujala Watershed Program of Government of Karnataka.

References

- Derpsch, R. (1998) Historical review of no-tillage cultivation of crops. In: *Conservation Tillage for Sustainable Agriculture- from an International Workshop*, Harare, 22 to 27 June, 1997. Part II (Annexes) (Benites, J., Chuma, E., Fowler, R., Kienzle, J., Molapong, K., Manu, J., Nyagumbo, I., Steiner, K. and van Veenhuizen R, Eds.), pp 205-218. Proceedings Deutsche Gesellschaft, GTZ, Eschborn, Germany.
- Derpsch, R. 2005. The extent of conservation agriculture adoption worldwide: Implications and impact. Keynote paper at the 3rd World Congress on Conservation Agriculture, Oct 3 to 7, 2005, Nairobi, Kenya organized by RELMA/ICRAF, Nairobi, Kenya.
- Dixit, Sreenath., Wani, S.P., Rego, T.J. and Pardhasaradhi, G. 2007. Knowledge-based Entry Point and Innovative Up-scaling Strategy for Watershed Development Projects. *Indian Journal of Dryland Agriculture and Development*. **22 (1)**:22-31.
- Duivenbooden, van N., Pala, M., Studer, C., Biolders, C.L. and Beukes, D.J. 2000. Cropping systems and crop complementarity in dryland agriculture to increase soil water use efficiency: a review. *Netherland Journal of Agricultural Science* **48**, 213-236.
- Falkenmark, M. 1986. Fresh water - Time for a modified approach. *Ambio*, **15(4)**,192-200.
- Falkenmark, M. and Rockström, J. (2004). Balancing water for humans and nature: the new approach in ecohydrology. Earthscan, London, UK. pp 322.
- Government of India. 2005. Serving Farmers and Saving Farming–2006: Year of Agricultural Renewal. Third Report. December 2005. National Commission on Farmers, Ministry of Agriculture, Government of India, New Delhi, India. pp 305.
- Government of India. 2008. Common guidelines for watershed development projects. National Rain-fed Area Authority (NRAA), Ministry of Land Resources, Government of Andhra Pradesh, India. pp 57.
- Harris, H.C., Cooper, P.J.M. and Pala, M. (1991) *Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas. Proceedings of an International Workshop sponsored by MAFRA/ICARDA/CIMMYT, 1519 May 1989 Ankara, Turkey*. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria, 352 pp.
- Hilhost, T. and Muchena, F. 2000. *Nutrients on the Move: Soil Fertility Dynamics in African Farming Systems*. International Institute for Environment and Development, London, UK. pp 146.
- Hobbs, P.R. and Gupta, R.K. (2002). Rice-wheat cropping systems in the Indo-Gangetic plains: Issues of water productivity in relation to new resource conserving technologies. In: *Water Productivity in agriculture: Limits and opportunities for improvement*, (Kijne, J.W, Ed.), pp 239-253. CAB International, Wallingford, UK.
- IIASA. 2002. Climate change and agricultural vulnerability. Special report for the UN World Summit on sustainable Development, Johannesburg, 2002 pp 160. (<http://www.iiasa.ac.at/Research/LUC/JB-Report.pdf>).
- IPCC. 2001. Intergovernmental Panel on Climate Change, *Third Assessment Report*. Cambridge University Press, Cambridge, UK. www.ipcc.ch
- Irz, X. and Roe, T. 2000. Can the world feed itself? Some insights from growth theory, *Agrekon*, **39(3)**, 513-528.
- Joshi, P.K., Jha, A.K., Wani, S.P., Laxmi Joshi and Shiyani, R.L. 2005. Meta-analysis to assess impact of watershed program and people's participation. *Comprehensive Assessment Research Report 8*. Comprehensive Assessment Secretariat (IWMI), Colombo, Sri Lanka. pp.1-18.
- Kerr, J., Pangare, G. and Pangare, V. 2002. Watershed development project in India: An evaluation. Research Report no. 127. Environment and Policy Production Technology Division, International Food Policy Research Institute, Washington, DC, USA. pp 102.
- Landers, J.N., Mattana Saturnio, H., de Freitas, P.L. and Trecenti, R. (2001) Experiences with farmer clubs in dissemination of zero tillage in tropical Brazil. In: *Conservation Agriculture, a Worldwide Challenge*, (García-Torres, L., Benites, J. and Martínez-Vilela, A, Eds.), pp.71-76. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.
- Molden, D., Karen Frenken, Randolph Barker, Charlotte de Fraiture, bancy Mati, mark Svendsen, Claudia Sadoff, and Max Finlayson, C. (2007) Trends in water and agricultural development In: *Water for Food: Water for Life- A Comprehensive Assessment of Water Management in Agriculture* (Moden D, Ed.), pp. 57-89. 'International Water Management Institute (IWMI), Colombo, Srilanka.
- Oweis, T. and Taimeh, A. 1996. Evaluation of small basin water harvesting systems in the arid region of Jordan. *Water Resources Management* **10**, 21-34.
- Pathak, P., Sahrawat, K.L., Rego, T.J. and Wani, S.P. 2005. Measurable biophysical indicators for impact assessment: changes in soil quality. In: *Natural Resource Management in Agriculture: Methods for assessing Economic and Environmental Impacts*. (Shiferaw, B., Freeman, H.A. and Swinton, S.M. Eds), pp 53-74. CAB International, Wallingford, UK,

- Pathak, P., Sahrawat, K.L., Wani, S.P., Sachan, R.C. and Sudi, R. (2009). Opportunities for water harvesting and supplemental irrigation for improving rainfed agriculture in semi-arid areas. In: Rain-fed agriculture: Unlocking the Potential. (Wani, S.P., John Rockstrom and Theib Oweis Eds.). Comprehensive Assessment of Water Management in Agriculture Series, CABI Publication, In Print.
- Rockström, J. and Falkenmark, M. 2000. Semiarid crop production from a hydrological perspective: Gap between potential and actual yields. *Critical Reviews in Plant Science* **19**(4), 319-346.
- Rockström, J., Nuhu Hatibu, Theib Oweis. and Wani, S.P. (2007). Managing water in rain-fed agriculture. In: *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture* (Molden, D. Ed.), pp. 315-348. Earthscan, London, UK and International Water Management Institute (IWMI), Colombo, Srilanka.
- Rosegrant, M., Ximing, C., Cline, S., Nakagawa, N. 2002. The role of rain-fed agriculture in the future of global food production. *EPTD Discussion Paper No. 90*, Environment and Production Technology Division, IFPRI, Washington DC, USA, pp 105. (<http://www.ifpri.org/divs/eptd/dp/papers/eptdp90.pdf>)
- Ryan, J.G. and Spencer, D.C. 2001. *Challenges and Opportunities Shaping the Future of the Semi-Arid Tropics and their Implications*. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India, pp 83.
- Sahrawat, K.L., Bhattacharyya, T., Wani, S.P., Ray, S.K., Pal, D.K. and Padmaja, K.V. 2005. Long-term lowland rice and arable cropping effects on carbon and nitrogen status of some semi-arid tropical soils. *Current Science* **89**(12), 2159-2163.
- Sahrawat, K.L., Wani, S.P., Rego, T.J., Pardhasaradhi, G. and Murthy, K.V.S. 2007. Widespread deficiencies of sulphur, boron and zinc in dryland soils of the Indian semiarid tropics. In: *Current Science*, **93** (10), 1-6.
- Seckler, D. and Amarasinghe, U. (2004). Major problems in the global water-food nexus. In: *Perspectives in World Food and Agriculture 2004* (Scanes, C. and Miranowski, J. Eds), pp 227-251. Iowa State Press/World Food Prize, Ames, Iowa, USA.
- SEI (Stockholm Environment Institute). 2005. *Sustainable pathways to attain the millennium development goals - assessing the role of water, energy and sanitation*. Document prepared for the UN World Summit, Sept 14, 2005, New York, USA SEI, Stockholm, Sweden. (<http://www.sei.se/mdg.htm>).
- Singh, P., Aggarwal, P.K., Bhatia, V.S., Murthy, M.V.R., Pala, M., Oweis, T., Benli, B., Rao, K.P.C., and Wani, S.P. (2009). Yield Gap Analysis: Modelling of Achievable Yields at Farm Level. In: Rain-fed agriculture: Unlocking the Potential. (Wani, S.P., John Rockström and Theib Oweis Eds.). Comprehensive Assessment of Water Management in Agriculture Series, CABI Publication, In Print.
- Somme, G., Oweis, T., Abdulal, Q., Bruggeman, A., Ali, A. 2004. Micro-catchment water harvesting for improved vegetative cover in the Syrian badia. *On-farm Water Husbandry Research Reports Series No 3*. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria, pp 33.
- Sreedevi, T.K., Shiferaw, B. and Wani, S.P. 2004. *Adarsha Watershed, Kothapally: Understanding the Drivers of Higher Impact*. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India. pp 22.
- Sreedevi, T.K., Wani, S.P., Sudi, R., Patel, M.S., Jayesh, T., Singh, S.N. and Tushar Shah. 2006. On-site and off-site impact of watershed development: A case study of Rajasamadhiyala, Gujarat, India. *Global Theme on Agroecosystems Report No. 20*. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India, pp 48.
- Sreedevi, T.K. and Wani, S.P. (2009). Integrated farm management practices and up-scaling the impact for increased productivity of rainfed systems. In: Rain-fed agriculture: Unlocking the Potential. (Wani, S.P., John Rockstrom and Theib Oweis Eds.). Comprehensive Assessment of Water Management in Agriculture Series, CABI Publication, In Print.
- Thirtle, C., Beyers, L., Lin, L., McKenzie-Hill, V., Irz, X., Wiggins, S. and Piesse, J. 2002 The impacts of changes in agricultural productivity on the incidence of poverty in developing countries. *DFID Report No 7946*. Department for International Development (DFID), London, UK.
- Twomlow, S., Shiferaw, B., Cooper, Peter. and Keatinge, J.D.H. 2006. *Integrating Genetics and Natural Resource Management for Technology Targeting and Greater Impact of Agricultural Research in the Semi-Arid Tropics*, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India, pp 28.
- UNEP (United Nations Environment Programme). 1997. *World Atlas of Desertification, Second Edition*.
- UNStat 2005. www.unstat.com. Last accessed in 2005.
- Wani, S.P., Pathak, P., Tam, H.M., Ramakrishna, A., Singh, P. and Sreedevi, T.K. (2002) Integrated watershed management for minimizing land degradation and sustaining productivity in Asia. In: *Integrated Land Management in the Dry Areas*. (Zafar Adeel Ed.), pp 207-230. *Proceedings of a Joint UNU-CAS International Workshop, 8-13 September 2001, Beijing, China*, United Nations University, Tokyo, Japan.

- Wani, S.P., Pathak, P., Jangawad, L.S., Eswaran, H., Singh, P. 2003a. Improved management of Vertisols in the semi-arid tropics for increased productivity and soil carbon sequestration. *Soil Use and Management*, **19**, 217-222.
- Wani, S.P., Pathak, P., Sreedevi, T.K., Singh, H.P. and Singh, P. (2003b). Efficient management of rainwater for increased crop productivity and groundwater recharge in Asia. In: *Water Productivity in Agriculture: Limits and Opportunities for Improvement*. (Kijne, J.W., Barker, R. and Molden, D. Eds.), pp. 199-215. CAB International, Wallingford, UK; International Water Management Institute (IWMI), Colombo, Sri Lanka.
- Wani, S.P., Balloli, S.S., Kesava Rao, A.V.R. and Sreedevi, T.K. 2004. Combating drought through integrated watershed management for sustainable dryland agriculture. In: *Regional Workshop on Agricultural Drought Monitoring and Assessment Using Space Technology*, 4 May 2004, National Remote Sensing Agency (NRSA), Hyderabad, India, pp. 39–48.
- Wani, S.P., Meera Reddy, Sreedevi, T.K. and Damle Raju (eds). 2006a. *Corporate Science and Technology Institutions – Partnerships for Inclusive and Sustainable Development and Economic Growth: Proceedings of the CII-ICRISAT Workshop*, 27 February 2006, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India. pp 38.
- Wani, S.P., Ramakrishna, Y.S., Sreedevi, T.K., Long, T.D., Thawilkal Wangkahart, Shiferaw, B., Pathak, P. and Kesava Rao, A.V.R. 2006b. Issues, concepts, approaches and practices in integrated watershed management: Experience and lessons from Asia. In: *Integrated Management of Watersheds for Agricultural Diversification and Sustainable Livelihoods in Eastern and Central Africa; Lessons and Experiences from Semi-Arid South Asia*. Proceedings of the International Workshop held at ICRISAT, Nairobi, 6–7 December 2004. International Crops Research Institute for the Semi-Arid Tropics, (ICRISAT) Patancheru 502 324, Andhra Pradesh, India, pp. 17-36.
- Wani, S.P., Joshi, P.K., Raju, K.V., Sreedevi, T.K., Wilson, J.M., Shah Amita, Diwakar, P.G., Palanisami, K., Marimuthu, S., Jha, A.K., Ramakrishna, Y.S., Meenakshi Sundaram, S.S. and D'Souza, Marcella. 2008a. Community Watershed as a Growth Engine for Development of Dryland Areas. A Comprehensive Assessment of Watershed Programs in India. Global Theme on Agroecosystems Report no. 47, Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. pp 145.
- Wani, S.P., Joshi, P.K., Ramakrishna, Y.S., Sreedevi, T.K., Piara Singh and Pathak, P. (2008b). A new paradigm in watershed management: A must for development of rain-fed areas for inclusive growth. In: *Conservation Farming: Enhancing Productivity and Profitability of Rain-fed Areas* (Anand Swarup, Suraj Bhan and Bali, J.S Eds), pp 163-178. *Soil Conservation Society of India*, New Delhi, India.
- Wani, S.P., Sreedevi, T.K. and Marimuthu, S. 2008c. *A Comprehensive Assessment of Watershed Programmes in India*. Proceedings of the Review Meeting and Component Workshops, 23-27 July, 2007. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India. pp 332.
- Wani, S.P., Sreedevi, T.K., Rockström Johan. and Ramakrishna, Y.S. (2009). Rainfed Agriculture – Past trends and future prospects. In: *Rain-fed agriculture: Unlocking the Potential*. (Wani, S.P., John Rockström and Theib Oweis Eds.). Comprehensive Assessment of Water Management in Agriculture Series, CABI Publication, In Print.
- WHO (World Health Organization). 2000. Gender, health and poverty. *Factsheet No. 25*, (<http://www.who.int/mediacenter/factsheets/fs251/en/>).
- World Bank. 2005. *Agricultural Growth for the Poor: An Agenda for Development*. The International Bank for Reconstruction and Development. The World Bank, Washington, DC, USA. pp19.

Fast-tracking *Low-Disturbance No-Tillage* for Emerging Market Agricultures

C. John Baker¹ and Volodymyr Khorishko²

¹Centre for International No-Tillage Research and Engineering, and CEO, Baker No-Tillage Ltd, Feilding, New Zealand (*Email: baker@crossslot.com)

²Agro-Soyuz Corporation, 1 Nizhdneprovskaya vul, Yubileyniy, Dnipropetrovsk, Ukraine 52005 (Email nila@agro.dp.ua)

The pros and cons of introducing various intensities of conservation-tillage (ranging from medium-disturbance minimum-tillage to low-disturbance no-tillage with maximum residue retention) are examined for emerging market agricultural systems, together with the demands that each of these options places on effective technology-transfer. Recent experience in Ukraine illustrates that “cheapest” and “simplest” are not always the best final options but may be effective interim steps. Emerging market agricultures have an opportunity to avoid many of the mistakes made by early-adopter agricultures elsewhere. History shows that farmers the world over slowly but inevitably move towards the most advanced technological options in agriculture once their cost-benefits become proven. Since developments in emerging market agricultures often follow early adopter agricultures elsewhere, there is an opportunity to fast-track low-disturbance no-tillage systems and avoid the mistakes that early-adopters have already made en route to identifying the most cost-effective options. The pathway to true agricultural sustainability through soil reparation has the potential to occur faster in emerging market - agricultures than elsewhere. Resource-allocation should therefore reflect this potential.

The agricultural soils in almost every nation on earth have suffered from historical destructive *Intensive Tillage*. History is littered with failed civilizations caused by ignorance of the damage that *Intensive Tillage* does to precious soil resources (Montgomery, 1961). But in an era of almost universal technological awareness, almost every nation is now trying to rectify and ameliorate these historical soil problems by encouraging their famers to convert to some form of *Conservation Agriculture*.

Convincing farmers to convert from *Intensive Tillage* to *Conservation Agriculture* is an interesting study in human behaviour as well as economics and agronomics. The first problem is convincing farmers to admit that what they have been doing for centuries is wrong. Then there is the problem of convincing them to cease doing what has nonetheless worked and instead try something new. In the end, it is economics that drives both decisions. So the problem then shifts to demonstrating the cost-effectiveness of *Conservation Agriculture*. This paper centres on the cost-effectiveness of the various *Conservation Agriculture* options together with the technology-transfer mechanisms that must accompany such radical departures from the “norm”.

Comparing the Categories of Conservation Agriculture

The term *Conservation Agriculture* covers a number of optional practices. *Low Disturbance No-Tillage* identifies the most beneficial end of the scale of objectives. By definition, *Low-Disturbance-No-Tillage* involves no disturbance of the soil at all prior to seeding and the absolute minimum of soil and residues disturbance during seeding. *Low-Disturbance-No-Tillage* maximizes residue-retention and the opportunities that this creates for crop rotations, cover crops and integration of animal and plant enterprises (Derpsch and Cullinan, 2006). But it places the highest possible demands on seeding machines.

Minimum Tillage and *Strip Tillage* both accept limited levels of soil and residue disturbance and inversion in order to facilitate operation of simpler (and even conventional) seeding machines, short of resorting to full *inversion tillage* or ploughing.

Minimum Tillage is the most easily implemented *Conservation Agriculture* technique and therefore the most popular. The first step in *Minimum Tillage* is to eliminate ploughing and substitute some other form of shallower tillage instead. Tillage depth is reduced from perhaps 150 - 200 mm for *Intensive Tillage* to 75 -100 mm for *Minimum Tillage*. Similarly, *Strip Tillage* seeks to reduce the width (but not necessarily the depth) of the tilled zone to only that necessary to operate conventional seeding openers. It leaves the zones between the sown rows untilled. *Minimum Tillage* may therefore be regarded as vertical minimization of soil disturbance and *Strip Tillage* as horizontal minimization of soil disturbance. The key issue however, is that both *Minimum Tillage* and *Strip Tillage* involve some allowable tillage.

There are many practices that claim to fulfil the broad definition of *No-Tillage*. But many of these are better described as *Minimum Tillage*. Unfortunately, incorrect interpretations of the term *no-tillage* often skew statistical data on how much *No-Tillage* is being undertaken in any one country because it is more politically advantageous to be seen to be “*No-Tilling*” than “*Minimum Tilling*”. Some high-disturbance practices are often erroneously listed as *No-Tillage*. We therefore need to distinguish between *Low-Disturbance-No-Tillage* and *High-Disturbance-No-Tillage* and between *High-Disturbance-No-Tillage* and *Minimum Tillage*. Often the only difference between the latter two is that with *High-Disturbance-No-Tillage* the seeding openers create the soil and residue disturbance whereas during *Minimum Tillage* separate tillage tools disturb the soil ahead of the seeding openers. But the end result is often difficult to distinguish between the two. Very little (maximum 30%) residue-retention occurs with either.

Understanding the differences described above can have an important effect on decision-making by policy makers, machinery designers, agronomists and aid agencies, and certainly has a profound influence on the cost-effectiveness of each technique as a conservation tool aimed at making food production truly sustainable in any given region.

Ukraine as an Example

Emerging market agricultures, like Ukraine, provide interesting examples of the opportunities on offer that have yet to be taken up universally. Most of Ukraine’s excellent soils had been subjected to almost indiscriminate *Intensive Tillage* for at least 50 years. But ironically, this has provided post-independence farm owners and managers with an unusual opportunity to move towards the best of modern sustainable methodologies without the hindrance of having to take the blame for historical failures. If historical decisions were wrong, no blame could be attached to present land owners or managers. The first impediment of human behaviour (admitting to mistreating the soil in the first place) does not exist.

The second issue of human behaviour (deciding how to rectify the situation) remains common to all farmers regardless of historical blame. But again, ironically the historical timing of key political events means that some of the options for soil amelioration have only recently become available to farmers in emerging market agricultures such as Ukraine, well after most had been tried by farmers in the Americas, Australia and Western Europe. In particular, the mistakes made by early-adopters in the process of pioneering the new *Conservation Agriculture* techniques, need not be repeated by forward-thinking farmers in emerging market agricultures.

Many early adopters ignored the cumulative evidence that showed that the cost-effectiveness of various *Conservation Agriculture* techniques increases with residue retention and decreases with disturbance of the soil. Derpsch and Cullinan (2006) even claimed that residue retention was a more important conservation objective than simply ceasing to disturb the soil. And yet many machinery designers the world over have ignored this phenomenon and instead relegated residue retention to a position of lesser importance than machine-cost, ease of operation or the ability to avoid blockage by these same surface residues.

Minimum-tillage vs Low-Disturbance-No-Tillage: Mistakes by early-adopters

Creating drill and planter openers to handle residues without blockage (and avoid other undesirable side effects such as “hairpinning”) while simultaneously sowing seed and fertilizer in a favourable micro-environment, is a demanding design problem. But effective designs have existed since 1979 and were officially recognised by the US Senate as early as 1988 (anon., 1988) and ranked highly by USDA’s Revised Soil Loss Equation 2 (Baker, Unpublished data, 2008; D. Eddy, pers.com., 2008; Nowatzki *et al*, 2007). The mistake that many farmers and agencies make is to assume that significant new innovations in this field will first appear under recognised brand names. Only the most adventurous and knowledgeable farmers have identified their own *Conservation Agriculture* performance criteria and searched independently for machines that would fulfil these functions regardless of brand. Others, however, have been content to be led by major machinery companies without realising that these companies are driven by existing competing investments in tractor and tillage equipment, and therefore devote only minimal resources to innovation in *Conservation Agriculture*. In *Conservation Agriculture*, the big companies are not the leaders. The small companies are.

The practices of *Minimum Tillage*, *Strip Tillage* and *High-Disturbance-No-Tillage* are attributable to these limitations. The sad thing is that little has changed in this regard in 30 years that might force major machinery companies to take a leading role. It would be unrealistic to expect them to. Only when innovative short-line companies

hurt major companies in the market place, will the latter take notice of new developments. That is undoubtedly occurring in *Conservation Agriculture* but only at a slow pace.

Nonetheless, the sustainability value of *Low-Disturbance-No-Tillage* is becoming increasingly obvious. The Americas, Australia and Western Europe at first found that their attempts to achieve *Low-Disturbance-No-Tillage* reduced crop yields and increased the incidence of crop failure compared with *Intensive Tillage*. Most *Low-Disturbance-No-Tillage* involves disc-type openers while *Minimum Tillage* and *High-Disturbance-No-Tillage* are most commonly undertaken by shank-, hoe- or tine-type openers. And fertilizer banding is certainly easier to achieve with the latter. So a shift from disc to shank-type openers gradually occurred over the past 20 years. Despite its conservation value, residue retention was almost forgotten.

A contrasting situation arose in New Zealand. In that country, wide hoe-type openers and *Minimum Tillage* have never been popular because most crop seeding occurs in spring into sod-covered soils that are not immediately friable. *Low-Disturbance-No-Tillage* with triple disc openers and very narrow points had been the dominant *Conservation Agriculture* practice in New Zealand from the time that no-tillage was first attempted in fragile low-fertility soils in the 1950s. But until a New Zealand-invented *advanced Low-Disturbance-No-Tillage* technology appeared in the mid 1990s the success rate of *Low-Disturbance-No-Tillage* in that country had been inconsistent and the adoption rate never rose above 4% of all seeding. The advent of *advanced Low-Disturbance-No-Tillage* methods in 1995 had a profound effect on adoption in New Zealand. Annual surveys have consistently shown 95% - 99% success rates with the new technology (Baker, 2007). This factor alone triggered a growth in adoption of *Low-Disturbance-No-Tillage* by all methods to around 25% of all seeding by 2008. On average, about one fifth (50,000 hectares) of all *Low-Disturbance-No-Tillage* in New Zealand is now undertaken by the new *advanced* technology alone, which has proven to have no disadvantages. In one district it is estimated to already account for 60-75% of cereal seeding by all methods (anon. 2008).

Minimum-tillage vs No-Tillage: The Lessons for Emerging Market Agriculture

Faced with similar soil problems as early-adopter countries, but without the embarrassment of self-blame, Ukraine and other emerging market agriculture farmers have an opportunity to learn from the mistakes of the Americas, Australia and Western Europe, followed by the almost unique success of New Zealand, and become international front-runners in *Conservation Agriculture*. The key is moving directly from either *Intensive Tillage* or *Minimum Tillage* to *advanced Low-Disturbance-No-Tillage* techniques (i.e. eliminating the ineffective *High-Disturbance-No-Tillage* or *less-advanced Low-Disturbance-No-Tillage* phases).

While *Minimum Tillage*, *Strip Tillage*, and *High-Disturbance-No-Tillage* are seen as “easy” options, the limited crop yield potential from each of these “part-way” measures renders them less cost-effective than going directly to *advanced Low-Disturbance-No-Tillage* that maximize residue-retention and crop yields and minimize failures. A significant example illustrates the point.

A Ukraine farming company leased 17,000 hectares of prime soil that had been poorly managed under *Intensive Tillage* during the former collective farming era. They studied early-adopter *Conservation Agriculture* methods in North America and Western Europe and adopted a *Minimum Tillage* program that mirrored methodologies, management techniques and machinery in those countries. Their soils showed immediate improvement. But after 11 years they felt that the rate of improvement of their soils had stalled. They began looking for *advanced Low-Disturbance-No-Tillage* techniques that would lift their soil health to the next level. They found them in New Zealand. The challenge then became to adapt the New Zealand techniques and machinery to Ukraine and further, to disseminate the new-found information and technology to other emerging market agricultures nearby.

The latter challenge requires an unusual dedication to technology transfer.

The virgin Ukrainian soil that had remained free of tillage for the past 50 years, remained healthy with good crumb structure, high porosity and bio-channelling to a depth of 150mm and beyond.

But after many years of *Intensive Tillage*, the crumb structure was no longer evident, being replaced by low-porosity, compaction and cracking to the full 150 mm depth. Bio-channelling was almost non-existent.

The same soil after 11 years of *Minimum Tillage* was characterised by two distinctly different layers. The layer deeper than 75 mm (which had not been tilled during this period) had recovered much of its crumb structure, porosity and bio-channelling. But the surface layer above 75 mm (which was still being tilled under a *Minimum*

Tillage regime) showed all of the same destructive properties as full tillage. Most noticeable, was the clear demarcation line between the shallower (tilled) and deeper (untilled) layers.

Clearly, the shallower *Minimum Tillage* had left the deeper layers undisturbed and this had improved the deeper (75 – 100 mm) part of the profile, but had been incapable of progressing the soil improvement above 75mm. The decision of the farm managers to employ *advanced Low-Disturbance-No-Tillage* to “complete the job” was therefore logical and enlightened.

Cost-benefits

Knowledge of two factors is required to accurately assess true cost-benefits of any *Conservation Agriculture* system:

- (a) **Costs:** In general terms, the costs per hectare of *Minimum Tillage*, *Strip Tillage* and *High-Disturbance-No-Tillage* are usually lower than the costs of *Low-Disturbance-No-Tillage*.
- (b) **Benefits:** The benefits of *advanced Low-Disturbance-No-Tillage* are almost always higher than *Minimum Tillage*, *Strip Tillage*, *High-Disturbance-No-Tillage* and *less-advanced Low-Disturbance-No-Tillage*.

The key question is which option has the highest *cost-benefit* (i.e. benefits minus costs)?

All too often, farmers and financiers regard the capital cost of *Conservation Agriculture* machines as the only criterion on which to make cost-benefit assessments. Such simplistic assessments are flawed and fail to recognise, quantify, and weight the critical machine and system functions that determine both agronomic and mechanical excellence amongst no-tillage machines. Thirty of the most critical functions are listed in Appendix 1. Ratings (ranging from 1 at the lower end to 5 at the top end) are ascribed to each function and then weighted according to whether the function in question has an agronomic (a) or mechanical (m) influence during *No-Tillage*. Agronomically-weighted functions are listed in Appendix 2 and mechanically-weighted functions are listed in Appendix 3. Most assessments are referenced to published scientific experiments or field experience, which are summarized in the “References” section.

Comparisons are made between machines that perform *advanced Low-disturbance-No-Tillage* (using a disc-and-wing-combination no-tillage opener system) and those that perform *less-advanced Low-disturbance No-tillage* (using double disc, narrow hoe, wide hoe, sweep, angled disc, or slanted disc opener systems).

Table 1 summarizes the factors (including non-machine factors) that determine true *cost-benefits* for *advanced* and *less-advanced No-Tillage* openers and machines, regardless of whether or not these machines fall into the *Low-Disturbance-No-Tillage* or *High-Disturbance-No-Tillage* categories.

Conservation Agriculture Technology Transfer in Ukraine

The acceptance of any new agricultural technology in a naturally conservative market has always been difficult. Tradition and adherence to what already works are strong negative forces in an industry (agriculture) in which many of the risks (weather and pests, for example) are simply unpredictable. But history also shows that farmers gradually gravitate towards new technologies that demonstrate strong cost-benefits, almost regardless of the initial price.

Combine harvesters are perhaps the best historical example of an expensive machine that became the norm world wide as cost-benefits became obvious. But it took 50 years. More recently, large square balers broke through the cost-benefit barrier after languishing behind firstly small rectangular balers and then round balers. In the end, it has been the ease of handling, transport and storing of large square bales that has made the difference. This took 30 years.

What must happen now with *Conservation Agriculture* is for the rate of acceptance of the best techniques to be accelerated rather than allowed to merely “evolve” over a 30-50 year period.

Neither combine harvesters nor large square balers benefited from a deliberate and planned technology- and knowhow-transfer effort aimed at education and training. Modern communication technologies now provide resources that *Conservation Agriculture* should utilize with the objective of accelerating the adoption of *advanced Low-Disturbance No-Tillage*.

Table 1. Cost-benefit comparison of advanced and less-advanced no-tillage options

Effect, function, or factor	Advanced Low-Disturbance-No-Tillage	Less-advanced Low-Disturbance-No-Tillage & High-Disturbance-No-Tillage
Capital cost of drill or planter plus tractor(s) and sprayer	Higher than <i>less-advanced No-Tillage</i> options, but about equal to the total package of machines and tractors required for <i>Intensive Tillage</i> .	Relatively low. Significantly less than the total package of machines and tractors required for both <i>Intensive Tillage</i> and <i>advanced Low-Disturbance No-Tillage</i> .
Running costs (fuel, labour & maintenance)	Considerably less than <i>Intensive Tillage</i> . Similar to <i>less-advanced No-Tillage</i> .	Considerably less than <i>Intensive Tillage</i> . Similar to <i>advanced Low-Disturbance-No-Tillage</i> .
Typical service life of machines	10-20 years.	3-5 years.
Annual depreciat'n	5-10% per year over 10-20 years.	20-33% per year over 3-5 years.
Inflation protection	The amount of capital initially invested is inflation-proofed for up to 20 years.	After each short service life, each replacement machine will cost progressively more.
Agronomic performance rating (see appendices 1 & 2 for details)	92/100 rating for the best of the <i>advanced Minimum-Disturbance-No-Tillage</i> machine types (see appendices 1 & 2 for details)	Range of 39-58/100 rating for 6 different <i>less-advanced No-Tillage</i> machine types (see appendices 1 & 2 for details)
Mechanical performance rating (see appendices 1 & 3 for details)	89/100 rating for the best of the <i>advanced Minimum-Disturbance-No-Tillage</i> machine types (see appendices 1 & 3 for details)	Range of 47 - 60/100 rating for 6 different <i>less-advanced No-Tillage</i> machine types (see appendices 1 & 3 for details)
Difference in wheat yield required to make the net returns/hectare equal for both <i>No-Tillage</i> options	<i>Advanced No-Tillage</i> would need to produce an additional 2.89% yield to have the same net cost as <i>less-advanced No-Tillage</i> (See appendix 5a for details). But it would need to actually <u>lose</u> 3.43% yield to have the same net cost as <i>Minimum Tillage</i> (See appendix 4b for details).	0% (base-line for comparison in Appendix 4a)
Typical field and test-plot crop yield comparisons	Frequently exceeds <i>Intensive Tillage</i> , <i>Minimum Tillage</i> , <i>Strip Tillage</i> and <i>less-advanced No-Tillage</i> (by 10-45%). Highest wheat plot yield so far recorded is 16.8 tonnes/hectare or 256 bushels/acre.	At best, maintains the same yields as <i>Intensive Tillage</i> , <i>Minimum Tillage</i> or <i>Strip Tillage</i> . At worst, yields are frequently inferior to <i>advanced No-Tillage</i> , <i>Intensive Tillage</i> , <i>Minimum Tillage</i> and <i>Strip Tillage</i> .
Crop failure rate	1-5% failure rate recorded from regular survey data. The failure rate of <i>Intensive Tillage</i> is probably much higher than this.	High failure rates have given <i>No-Tillage</i> using <i>less-advanced technologies</i> a "hit and miss" reputation amongst farmers.
COST-BENEFIT	<u>Cost-benefit is typically very positive even although the capital cost is higher than less-advanced No-Tillage options. The benefits arise from lower depreciation costs and higher performance ratings (both agronomic and mechanical). The latter are approximately twice those of less-advance options and manifest themselves in less crop failures and higher yields.</u>	<u>Even a 3-fold reduction in capital cost is not sufficient to offset the high depreciation rate together with the relatively high crop failure rates, inferior crop yields and lower performance ratings (both agronomic and mechanical). Cost-benefits are therefore almost invariably lower than advanced No-Tillage options and often also Intensive Tillage.</u>

No amount of technology-transfer resourcing will create acceptance of technologies that demonstrate poor cost-benefits. ICI and Monsanto found this out to their cost when both companies promoted low-cost low-performance no-tillage in the 1960s and 1970s. But as knowledge about the causes of early *No-Tillage* failures has grown and cost-benefits can now be measured in terms of repeatable crop yields and gross margins alongside unprecedented awareness about environmental responsibility, the stage is set for a focused and successful technology-transfer program.

The Agro-Soyuz Corporation of Dnipropetrovsk, Ukraine has evolved a comprehensive agri-technology-transfer system that expands on a successful model first developed by Jim Kinsella and the BASF agricultural chemical company in Lexington, Illinois, USA. Both systems contrast with how many large equipment companies have approached the issue of technology education.

The main difference is the willingness of those marketing a new system to “practice what they preached” on an economic farm scale so as to demonstrate how *Conservation Agriculture* can work sustainably and economically.

The Agro-Soyuz facility has the following (almost unique) features:

- A comprehensive farming facility of 17,000 hectares that demonstrates both arable and integrated animal enterprises. A portion of the grain grown on the farms is sold directly into the international market and the balance has value-added through “in-house” animal enterprises as diverse as ostriches, emus and rabbits as well as modern large dairy enterprises.
- An impressive central conferencing facility is located on the farm. This helps focus participants on the intended theme and is also an effective promotional tool.
- A sub-facility stands alongside for intensive training of smaller selected groups such as farm managers and sale persons.
- Currently, the facility has an annual throughput of some 7,000 delegates.
- Tasteful acknowledgement of the nationalities of visiting participants is provided in the form of United-Nations-style arrays of national flags.
- The facility is complemented by a comprehensive in-house library of international *Conservation Agriculture* literature.
- Access is provided to the corporation’s own extensive farming operations alongside, which are used to demonstrate both new methodologies and “best-practices”, often in deliberate comparison with other less-effective options.
- Large portable shelters can be erected at short notice on selected fields to allow viewing of test plots as well as limited machinery operations during inclement weather.
- A wide selection of distinguished international speakers is used.
- Government sponsorship by way of payments for courses and conferences on selected topics of importance.
- There is an obvious commitment to what the corporation is doing and trying on its own farms.
- Progressive conferencing is practiced where new enterprises are developed and evolved on a year-by-year basis under public scrutiny.
- Machinery operation and management training programs are part of the new techniques and methodologies.

The resource focuses the corporation on educating farmers and consultants in new technologies and advances in farm management. It is privately operated and provides a perfect spring board for the introduction of new advanced technologies and systems such as *advanced Low-Disturbance No-Tillage*.

Conclusion

Decision-makers and aid agencies should focus on assisting farmers in emerging market agricultures to make the jump directly from either *Intensive Tillage* or *Minimum Tillage* directly to *advanced Low-Disturbance-No-Tillage* rather than waste time and money on the intermediate steps of either *High-Disturbance-No-Tillage* or *less-advanced Low-Disturbance No-Tillage*. History shows that in common with other new farming technologies and systems, farmers will eventually gravitate towards the most cost-effective options anyway, almost regardless of capital cost. It is therefore difficult to justify wasting time and money on interim measures that early-adopter-agricultures have already shown will never achieve all of the desirable objectives required to make world food production truly sustainable?

References

- Anonymous (1988) *Conservation Tillage Technology Research: Implications for a Sustainable Agriculture*. Hearing before the Subcommittee on Agricultural Research and General Legislation of the Committee on Agriculture, Nutrition, and Forestry, United States Senate, 101st Congress, March 15, 1989, pp 48-70.
- Anonymous (2008). *No-tillage proves a powerful tool*. Straight Furrow (New Zealand), November 18, 2008, pg 20.
- Baker, C.J.; Saxton, K.E.; Ritchie, W.R.; Chamen, W.C.T.; Reicosky, D.C.; Ribeiro, M.F.S.; Justice, S.E. and Hobbs, P.R. (2006). *No-Tillage Seeding in Conservation Agriculture* (Eds. Baker, C.J. & Saxton, K.E.). Published by Food and Agriculture of the United Nations, Rome Italy and CABI, Oxford, United Kingdom. 326 pages.
- ISBN numbers: ISBN-10:84593-116-5 (CABI); ISBN-13:978-1-84593-116-2 (CABI); ISBN -92-5-105389-8 (FAO)
- Baker, C. J. (2007) Are we there yet? Proceedings National No-Tillage Conference, Des Moines, Iowa, USA, pp 31-37.
- Derpsch, R.; Cullinan, A. (2006). Keep soil covered for longer life. Farming Ahead (Australia), # 172, pp 37-39.
- Nowatzki, J.; Ashley, R. and Hofman, V. (2007). *Conservation Tillage Seeding Equipment*. North Dakota State University (USA) Extension Service Bulletin # AE=1351

Comparison of *no-tillage* openers and machines: Rationale, explanations and references

This document supports the numerical comparisons of the vital functions that no-tillage openers and machines must perform in order to provide as near fail-safe seeding as possible during the practice of Low-Disturbance No-Tillage. In most cases, robust scientific data exist in support of the assessments made. In other cases field experience supports the assessments. The references are to passages in the English and Russian language versions of “*No-Tillage Seeding in Conservation Agriculture*” (Baker *et al*, 2006). Details of specific sources are given below:

Function Number	English translation (page numbers)	Russian translation (page numbers)
1	134-158	160-187
2	86-89, 94, 98, 105, 159-167	105-109, 116, 119, 128, 188-198
3	60-73	77-91
4	159-167	188-198
5	159-167, 99-106	188-198, 121-141
6	99-106	121-141
7	99-117	121-141
8	106-117	129-141
9	111, 190-195	133
10	no reference	no-reference
11	60-73, 74-84, 85-98	77-91, 92-103, 104-120
12	74-84	92-103
13	85-98	104-120
14	85-89	104-120
15	60-73	77-91
16	60-73	77-91
17	34-59	48-76
18	118-133	142-160
19	118-133, 53-56	142-160,
20	126	151
21	131-133	157-159
22	71-72	90-91
23	no reference	no reference
24	field experience	field experience
25	field experience	field experience
26	field experience	field experience
27	190-203	223- 239
28	190-203	223-239
29	11-20	21-32
30	189-194	222-229

Appendix 1

**List of functions that influence either agronomic or mechanical performance of *no-tillage* drills, planters or openers
(Parentheses indicate whether each dominant effect is agronomic (a) or mechanical (m))**

Function Number	Function
1	Mechanically handles heavy residues without blockage (m)
2	Avoids lodging seeds in residue hairpins (either creates no hairpins or avoids lodging seeds in them) (a)
3	Retains residues as extensive soil cover after passage of the openers (conservation objectives) (a)
4	Maintains most important functions at high speed (above 10m km/hr) (m)
5	Ability of individual openers to faithfully follow ground surface variations (a)
6	Ability of openers to seed accurately at a shallow depths (e.g. small seeds at 15 mm or less) (a)
7	Range of vertical travel of individual openers (a)
8	Ability to maintain consistent downforce regardless of the vertical position of opener (a)
9	Ability to automatically adjust opener downforce to match changing soil hardness (a)
10	Ability to sow seeds spread across a ribbon in each row (i.e. not in a narrow row) (a)
11	Creates a favourable slot microenvironment in a wide range of conditions (including sub-optimal) (a)
12	Retains vapour moisture in the slot in dry soils (which affects germination and emergence) (a)
13	Creates favourable in-slot aeration in wet soils (which affects germination and emergence) (a)
14	Avoids in-slot soil compaction or smearing that can crust as it dries (a)
15	Self-closes the slot (2)
16	Facilitates slot closure by other components operating after passage of the openers (m)
17	Maximizes soil-seed contact even in difficult (e.g. "plastic") soil conditions (a)
18	Bands any form of fertilizer (dry, liquid or gas) simultaneously with, but separated from the seed (a)
19	Applies high rates of banded fertilizer without risk of "seed burn" (a)
20	Can band gas or liquid fertilizer simultaneously with dry fertilizer (m)
21	Applies total fertilizer in one pass (excluding crops that also require post-emergence fertilizing, e.g. corn or winter wheat) (a)
22	Minimal adjustment(s) required when going from one soil or residue condition to another (m)
23	Opener components are self-adjusting as they wear (m)
24	Ability to function in stony soils (m)
25	Avoids bringing stones up onto the ground surface (m)
26	Opener functions are unaffected by hillsides (m)
27	Service life is greater than 5 years or 5,000 hours (m)
28	Low-cost/long-life soil wearing components (m)
29	Likely influence on crop yield (a)
30	Is easy to pull through the ground (m)

Source: Baker *et al* (2006)

Weighted agronomic ratings of a range of *no-tillage* openers and machines
Range: 1 to 10 (1=lowest, 10 = highest)

Function Number	Double Disc	Narrow Hoe	Wide Hoe	Sweep	Single disc	Slanted Disc	Disc &wing combo.
1	4	2	1	1	4	4	5
2	2	10	2	10	4	4	10
3	10	6	2	4	8	10	10
4	4	3	1	2	3	3	5
5	4	4	2	4	8	4	10
6	4	4	2	2	4	2	10
7	4	4	2	2	4	2	10
8	4	6	2	2	6	6	10
9	2	2	2	2	2	2	10
10	2	2	2	6	6	8	2
11	2	8	4	4	6	1	10
12	2	6	4	6	4	8	10
13	2	6	8	6	6	6	10
14	2	2	2	6	10	10	10
15	4	4	2	6	6	8	10
16	1	4	3	4	4	5	5
17	6	8	6	8	6	8	10
18	2	8	4	6	2	6	10
19	2	8	8	8	2	8	8
20	1	1	5	5	1	1	5
21	2	6	10	10	2	2	10
22	4	3	3	3	1	1	5
23	1	4	2	2	1	1	4
24	3	4	3	1	3	2	4
25	5	1	1	1	5	5	5
26	4	4	3	2	1	3	5
27	2	3	3	3	2	2	5
28	2	5	4	4	3	2	2
29	2	8	6	6	6	8	10
30	4	3	2	1	4	3	1
POSSIBLE	240	240	240	240	240	240	240
TOTAL	93	139	101	127	124	135	221
% POSSIBLE	39%	58%	42%	53%	52%	56%	92%

Weighted mechanical ratings of a range of *no-tillage* openers and machines
Range: 1 to 10 (1=lowest, 10 = highest)

Function Number	Double Disc	Narrow hoe	WideHoe	Sweep	Single disc	Slanted Disc	Disc &wing combo.
1	8	4	2	2	8	8	10
2	1	5	5	5	2	2	5
3	5	3	1	2	4	5	5
4	8	6	2	4	6	6	10
5	2	2	1	2	4	2	5
6	2	2	1	1	2	1	5
7	2	2	1	1	2	1	5
8	2	3	1	1	3	3	5
9	1	1	1	1	1	1	5
10	1	1	2	5	1	1	1
11	1	4	2	3	3	4	5
12	1	3	2	3	2	4	5
13	1	3	4	3	3	3	5
14	1	1	1	3	5	5	5
15	2	2	1	3	3	4	5
16	2	8	6	8	8	10	10
17	3	4	3	4	3	4	5
18	1	4	2	3	1	3	5
19	1	4	4	4	1	4	4
20	2	2	10	10	2	2	10
21	1	3	5	5	1	1	5
22	8	6	6	6	2	2	10
23	2	8	4	4	2	2	8
24	6	8	6	2	6	4	10
25	10	2	2	2	10	10	10
26	8	8	6	4	2	6	10
27	4	6	6	6	4	4	10
28	4	10	8	8	6	4	4
29	1	4	3	3	3	4	5
30	8	6	4	2	8	6	2
POSSIBLE	210	210	210	210	210	210	210
TOTAL	99	125	102	110	108	116	187
% POSSIBLE	47%	60%	49%	52%	51%	55%	89%

Function: 30 desirable functions or design factors of *no-tillage* openers/machines are identified.

Opener types: All openers and machines are identified generically by type rather than brand name. Several different brand names might exist for any one opener/machine type, but only one brand name existed at the time of writing for the "disc and wing combo" opener/machine.

Ranking: The ability or otherwise of each opener/machine type to fulfil each function was initially ranked (1 – 5). 1 = poor or weak ability to fulfil the function. 5 = excellent ability to fulfil the function. Then, the individual rankings were weighted according to whether the function was likely to affect the agronomic performance (a) or the mechanical performance (m) of the opener or machine. If the effect was likely to be *mainly* agronomic, those factors were multiplied by 2 and the remaining factors multiplied by 1. Conversely if the effect was likely to be *mainly* mechanical, those factors were multiplied by 2 and the others by 1.

Two separate tables were created, one weighted towards agronomic factors and the other weighted towards mechanical factors. Interestingly, both tables gave similar results indicating that designers who had recognised good agronomic functions had also ensured that the excellence of the engineering matched the excellence of the agronomy.

In some cases (e.g. Function number 18, *banding of fertilizer*) this was regarded as an agronomic function because it affects crop yield. So too, is number 19, *applying high rates of fertilizer without risk of fertilizer "burn"*. But whether or not such fertilizers can be *applied in dry, gaseous or liquid form* (number 20) was considered to be a mechanical function as it affects mainly the form in which the fertilizer can be applied (and perhaps the economics of which form to choose). But the chosen form of fertilizer is likely to have less effect on the response of the plants than in the position in which the fertilizer is banded.

Possible scores: The theoretically maximum possible score that a "perfect" opener/machine could total in the agronomic listing was 240. The theoretical maximum score for mechanical factors was 210.

% Possible score: This is the actual total score for each opener or machine expressed as a percentage of the maximum theoretically-possible score. It is an indication of how closely that particular opener or machine comes to being theoretically "perfect" for *no-tillage*, given our present level of knowledge.

Comparison of the costs of sowing wheat using *advanced low-disturbance-no-tillage* (See column labelled “Cross Slot” on line 7) versus *less-advanced no-tillage* (See column labelled “Brand X” on line 7)

Farm Application					
	Area covered	ha / yr		500	
	Crop value	\$/tonne		\$200.00	
	Average yield	tonnes/ha		8	
Purchase & Operational Costs				Machine	
				Cross Slot	Brand X
				Comparison	
	New cost of machines ¹	\$		\$300,000.00	\$100,000.00
	Drill / planter width	meters (m)		9	9
	Seeding speed ^{2,3}	km/hr		10	10
	5-yr depreciated value ⁴	% new cost		60	10
	Annual interest	%		8	8
	Repairs ⁵	% price/1000 hr use		5	5
	Supplemental operations ⁶	\$/ ha		30	30
	Estimated Yield Advantage ⁷	% of avg. yield		0	0
	Labour and Fuel	\$/ hour use		30	30
Ownership & Operational Costs				Difference	
	Annual usage	hours / yr		56	0
	Labour and Fuel	\$/ ha		\$3.33	\$0.00
	Av. 5-yr depreciation	\$/ ha		\$48.00	\$12.00
	Interest	\$/ ha		\$48.00	\$32.00
	Repairs	\$/ ha		\$1.67	\$1.11
	Supplemental Operations	\$/ ha		\$30.00	\$0.00
	Estimated Yield Advantage	\$/ ha		\$0.00	\$0.00
	Total cost	\$/ ha		\$131.00	\$45.11
Machine Comparison					
	Cost Difference ⁸		\$/ ha		\$45.11
	Yield advantage required from Cross Slot (tonne / ha)				0.23
	Yield advantage required from Cross Slot (% average yield)				2.82

Appendix 4b

Comparison of the costs of sowing wheat using *advanced low-disturbance no-tillage* (See column labelled "Cross Slot" on line 7) versus *minimum tillage* (See column labelled "Brand X" on line 7)

Farm Application					
	Area covered	ha / yr	500		
	Crop value	\$/tonne	\$200.00		
	Average yield	tonnes/ha	8		
Purchase & Operational Costs				Machine	
				Cross Slot	Brand X
				Comparison	
	New cost of machines ¹	\$	\$300,000.00		\$100,000.00
	Drill / planter width	meters (m)	9		9
	Seeding speed ^{2,3}	km/hr	10		10
	5-yr depreciated value ⁴	% new cost	60		10
	Annual interest	%	8		8
	Repairs ⁵	% price/1000 hr use	5		5
	Supplemental operations ⁶	\$/ ha	30		130
	Estimated Yield Advantage ⁷	% of avg. yield	0		0
	Labour and Fuel	\$/ hour use	30		30
Ownership & Operational Costs				Difference	
	Annual usage	hours / yr	56	0	56
	Labour and Fuel	\$/ ha	\$3.33	\$0.00	\$3.33
	Av. 5-yr depreciation	\$/ ha	\$48.00	\$12.00	\$36.00
	Interest	\$/ ha	\$48.00	\$32.00	\$16.00
	Repairs	\$/ ha	\$1.67	\$1.11	\$0.56
	Supplemental Operations	\$/ ha	\$30.00	-\$100.00	\$130.00
	Estimated Yield Advantage	\$/ ha	\$0.00	\$0.00	\$0.00
	Total cost	\$/ ha	\$131.00	\$54.89	\$185.89
Machine Comparison					
	Cost Difference ⁸		\$/ ha		-\$54.89
	Yield advantage required from Cross Slot (tonne / ha)				-0.27
	Yield advantage required from Cross Slot (% average yield)				-3.43

Session 2.3: Capacity Building

Capacity Building: Harnessing Off-farm Employment Avenues in Harmony with On-farm Resources

J.C. Katyal

CCSHAU, Hisar, 125 004, Haryana, India

Wide scale unemployment and disguised unemployment in agriculture sector challenge the goal of global food, nutritional and environmental security. Developing countries of the world are hub of this social scourge. Unemployment is precipitator of poverty and root of social unrest and growing disruptive activities. It is here where majority of the population lives in rural areas and depends on agriculture for livelihood. Agriculture by far remains the largest employer of available workforce in the world.

In the Asia-Pacific region, most of the 250 million farm households are small land holders or are near landless. In India alone, number of small and near landless farmers (land holding < 2 hectares) is 83.5 million (or 88% of the total land holders). Of the total workforce of 402 million in India, 58 % (32% cultivators and 26% landless labourers) is directly or indirectly dependent on agriculture for its livelihoods. This figure for the world is 42% and for the US less than 3%. India's 58% agriculture dependent workforce contributes less than 20% to the gross domestic product, which indicates glaring under-productivity of this otherwise valuable human resource. For instance, because of seasonal nature there is no full-time work in agriculture. Generally, farm workers are employed for 100 to 150 days a year. They have no work for nearly 200 days. Since both men and women contribute to farm work, the latter suffer maximum when there is no paid job to do.

Without any gainful employment majority of the people in rural areas suffer from unaccepted levels of deprivation in terms of human well-being; women are hit the hardest. This happens since women own no or very little assets (primarily land) on which they can fall back for decent livelihoods. Then this group of people have limited access to enabling conditions like education and training. They are more likely to be illiterate or not possessing adequate levels of education required for development of skills. State of education is far inferior among women to men. Consequently, possibility of absorption of illiterate workers in economic sectors other than agriculture becomes increasingly difficult (GOI, 1990, Visaria and Minhas, 1991, and Acharya, 1993). This situation is not unique to India alone, but repeats in other developing nations too.

Due to perpetual and growing dominance of small land holders and landless workers, there are limits to create employment for every working member of a rural household by improving on-farm productivity alone. There is need to simultaneously expand scope of off-farm activities that demand more labour but less land. The information generated far points out that education and training are expected to encourage more mobility, expand opportunities for livelihood diversification into off-farm vocations by decreasing dependence on agriculture. This paper dwells on the role of human competence and capacity building through education and training to enhance scope and possibilities of off-farm self-employment. While doing that it integrates the crucial role of other inputs, institutional mechanisms, policy and physical infrastructure for self-employment. The paper identifies that it is the lack of knowledge and skills about an appropriate technology, resources and enabling infrastructure that have been and continue to be the major impediments to adoption of modern and conservation agriculture (CA) practices and livelihood security. In India, only 40% farmers have access to scientific methods of farming. This report tilts heavily in favour of Indian experience.

Human Resource Development for Converting Input (resource) Intensive Agriculture into Input (resource) Efficient Agriculture

Mushtaq Ahmad Gill and Naveed A Awan

South Asian Conservation Agriculture Network (SACAN), Lahore, Pakistan

Excessive water availability over the years has made farmers of South Asia to adopt production technologies having poor to moderate water productivity of rice-wheat systems. Policies with the advent of Green Revolution in the subcontinent facilitated the adoption of short duration high yielding varieties exceedingly responsive to higher input use that promoted input intensive agriculture. Alongwith this, a vast area of barren uncultivated land was brought under cultivation through intensification of resources and diversification in cropping patterns. Presently, unchecked population growth, shrinking water and non water resources, prevailing poverty situations and environmental threats due to indiscriminate use of water and non water inputs (resources) are making it hard to address the challenges of increasing production even by intensification of input uses. It is, therefore, highly imperative to bring another green revolution with ensuring arresting and/or reversing degradation of resources caused by input (resource) intensive agriculture in the past. Networks like European Conservation Agriculture Federation (ECAAF), African Conservation Tillage (ACT), and Professional Alliance for Conservation Agriculture (PACA), and others are playing pivotal role for promotion of input efficient agriculture through knowledge development, information exchange, research coordination and extension education. Need for establishment of similar network in south Asia was also felt for effective promulgation of Resources Conservation Technologies in the region. Accordingly, South Asian Conservation Agriculture Network (SACAN) was established with the major objective of promoting efficient use of inputs (resources) in south Asian region on the pattern of other networks working for the same cause in rest of the world. It was also observed that Human Resource Development is a most critical issue in wide scale adoption of efficient input use techniques for which SACAN followed Resource Conservation Technology Transfer Model (ICTRIM) as an approach involving a process of capacity building of stakeholder in adoption of Resource efficient technological package *inter-alia* includes bed planting of wheat and rice, zero tillage, crop residue management, N-management in rice through Leaf Colour Chart (LCC) etc. This approach adopted by SACAN by following RCTTM proved very successful in achieving the fruitful results. It was, resultantly, learnt that human resource development through capacity building of stakeholders can work as catalyst in successful and sustainable adoption of the input efficient agriculture introduced to farmers for enhancing agricultural productivity and improving livelihood in rural areas. Human Resource Development and intensified capacity building are, therefore, factors of prime importance that may enhance adoption and ensures sustainability of input (resource) efficient agriculture and RCTTM developed by SACAN may provides an effective pathway to other local, regional and international networks as well.

Keywords: Human Resource development, resource efficient, SACAN, RCTTM, capacity building, productivity enhancement, livelihood improvements

Session 2.4: Enabling Policies

Policies and Institutions to Promote the Development and Commercial Manufacture of Conservation Agriculture Equipment

Brian G Sims^{1*}, Peter Hobbs² and Raj Gupta³

¹Engineering for Development, Bedford UK

²Department of Crop and Soil Sciences, Cornell University, Ithaca, NY 14850

³CIMMYT, Kathmandu, Nepal

(*Email : BrianGSims@aol.com)

CA is practised on about 100m ha worldwide. It is now a farmer-proven technology resulting in energy savings and dramatic reductions in soil erosion. CA is complementary to other resource conserving technologies (e.g. raised beds, agroforestry and terracing) which together confer greater eco-system resilience to production systems. CA equipment (principally for planting and weed control) can be tractor, animal or human powered. Illustrations of CA equipment supply situations in South America, Africa and Asia are given; the range of equipment available is described as is the range of stakeholders in the CA equipment input supply chain. National and international policy-maker level issues to facilitate the local manufacture and provision of appropriate CA equipment are emphasised. These include: formulation of mechanization strategies; improvement of rural infrastructure; facilitation of finance options; tax relief and subsidies; batch purchase; facilitation of testing and R&D services; technical and business management training; provision of quality extension services; land tenure reform; revision of obsolete policies; inclusion of CA in academic curricula, etc. Policies and strategies for other stakeholders (manufacturers, importers, retailers, hire and repair service providers and farmers) are also discussed. The main conclusions indicate the need for policy action at government level to promote CA for environmental protection, improve the quality and supply of CA equipment and encourage farmer adoption of CA.

Key words: Energy saving, resource conserving technologies, specialist CA equipment, equipment supply chains and stakeholders, constraints to adoption, policy and strategy implications for policy makers and other stakeholders

Setting the Scene

Conservation agriculture (CA) and one of its principal components no-till (NT) is taking off around the world. No longer is it a novel idea to protect the soil surface with vegetation and to sow seeds directly through the mulch. It is notoriously difficult to obtain precise statistics on a worldwide scale (Derpsch, 2008a&b) but it is estimated that there are about 100m ha of NT at the moment (Table 1). And this figure is steadily growing.

In terms of global distribution, Figure 1 shows the relative importance of different regions of the world.

As Huggins and Reganold (2008) point out, although no-till is feasible in practically all agricultural situations, the high cost of equipment and herbicides often diminishes the attractiveness of adoption¹. Of the more than half a billion farms in the world, 85% are less than 2ha. In this sector, with poverty stalking the farm families, a radical change of system is even more difficult to contemplate.

Giller *et al.* (2008) review small farmer constraints to adopting CA from an African perspective. These include: the fear of decreased yields in the initial years; increased labour requirements when herbicides are not available²; a gender shift of the work burden towards women; and lack of mulch due to low productivity and pressing needs for feeding crop residues to livestock.

CA is a Proven Technology

Tilled soils, exposed to the damaging impacts of water and wind, are in their most erodible state. Soil erosion results in astronomical costs to national economies. Losses in the US, for example are estimated to cost US\$30-44 billion annually (Morgan, 2005). Increasingly intensive use of land as the World population inexorably climbs from 6.5 billion to more than 9 billion will mean that erosion rates will continue to increase unless more sustainable

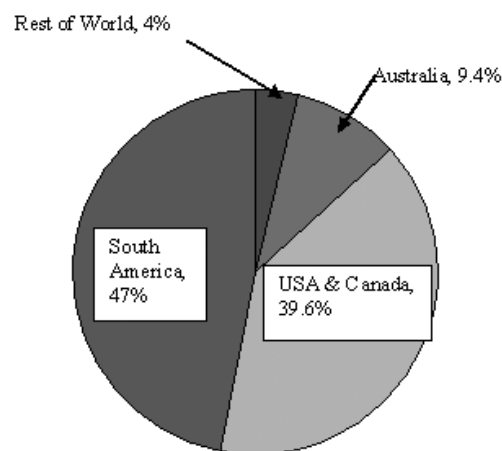
¹Although, no-till is possible without costly equipment and without herbicides. In India, a no-till drill costs about US\$500 and less herbicide is needed than with conventional wheat. Some African basin systems don't need costly equipment.

²In South Asian rice-wheat systems, weeds are actually less in NT till wheat, so herbicide use is no more than in traditional systems and over time with NT and herbicides, weeds become less of a problem.

Table 1. Estimated areas of no-till agriculture in the world

Country or region	Area of no-till (million ha)
USA	25.3
Brazil	23.6
Argentina	18.3
Canada	12.5
Australia	9.0
Indus and Ganges basins	1.9
Paraguay	1.7
Bolivia	0.5
South Africa	0.3
Venezuela	0.3
Spain	0.3
Uruguay	0.3
France	0.2
Chile	0.1
Colombia	0.1
China	0.1
Others	1.0
TOTAL	95.5

After Huggins and Reganold, 2008

**Figure 1.** No-till adoption in different World regions

Source: After Derpsch, 2008b

production methods are employed. Furthermore, soil erosion releases vast amounts of CO₂ into the atmosphere, contributing to the greenhouse effect and global warming. Lal (1995) estimates that soil erosion releases 1.14×10^9 tonnes of C annually in this way.

Given this situation of increasing costs and falling yields, it is not surprising that CA systems have evolved in parallel with advances in technology (especially in herbicide and machinery development). Today CA is no longer a novelty, but rather it is a farmer-proven technology. Traditional soil tillage (usually plough-based) has been seen to degrade soils and result in loss of crop productivity³. CA adoption was a direct response to soil degradation and the increasing number of CA adopting farmers is testimony that it is an economically viable system for achieving agricultural sustainability (Hobbs *et al.*, 2008).

CA, with its minimal soil disturbance and maintenance of permanent soil cover, tends to mimic natural systems, particularly that of the rainforest. In the rainforest, nutrients are recycled via leaf fall and decomposition which requires a rich soil biota. Removal of this cover, and destruction of the natural channels for water infiltration and gaseous exchange, means that natural sustainable systems need to be replaced by expensive and damaging tillage. Permanent soil cover also provides other important benefits to the soil (the control of soil temperature and moisture content are two of them) but above all, cover protects the soil from the degrading effects of wind and water erosion. Erosion can be brought down from annual rates greater than $50t\ ha^{-1}$ under traditional tillage to natural rates in the region of $0.005t\ ha^{-1}$ per year (Morgan, 2005).

Energy Savings in CA

Modern agriculture has prospered but at the cost of becoming dependent on cheap fossil fuels. Fossil fuels are used to power mechanized traction for tillage, cultivation, spraying and harvest, but also for pumping irrigation water, powering dryers and transport of agricultural products and inputs. Fossil fuel energy is also used for powering the Haber-Bosch conversion of nitrogen into urea, a major source of nitrogen fertilizer, the most important nutrient limiting crop yield. The World is very close to "peak oil" (the maximum rate of global fossil fuel extraction) and may have already passed it. Once "peak oil" is reached, available oil declines and the days of cheap fossil fuel will be gone as extraction will fall short of demand. At the same time extraction costs increase as the process becomes more difficult and prices rise both for oil and also the agricultural production that uses it. The rapid spike in fossil fuel

³Having said that, farmers also recognize that soil tillage will release available soil nutrients and so enhance yields in the short term. However as a strategy this leads to tilled soils requiring more tillage to slow the decline in yields due to long-term falling soil fertility.

prices in the past year is an example of this impact and partly explains the increase in food prices. This will happen well into the future and will require agriculture to use this natural resource more efficiently and ultimately to identify alternative energy sources.

No-tillage is an appropriate technology to achieve more efficient energy use in agriculture. In NT, crops are planted in just one pass of the tractor, animal powered seeder/planter or person equipped with a jab-planter. Data from South Asia, where wheat follows a transplanted rice crop, show that farmers save up to \$US55 ha⁻¹ in diesel costs or 50-60 litres ha⁻¹ less diesel for land preparation (Hobbs and Gupta, 2003). This is an extreme case because of the difficulty, in traditional tillage systems, of obtaining a fine seedbed on soils that has been puddled for rice (ploughed when saturated). It requires multiple passes of the local 9-tined cultivator or disc harrow to get a fine tilth. Adoption of NT technology gives significant savings in energy for farmers and in 2006 it is estimated that 4.0 of the 13.5 million hectares of rice-wheat in the Indo-Gangetic Plains of South Asia used NT wheat (RWC website⁴). There were also savings in water pumping (much of the wheat acreage is irrigated) since water flows more rapidly across no-tilled fields compared to ploughed fields. Fertilizer efficiency also increased because the nitrogen and phosphorus inputs were drilled with the NT equipment rather than broadcast as in conventionally tilled wheat plots. The hundred million hectares of NT reported for the World (Derpsch, 2008 a & b) means large fossil fuel savings and reductions in greenhouse gas emissions. Yields have also not been sacrificed by adopting no-tillage and in fact they have been sustained and increased over time by this technology as a result of improved soil structure and health (Hobbs, 2007). In the RW systems of South Asia, yields are higher than conventionally tilled plots (100-200kg ha⁻¹ more).

Complementarity with other Resource Conserving Technologies (RCTs)

Resource-conserving technologies (RCTs) include a wide range of practices: NT and minimum tillage lead to dramatic reductions in tillage operations, and hence costs, a crucial incentive for resource-poor, undercapitalized farmers to adopt them. Other technologies include surface seeding, raised-bed planting, skip furrow irrigation in row planted cropping systems, laser or other land leveling, intercropping, water harvesting and supplemental irrigation, organic farming, mulching and residue management, live fences and vegetative barriers, agroforestry and horticulture, integrated nutrient management, integrated pest management, integrated tree-crop-livestock farming systems, contour farming, and terracing. RCTs have been shown to increase production and improve soil health, make ecosystems more resilient and reduce their vulnerability to climate change. They are often seen as the center-piece of sustainable land management but need vital economic, institutional and policy options to promote their adoption. RCTs help produce more crop at less cost (saving labour, fuel, energy, water, and other inputs) and minimizing environmental impacts. They also provide a platform for diversification and intensification of production systems.

The Need for Specialist Equipment

CA practices are based on the need to keep the soil is permanently covered and for crops to be sown through this cover with minimal soil disturbance. Although this can be achieved by hand (see Figure 2) no-till machinery has been (and is being) developed and is today widely available.

Traditional implements for tillage, such as mouldboard and disc ploughs, cultivators and harrows, are not needed for CA. Equipment for CA⁵ can be manual, animal or tractor powered. Tractor mounted equipment offers many different designs from cutting discs and rotary systems that penetrate the mulch and open the soil for seed and fertilizer placement, to other innovative systems that push or blow away the loose residues for planting before returning them as mulch.

Vegetation management can be mechanical (using manual slashing or animal or tractor-drawn knife rollers and residue handlers); or chemical with herbicides such as glyphosate (systemic) or paraquat (contact). Herbicide application can be manual with weed wipers or sprayers (back-pack or hand-pulled) or by animal or tractor pulled sprayers. There is a wide range of animal-drawn and tractor mounted spraying equipment (see Figure 3 for example).

Effective CA adoption requires suitable, good quality equipment to be available to farmers. This in turn requires an active manufacturing sector to research, adapt and make available this equipment and spare parts in suitable

⁴http://www.rwc.cgiar.org/Pub_Datasheets.asp accessed 5th November 2008

⁵Detailed information on machinery options for CA can be found at: www.fao.org/ag/ca



Figure 2. Planting sticks (possibly with steel tips) can be used to plant through soil cover. They have been used for generations, for example in many Latin American cultures. But more sophisticated equipment is preferable for increasing productivity and sowing larger areas.



Figure 3. Spraying weeds before no-till planting. The animal-drawn sprayer greatly enhances the productivity of labour and a well-calibrated machine will give a precise application rate.

numbers for accelerated adoption. The most effective model is found in all parts of the World where no-till and CA has been rapidly adopted; it has the manufacturers actively involved in innovative networks of concerned stakeholders working together to identify and improve appropriate equipment priced to meet farmer circumstances.

Who is Providing CA Equipment in South America, Africa and Asia?

South America

In Latin America the major producers of CA machinery for all sizes of farm and all power sources are to be found in Brazil. However increasingly other countries (notably Argentina and Mexico are entering the international market (Derpsch, 2008 a & b). Concern for the conservation of natural resources (especially soil) in southern Brazil was born in the mid 1970s (Casão Junior & Guilherme de Araújo, 2008). Pioneer farmers investigated possibilities of reduced tillage through the import of equipment from Europe and North America. Research and development at national and regional centres, but always in close collaboration with the manufacturing industry, followed and led to further developments throughout the 1980s (especially with improvements in cutting discs). By the 1990s no-till drills and planters were available on the market. At this time small-scale farmers were encouraged to adopt CA through federal government subsidies for CA machinery. This, of course, stimulated the manufacture of suitable equipment. Today there are over 25m ha of CA in Brazil, and about 300 different models of no-till planter in commercial production by over 25 manufacturers. An important lesson learnt from the Brazilian experience is that the success achieved is due to the synergistic partnership between the public sector (at state and national levels); the private sector (input suppliers and machinery manufacturers; and development organizations (particularly the World Bank).

Africa

The situation in Africa is in stark contrast to the achievements in South America. Equipment is being imported (from Brazil principally) to countries such as South Africa. But the indigenous manufacturing industry is in its infancy. In East Africa there are several manufacturers making simple equipment, mainly based on Brazilian concepts – although the Zamwibe herbicide applicator made in Zambia is a notable exception to this. These include jab planters, animal-drawn planters and knife rollers. International development organizations, especially FAO, have mounted several pilot projects for CA (FAO, 2008a). These have included the provision of machinery for no-till planting, knife rollers and herbicide application sprayers for human and animal traction. FAO also organized a trade mission in 2008 to take would-be East African entrepreneurs to Brazil to interact with their Brazilian homologues. The purpose was to energize the East African CA equipment manufacturing sector to produce equipment adapted

to their local conditions. Reduced tillage animal-drawn rippers are made extensively in East African countries together with sub-soilers for removing hardpans as a prerequisite to CA. Of course hoes and machetes are made industrially in a range of African countries, and are also imported into the region from China and India.

Asia

In South Asia and China, where farmers generally have very small land holdings they are also benefiting from the NT revolution. In S. Asia and China local artisans have taken up the challenge of producing the needed CA and RCT equipment. In India, for example, there are many small scale manufacturers of NT drills. In S. Asia this came about as these same manufacturers switched from making simple seed drills to modifying the furrow openers (imported from New Zealand Harrington and Hobbs, 2009) strengthening the frames and producing low cost, tractor powered NT seed drills. Whereas a heavy, complex NT drill may cost thousands of dollars in developed countries, developing countries can provide farmers a drill that does a similar job for US\$500 or less. In some African and S. American countries and also in S. Asia and China local artisans can also produce low cost animal and manual powered equipment for no-till and other RCTs. Larger companies in India and Pakistan manufacture laser land levelers that have made this technology affordable to local farmers and resulted in improved efficiency in water and input use.

In a country like India, where 60% of the population is involved in agriculture and where many farmers cannot afford to own their own tractors, contract ploughing was common. Farmers would rent the services of farmers who owned tractors to plough their land or at least undertake the first couple of tillage passes. In a similar manner, resource poor farmers who don't own tractors have also benefited from no-tillage by contracting service providers to plant their land. In this way, there are many farmers with small land holdings who have adopted NT and there are many villages in India where the entire village uses this new efficient way to establish wheat after rice.

Although national policies in S. Asia focus on agriculture and the manufacturing sectors, little attention is paid to the farmers' need for good agricultural implements. S. Asian farm machinery supply enterprises for tractor and other farming equipment are mainly serviced by small and medium size private entrepreneurs (SMEs). Services include laser land levelers, NT drills, bed making systems, sprayers, input dealers and contract farming units. Unfortunately, in spite of the acknowledged importance of the role of these services in the national economy, the sector doesn't feature adequately in government support and motivation programs. In reality, services such as land leveling and no-till / raised bed planting are providing employment opportunities to jobless rural youths and employment in small scale manufacturing and transport related sectors (Gupta and Sayre, 2008).

CA & RCT Machinery Supply Chains

Brief Description of Currently Available Equipment

The CA equipment available worldwide can be classified according to the power source used: manual; draught animal; and motorised.

Manual Equipment

Possibly the most useful and universally used tool for planting through mulch is the jab-planter. Sold in their millions and owned by countless CA farmers the jab-planter can be used for all crop types and can be adapted to apply fertilizer at the same time as planting (Figure 4).

Other manually operated equipment for cover crop and weed management includes the Zamwipe herbicide applicator (Figure 5) and a range of more conventional sprayers (Figure 6).

Animal-drawn Equipment

Draught animal powered CA implements comprise many NT planters as well as herbicide sprayers of different tank capacities. One residue and cover crop management tool is the knife roller (which can also be tractor-drawn) for crushing vegetation and providing a dead vegetative mulch prior to no-till planting (Figure 7). This type of equipment is only suitable for small family farms and in fact the tendency in Brazil is for farmers to move away from draught animals and to use small tractors as the preferred power source.



Figure 4. Farmers try a variety of jab-planters (fitted with hoppers for both seed and fertilizer) to plant through crop residues on the soil surface. Photo: John Ashburner



Figure 5. Zamwipe herbicide applicator



Figure 6. Knapik hand-pulled sprayer



Figure 7. Animal-drawn knife roller



Figure 8. Tractor-mounted no-till planter

Tractor-powered Equipment

Tractor-mounted no-till planters, although under continuous development, have now reached very high levels of technical effectiveness. Machines are available for planting wide-row crops (maize, soya, sunflower) and also for narrow-row crops such as cereals, canola and cover crops (Figure 8). Tractor-mounted sprayers have been commercially manufactured since long before the advent of CA. Laser land levelling machinery, bed planters, improved water distribution systems (sprinklers and drip) and other RCT equipment are also available in S. Asia and China through small scale manufacturers.

Stakeholders in the Equipment Supply Chain

For CA equipment to arrive into the hands of the farmer and for there to be an effective service backup network to sustain it in use, a well-functioning supply chain is required. When the complexities of the supply chain have been identified in any particular scenario, then the appropriate policies and institutions needed to nourish the provision of appropriate technology can be formulated and can be put in place.

The different stakeholders in the CA equipment supply chain will usually include the following groups:

- Policy makers
- R&D institutions
- Extension and training services
- Finance institutions
- Manufacturers, importers and retailers for equipment and spare parts
- Machinery hire services
- Machinery repair services
- Farmers

A fundamental aspect of all stakeholders in the CA equipment supply chain is that they will normally need to derive all or part of their livelihoods from their participation. Although government policy makers and public sector

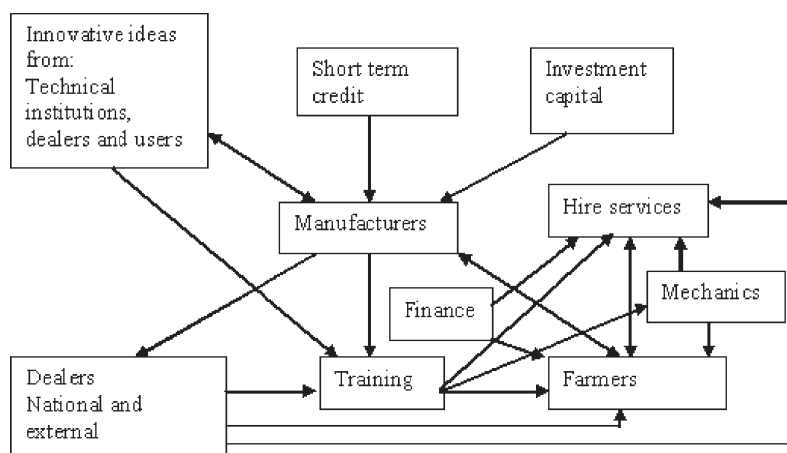


Figure 9. Machinery supply chain for CA tractor powered equipment in southern Brazil

R&D and extension institutions (and even finance institutions) will often be civil servants and will probably not be at high risk if there are failures in the supply chain network. The way that the stakeholders may interact is illustrated in Figure 9.

From Figure 9 it can be seen that CA equipment manufacturers have access to innovative ideas from a number of sources, including public sector R&D. A national dealer network supplies technical back up (and training) for end users (farmers and contractors) and at the same time is kept fully up to date and trained by the manufacturers themselves. The policy environment which has led to this well-functioning supply chain has, in the past been encouraged by government policies which have included extending credit and subsidies to farmers for machinery purchase, collaborative research between research institutions, manufacturers, input suppliers and international donors. It has received careful nurturing over several decades to evolve into its present state (Casão Junior & Guilherme de Araújo, 2008).

Constraints to Greater Adoption of CA Equipment

There are several constraints to increased adoption and scaling up of the area sown to CA and RCTs. One of the most important is the innate conservative nature of farmers; they are adverse to taking risk and experimenting with new technology. Changing this mindset of a farmer requires a new paradigm for extending technology. In S. Asia it required several components (Harrington and Hobbs, 2009); first a local champion who would promote the technology; second the identification of innovative farmers willing and able to experiment and take a risk; and third, a suitable NT drill was needed which was affordable and performed well. Once these were in place and innovative farmers obtained good results, other farmers were shown the results through visits and farmer to farmer extension; accelerated adoption then occurred. Where the technology was demonstrated to farmers by extension or researchers using the older, top down extension approach, results were much slower; there had to be active participation and experimentation by farmers to convince them of the merits of adoption.

The availability of suitable equipment was also a major constraint to adoption in the early years of adoption and can account for the usual 10-15 year lag phase seen in many countries from when NT technology was first introduced until it became widely adopted. The manufacturers had to get up to speed in manufacturing sufficient numbers of drills to meet demand. The first hurdle was to convince them to invest in the manufacture of NT drills. This was achieved in S. Asia by university engineers working closely with local artisans in adapting conventional seed drills to NT drills with just a few modifications. These were then bought by scientists and extension using aid donor funds and made available to innovative farmers for experimentation. Neighbouring farmers saw the results and demanded they also test the equipment. In this way a supply and demand mechanism was generated that has led to a rapid expansion of CA equipment manufacturers and farmers adopting the technology. Similar stories occur in other regions.

One major factor in the success of scaling out is the manufacture of suitable, well constructed and good quality equipment. NT in India suffered a severe setback in the 1990s when very poorly constructed equipment was

delivered to farmers and failed to perform well. Some system needs to be in place to certify equipment at the manufacturing level to protect the farmer from unscrupulous people and ensure the technology works as intended.

Another major constraint in the adoption of CA technology exists when the scientific and extension communities in a country do not agree with the benefits of the technology and actively discourage adoption. In Brazil, it was the farmers and their associations who pressed forward with CA without the support of extension. In South Asia, there are still today, despite 4m ha of no-tillage, extension personnel who speak against the use of NT. This has slowed adoption since farmers, administrators and manufacturers are all confused as to who is right. Mass media messages promoting the benefits of CA are not produced. This uncertainty also leads to a lack of policies which would promote the manufacture and adoption of CA.

Policy and Strategy Implications for National and International Policy Makers

In this Section we discuss the policy implications for CA promotion and equipment manufacture from the viewpoint of policy makers. Section 4 will then look at the implications for other stakeholders in the CA supply chain. The aim is to offer some guidance for these stakeholders, or would-be stakeholders, in the CA promotion and supply arena.

National Policy Implications

Here the focus is on information for policy makers so that they may be guided towards creating a facilitating environment for CA supply chain entrepreneurs and so make an important contribution both to the supply of appropriate CA mechanization inputs for developing country agricultural sector producers (both farmers and processors) and also to the industrial sector via support for CA machinery manufacture.

Formulation, Revision and Implementation of National Mechanization Strategies

For many years international development institutions (such as FAO) have been promoting the importance of formulating and implementing national strategies so that the provision of farm power to the agricultural sector can take place in a logical ordered sequence with the best options being made available to all stakeholders in the supply chain (FAO, 2008b). This is a sound starting point and it is the contention of this paper that a national mechanization strategy is a necessary (but not sufficient on its own) starting point for facilitating access to CA mechanization technology which is needed for the sustainable adoption of CA. The following points indicate some of the main issues that would be relevant components of such a strategy.

Improvement of Rural Infrastructure

Rural infrastructure, particularly roads, is a major impediment to the free operation of markets. Poor infrastructure is a disincentive to market access and will always add to input prices. Infrastructure improvement is likely to form part of a wider national strategy for economic improvement (as was, and still is, the case in Brazil), however its importance to mechanization input supply is emphasized. One of the principal causes of failure of public sector machinery hire schemes has been the extraordinarily high cost of transport both in terms of distances and time involved, access to fuel and services in remote areas, and the damage done to farm machinery during transportation.

Facilitation of Financing Options for Machinery Acquisition

In many countries the majority of measures taken to improve CA equipment input will take place in the private sector. The commercial banking sector has frequently been averse to extending financial credit to relatively resource-poor farmers. But studies have shown that such investment is often highly profitable. This is especially the case for technologies with a lower capital cost and which demand a lower level of management skills. Draught animal power options are a case in point (Hollinger *et al.*, 2007) where financial instruments could be extended by the private sector at relatively low risk. To make such schemes even more attractive some government guarantee, perhaps in the form of crop insurance, would shield smaller-scale farmers who are working to emerge into the commercial sector through the adoption of sustainable CA, from the worst risks of crop failure and other catastrophes.

The Brazilian experience has been particularly illuminating with respect to financing. Early in the process of innovation in CA systems the government realized the need to extend attractive credit lines, especially to small and

medium sized farms. Programmes like FINAME⁶ from the National Economic and Social Development Bank targeted resource poor farmers and allowed them to raise production and family livelihoods through the acquisition of farm power and equipment for CA.

Experience teaches that policy makers would be well advised to channel lines of credit for input purchase through farmer and community groups. Channelling funds via influential Village Organizations in Pakistan is a successful case in point (Abbas, 2007).

Tax and Duty Relief for Agricultural Machinery and Raw Material Imports

Tractors and agricultural machinery are frequently given privileged status by governments actively promoting the development of their national agricultural sectors. Such equipment can usually be imported free of duty. However sometimes (as in the case of Kenya) machinery parts and raw materials (principally steel) are excluded from this arrangement and this puts the national manufacture of agricultural machinery at a disadvantage. Few developing country governments would want to jeopardize the development of their national industrial sector in this way. One simple way of providing tax relief to national CA equipment manufacturers would be to give them a rebate on the duty paid for materials that can verifiably be shown to have been used in agricultural machinery construction. The positive Pakistan experience of this arrangement is a useful model (Amjad, 2004).

Batch Purchase of Agricultural Machinery

Many people working to improve the development of the agricultural sector point to the need for a fresh impulse to the partnership between the private and public sectors of the economy (e.g. Simalenga, 2007).

One way to do this and to motivate the private sector to manufacture novel equipment to promote adoption of CA practices, particularly in the smaller scale farm sector, is to commission batch production of equipment which is then sold to farmers via the extension service or other outlet (Figure 10). In this way confidence in the market can be built and sustainable commercial production of CA machinery is a more probable outcome.

Provision of Impartial Machinery and Materials Testing Services

A mutually respectful collaboration between the public sector and the private sector would make it possible for the public sector to fund impartial machinery and materials testing centres in direct response to the needs of the manufacturing industry. Previous efforts (e.g. in East Africa and Pakistan) have shown that extremely few manufacturers seek advice and guidance from public sector institutions set up to provide those services. A new approach must consider the needs of the industry from the outset. A strategy for sustainability of the service would be to phase out public sector support over a number of years so that the service is maintained by and for the private sector. It is by no means certain that manufacturers would consider such a service to be a worthwhile investment. Local manufacturers in Tanzania, for example, make no or little use of the testing institution (CAMARTEC⁷) that is available to them. In Brazil, manufacturers tend to do their own testing and may outsource particular aspects that they believe can be done better by others. On the other hand, and also in Brazil, the role of public sector institutions in organizing side-by-side comparative evaluations of NT planters has been a notable success in improving the quality of production machines. The trials were made with crops sown 30 days before the public exhibition of the machines at work. This allowed farmers to compare the field performance of different machines and to judge the quality of seed placement and crop emergence (Figure 11).

The trials resulted in a marked improvement in planter performance and quality as positive elements were adopted more widely and less effective components eliminated.

R&D and Facilitation of Innovative Technology Provision

The public sector, especially in developing countries, has historically been notoriously less than successful in developing prototypes and moving them into commercial production via the public sector. R&D by researchers in isolation from other key stakeholders is a discredited paradigm. New models of collaborative participation are more

⁶Credit line (from BNDES- Brazilian Bank for Economic and Social Development [Banco Nacional de Desenvolvimento Econômico e Social]) for agricultural machinery purchase (Linha de Financiamento de Máquinas e Equipamentos do BNDES).

⁷Centre for Agricultural Mechanization and Rural Technology, Arusha, Tanzania



Figure 10. Batch orders from private sector manufacturers is one way that the public sector can reduce the risk for entrepreneurs and facilitate greater farmer access to CA mechanization inputs



Figure 11. No-till planter at a dynamic evaluation event in 2003 in Guaíra PR. (Photo Ruy Casão Junior)



Figure 12. The *Gralha azul* animal traction no-till planter and fertiliser applicator developed at IAPAR in the mid-1980s

likely to produce results, especially those that are capable of local manufacture at an affordable cost and that respond to technologies actively being sought by farming communities. When considering a novel technology like CA, a tripartite R&D arrangement, whereby the voices of farmers, manufacturers and researchers have equal value, is an activity that should be funded by the public sector and its longevity should be dependent on the production of outputs valuable to all parties.

Another way that the public sector should be involved in the development of the CA machinery input supply chain is by facilitating the introduction of valuable, farmer-proven, technologies from other regions. One example of this approach is CA in East Africa (Sims *et al.*, 2007). Box 1 gives another example, the introduction of raised beds for crop production under controlled traffic conditions in Pakistan and Zimbabwe.

The experience of IAPAR⁸ in Brazil in creating awareness and interest in draught animal powered NT planters is a useful example. Working with manufacturers and farmers, IAPAR was able to produce a planter which has served as the prototype for many lines of commercial production in ensuing years (Figure 12).

Technical and Business Management Training Schemes

There appears to be a great need, as well as a hunger (in many developing countries), for training programmes aimed at improving business management capabilities and technical competence. Large scale manufacturers, importers and dealers are, of course, fully conversant with the need for financial controls and with the tools needed for calculating costs and profits. Other sectors of the supply chain are sometimes less familiar with the methods required and are in need of orientation. These include small-scale manufacturers, hire service providers, machinery repair services and small to medium-scale farmers.

Technical training is needed at many levels from manufacturing skills needed by small-scale entrepreneurs, to servicing and repair requirements for new technology (e.g. combine harvesters and power tillers) to training in new practices for farmers (e.g. CA). Technical and financial training courses and programmes are expensive for individuals and constitute an ideal and acceptable way for governments to demonstrate their commitment to development.

The policies of particular governments are crucial in this regard. The current administration in Brazil under President Luiz Inácio Lula da Silva is particularly keen to promote technology exchanges between his country and the African continent. This situation should be exploited by training African entrepreneurs in the technical and financial skills needed for successful manufacture of productivity-enhancing agricultural equipment.

Provision of Quality Extension Services in Agricultural Mechanization

An active, motivated and well trained extension service is a prerequisite for a progressive, developing agriculture sector. Agricultural extension does not belong wholly in the public sector, but elements of it do. For example machinery demonstrators from larger scale manufacturers, importers and dealers are part of the extension effort

⁸Paraná State Agricultural Research Institute (Instituto Agronômico do Paraná)

and the public sector service should liaise closely with their counterparts in the private sector. Experience has taught that, unfortunately, extension services have too frequently tended to be neglected, attracting poorly trained recruits who then are poorly rewarded and have little of value to transfer to the farming community. The growing numbers of organized farmer groups (such as farmer field schools, earthworm clubs⁹, friends of the soil and no-till clubs) which are proactive in the technical assistance that they demand, are a healthy sign that extension services will need to respond to a greater extent to farmers' requirements. The public sector has a key role to play here in ensuring that the extension service delivers high value information and training and in return is highly regarded by the farming community that it serves. Another important aspect of extension of more complex technology such as CA and no-till is the use of farmer to farmer extension. This was successful in Brazil, S. Asia and probably all countries with significant CA adoption. It starts with an innovative farmer experimenting with the technology and this farmer informing his neighbours who are more likely to respond positively and trustfully to another farmer.

Land Tenure and Payment for Environmental Services Issues

One major impediment to adoption of CA and RCTs relates to land tenure. One frequently encountered way of farming in developing nations consists of a land owner allowing a tenant to cultivate his land with the proviso that part of the produce is given as rental payment. The actual amount given to the owner varies but it is often half of the produce and in many cases the tenant bears the cost of the inputs. This system provides little incentive for the tenant to improve his practices and adopt management systems that would improve the land quality and reduce negative environmental impacts. The tenant essentially wants to get the most out of the land with the least input cost. Tenants are also averse to taking any risk associated with a new technology like CA or RCTs since they are not interested in improved land quality over time. The main reason is that the owner has no obligation to renew the contract with the tenant so any investments in the owner's land would not benefit the tenant unless there was an obligation to continue the arrangement in subsequent years.

A policy that encouraged tenants to adopt CA or RCTs would be a win-win situation since the tenant would get at least equal yields at less cost and the owner would benefit from improved land quality. This could take the form of an equipment subsidy to allow the tenant to afford its use or a payment for improved environmental services such as a reduction in greenhouse gases or increased carbon sequestration. In fact, any policy that rewards farmers for improving environmental quality and services would provide incentives for them to adopt CA and RCTs. The big question is who would pay for this service, the government or consumers? Consumers could participate by paying a food surcharge that resulted in farmers being rewarded for positive environmental practices.

Revision of Obsolete Policies – The Case of Central Asia

The negative synergy between the biophysical and socio-economic drivers of land degradation has always been a challenge, particularly in Central Asia. Policies, institutions and markets have a large influence on land degradation and rehabilitation. Insecure land tenure and property rights, a virtual lack of extension services for the dissemination of good agricultural practices, and resettlement policies have all been seen to worsen land degradation problems. Cotton is of paramount importance in Central Asia due to its generation of foreign exchange revenues and consequent GDP improvement; and for providing employment and income security to millions of rural households. However cotton has also been blamed for economic stagnation, poverty and causing the ecological catastrophe known as the drying Aral Sea syndrome (<http://earthobservatory.nasa.gov/IOTD/view.php?id=1396>). The irrigation practices in cotton monoculture consume massive amounts of water from the Amu and Syr Darya rivers which feed the Aral Sea and the leaching of pesticides and fertilizers has resulted in pollution and salinization of the waters of the shrinking lake. Rudenko, *et al.* (2008) have indicated that restructuring the cotton production chain could result in a reduction in cotton area in the Khorezm region by about 70%. This implies that about 80 000 ha could be released from state control and diversified into alternative crops or land uses (e.g. tree plantations or forage production) and so making agriculture more environmentally friendly while maintaining its economic importance.

In agriculture, operations such as tillage, planting, harvesting, irrigation and agro-chemical application etc. are usually time-sensitive. Farmers find it difficult to acquire new implements appropriate for their small farms. Public sector machinery hire service providers are small, have meager resources and give little incentive for the staff to work the necessary extra hours in peak seasons. This frequently results in inordinate delays (with consequent yield losses) and conflicts among farmers requiring the services at the same time. Private sector hiring of agricultural

⁹ For example: clubes da minhoca; clubes amigos da terra; FEBRAPDP in Brazil

Box 1: Tractor hire services for raised beds and reduced soil compaction

Keeping traffic (wheeled, animal hoof and pedestrian) to a minimum in conservation agriculture systems is very important to reduce soil compaction. Confining traffic to permanent tracks or pathways and growing the crops on raised beds (1.2 m wide) between the pathways (0.6 m wide) can achieve this goal both under rainfed and irrigated conditions. Crops can then be produced under CA conditions on the raised beds where permanent cover can be maintained, crops of differing rooting depths rotated and crops sown with no-till.

One of the main limitations to the uptake of CA in Africa and Asia is the scarcity of mechanization services. The establishment of the raised beds is a one-off operation and the practice could be more widely adopted if tractor hire services were equipped and trained to use the appropriate tools required (ridger, bed-maker, chisel plough for initial hardpan bursting and perhaps no-till planters).

Such tractor hire services have worked well in Pakistan as part of an FAO food security programme. It is a good example of how farmers, machinery hire services and machinery suppliers can work together with international technical assistance programmes to raise agricultural production in a sustainable way.



High density carrot crop on raised beds in Zimbabwe

Source: Fintan Scanlan, FAO. Personal communication

implement services is increasing but has not yet approached its potential. If small-scale private entrepreneurs were to be further encouraged to manufacture agricultural implements, sell, service and lease them, then private markets could emerge for the provision of time bound operations and hence boost agricultural production. Some of these policy reforms have the potential to reduce unresponsive state controls and reduce the need for public services which may, in turn, result in enhanced production and productivity.

Further examples of the need to reform obsolete policies in some Asian situations are given in Box 2.

Box 2: Revision of obsolete policies, some examples from Asia

Agriculture in South Asia has mechanized over the past few decades, mostly through 4-wheel tractors, combines and various tillage implements; harrows and cultivators. This is yet to occur on a significant scale in Central Asia where farmers depend on leasing companies and imported heavy duty, fuel inefficient tractors often used for petty operations (mainly transport). Agricultural machinery providers in Central Asia generally supply new tractors with cultivators for soil tillage. These tractors are usually fitted with wide tyres that hamper operations in raised bed-furrow systems for planting high value and cereal crops. Similarly, combine harvesters also have insufficient adjustment to make their wheel track compatible with the bed and furrow layout being promoted to farmers as a way to improve resource efficiency. Appropriate CA planter designs, which can plant crops in the presence of anchored and loose residues, have yet to be developed and/or adapted by the machinery supply chain in the Central Asian region.

The rotary cultivator and planter (or 'rotavator') is being promoted in India at the moment by some parties. This system incorporates residues into the soil and plants crops in a single tractor pass. This is not a good way to establish crops since it destroys soil structure and leaves the soil surface bare, opposite to what CA tries to promote. Due to imbalances in the government subsidy component in India, this new reduced tillage system is being promoted at the expense of other more environmentally friendly and CA type machinery such as the Turbo and Happy seeders, zero till, and raised bed planters. The Turbo and Happy seeders work on the principal of picking up loose residues ahead of the no-tillage coulters and then replacing this residue on top of the soil after the coulter places the seed in the ground. To accelerate the pace of conservation agriculture adoption these policy distortions that subsidize the wrong equipment need to be removed and applied instead to equipment that results in environmentally friendlier CA equipment. Subsidies would be given to farmers who save water, reduce green house gas emissions and promote clean eco-friendly agriculture (such as CA). Policies also need to encourage private sector manufacture of CA equipment and imported complementary RCT machinery (including the laser land levelling systems and spare parts) by subsidising import duties, VAT and other taxes.

CA in School and University Curricula; Extension, Research and Farmer Training

Many farmers (especially smallholder farmers) often lack adequate access to research information, infrastructure and value-adding services, limiting their ability to produce more profitably and use natural resources more sustainably. In Central Asia, extension services are virtually non-existent and scientists have to perform both research and extension functions including overseeing the state controlled operations such as cotton picking. With the demise of the Soviet Union, the former channels of knowledge transfer have been disrupted. Involvement of the private sector, especially NGOs, private entrepreneurs, input and service providers, can partly fill the vacuum created by weak and non-existent extension systems.

Any research-extension framework must attempt to raise the efficiency, responsiveness and relevance of research to production while responding to farmers' needs for capacity building at different levels. In most parts of the Asian continent most graduates emerging from academia have no experience of CA. There is an urgent need for CA text books to help prepare the young minds for the big change- from 'plough-based to ploughless agriculture'. Promotion of CA requires a shift in the way research is conducted and knowledge is transferred to the farmers. In the case of smallholder producers, it should be farmer led participatory research. This would require new statistical tools and methodologies for analysis of the results of farmer field trials. With more and more farmer experimentation, the RCTs will 'co-evolve' with critical contributions from other agents of change (e.g. public research and extension systems, champion farmers, CA equipment manufacturers, custom service providers and private sector agri-input dealers).

Site Specific Policy Strategies

Agro-ecological regions are relatively homogenous areas delineated in terms of landscape, length of growing season and bio-climate. In spite of this, the socioeconomic resource endowments of the farmers who depend on land for their livelihoods vary greatly. Natural resource management (NRM) problems very often are location specific and the basic tenets of CA would need some fine tuning to address local issues. Different zones within an agro-ecological region (such as the Indo-Gangetic plains) suffer from one or more problems such as: (i) large yield gaps between those obtained on experiment stations compared to farmer plots. (ii) low yields but high production costs, (iii) a tendency for monocropping and no alternate sources of productivity growth. Crop diversification and intensification through inter-cropping (e.g. autumn planted sugarcane with chickpea / wheat / Indian mustard) and relay crops (wheat or mungbeans in standing cotton) in north-west parts of IGP are examples that can help resolve this problem; and (iv) high production risks as for example in low-lying flood prone environments, salt affected and degraded areas. Therefore we suggest that any policy on research for development must promote and address the following location specific issues:

- Bridging yield gaps that exist between what is attainable on experiment stations compared to lower yields on farmers' fields (improving production efficiency);
- Yield enhancing and cost cutting (resource saving) technologies;
- Generation of alternative sources of productivity growth (intensification and diversification) and;
- Reducing farmers' risks of natural calamities (e.g. mixed cropping in flood-prone areas and watershed management and water harvesting in drought prone areas).

The introduction of a new generation of agronomic and crop management practices appropriate to the sub-humid climates of the eastern Gangetic plains of South Asia offers tremendous opportunities for reducing the acreage of 'rice fallows' (i.e. lands that remains fallow during winter season due to late rice harvest) increasing land intensification and better exploitation of underutilized, but potentially productive, land and water resources.

Management and Use of Crop Residues

One of the key pillars of CA is the maintenance of permanent soil cover either through the use of previous crop residues or cover crops. Data have been compiled from various sources that show that NT without the use of residues can have a negative impact on yields (Sayre and Hobbs, 2004). These authors report on a multi-year study that looked at different residue management strategies on bed and flat planted wheat-maize systems in Mexico. The poorest treatment was no-till with no residue retention and the best no-till with residue retention. This study and many others highlight the importance of permanent soil cover which improves water infiltration, reduces erosion and

improves surface soil physical properties in addition to benefiting many soil biological and chemical processes (Hobbs *et al.*, 2007, 2008).

In many parts of the World, especially in developing countries, crop residues have multiple uses: they are fed to animals, used for making adobe type housing, and burnt as fuel. Unfortunately, they are also burnt in the field since they can be a hindrance to plough-based land preparation, especially where crops are harvested with unmodified combines that leave piles of loose residues in the field. This is the case in the NW areas of S. Asia and China after the rice is combine harvested and the farmer needs to plant the next wheat crop quickly; residue burning results in severe air pollution and also leads to degraded soils and loss of organic matter over time. This problem was addressed in S. Asia by developing equipment that could plant into loose residues and thus provide both minimal soil disturbance and permanent ground cover. Policies that would encourage engineers and manufacturers to research and develop solutions to these residue problems are essential if environmentally friendly CA practices are to be adopted widely. This was accomplished by a number of coulters and soil opening systems from the "Happy Seeder" (an Australian design¹⁰) that picks up the loose straw ahead of the seeding mechanism and then distributes it evenly on the ground following the seeder by blowing it out of the back of the equipment, to designs of coulters that don't rake the straw into piles, to strip till systems that cut the straw and plant the seed without blocking. Exchange visits of manufacturers to Australia and also within the region helped catalyze this development.

Interestingly, in the developed, temperate regions there is talk of using residue "waste products" for producing cellulosic ethanol. This is a more efficient system for producing ethanol than using corn grain, but would have serious implications for soil health, especially in tropical and sub-tropical environments since the residues are a valuable source of food for the biological component of the soil and soil physical structure. Policies are needed to restrict the burning of residues, initially to reduce air pollution but also to provide farmer incentives to use the residues for the benefit of the soil and the environment through adoption of CA.

Anticipation of Externalities

Within the future scenario for meeting the food security needs of the growing World population, externalities such as climate change, biofuel production, fossil fuel prices, fertilizer and other input prices make the task even more challenging and complex. The 2008 spike in fossil fuel costs was a major cause of the spike in food prices which have no doubt reversed the declining trend of output prices farmers have experienced over the last 40 years. But farmers also see an increase in the price of inputs like nitrogen fertilizers and crop protection chemicals that are dependent on fossil fuels for their production. In fact, if farmers had not received the increase in output prices in the past year, many would have been unable to afford the high prices of inputs and so would have obtained lower yields.

The situation was not improved when developed nations turned to production of biofuels from corn, soybeans, sugarcane and other crops as a substitute for fossil energy. Policies that required a percentage substitution of ethanol for fossil fuels and provided subsidies to biofuel producers and manufacturers also contributed to the recent price hikes. The biofuel crops competed with food crops on agricultural land and resulted in food crop shortages. Food reserves available for global trade dropped to the lowest level in the past 40 years and encouraged speculators to drive up the future prices of food. This had much less impact in developed countries where the percentage of a person's salary used for food is small. However, it had a major impact for the poor who pay a much higher percentage of incomes for food. These people had no extra money to absorb rising food costs and so essentially ate less. This resulted in food riots and the need for governments to introduce policies to distribute cheap food to the poor at a cost to the tax payers. A logical policy would be to discourage growing any biofuel crop on land that is needed for food production. The issue of use of residues for cellulosic ethanol also needs careful thought as mentioned above since these residues play an essential role in CA.

Global climate change, which is already occurring, is another major factor to consider in future food production. There are many possibilities with some regions benefiting from changes in temperature and rainfall patterns to others where these changes would be disastrous. One of the major concerns of global climate change is the melting of the polar ice pack. Data show this is happening much faster than anticipated. The result will be an increase in the level of the oceans affecting much of the agricultural land in coastal areas. Another concern is the melting of the Earth's glaciers that supply fresh water for agriculture and human needs; the Himalayan glaciers are

¹⁰<http://www.aciar.gov.au/system/files/sites/aciar/files/node/5019/Final+report+PLIA-2006-180.pdf>

an example of this. These are the major sources of fresh water for the irrigated food bowls of NW India and Pakistan, an area of the World that is dependent on irrigation and would be a desert without it. Other global climate change effects would be temperature changes (up or down), droughts, floods, and more erratic and violent weather (hurricanes, typhoons, etc.) that could seriously affect mankind's ability to produce enough food for the World's population or at least in countries seriously affected by climate change. The increase in fossil fuel prices also affects responses to emergencies with food aid because of increased transportation costs. Policies must be implemented to reduce the impact of greenhouse gas emissions on climate change. Policies are needed to reward activities that result in increased carbon sequestration and reduce these emissions. Policies that would promote the use of environmental and sustainable farming practices like CA and RCTs are one way to achieve this.

The Pros and Cons of Subsidies

Subsidies are part and parcel of agriculture in many countries of the World. Developed and developing countries use them to help make farming profitable in an environment where governments also want cheap food and/or want to be competitive on pricing of agricultural products for World trade. There have also been discussions about providing subsidies for CA equipment which would be beneficial to farmers if they resulted in cheaper equipment needed for no-tillage and planting into loose residues. Others argue that no-tillage already results in savings to farmers and improved profits so why use valuable taxes to provide an incentive? In many cases the subsidies don't end up in the hands of the farmer, but are usurped by businesses and other intermediaries. A subsidy made to a manufacturer of equipment for CA may not result in a cheaper price of equipment for the farmer, if the manufacturer decides not to lower the price of his machine. However, the cost of some new agricultural technologies like land levelling are extremely high and it may be better to subsidize this practice for the environmental benefits obtained in water savings, greenhouse gas emissions and improved productivity. The policy should also insist that the benefits reach the farmer through lower equipment and rental costs.

There are other examples of poor subsidy policy. In the Punjab province of NW India, the State Government provided a subsidy of free electricity for pumping groundwater in agriculture. Farmers were happy at first as irrigation water costs were reduced, but the policy resulted in farmers keeping their pumps operating for 24 hours a day and ignoring the need to improve water productivity. In fact, the electric supply in the State could not handle this demand and the result was frequent blackouts and no electricity available for anyone to pump water. A better policy would have encouraged and rewarded farmers and users who used water more efficiently and adopted farming practices like CA that improved water productivity.

Closing the Knowledge Gap

Another factor that limits CA adoption is lack of knowledge. If a farmer does not know about CA and what it can do to improve his livelihood, then he will not adopt it. Similarly, if the proper equipment is not available to allow a farmer to experiment with CA, he will not be able to benefit from its use. Policies are needed to improve communication and knowledge concerning CA through subsidies for production of extension materials in various media including hardcopy, radio, TV and even internet and web based material. It is hoped that in the future electronic access to knowledge through the internet and also mobile phones will be much more accessible to farmers than today even in developing countries.

The traditionally used method for transfer of technology to farmers is to lay out a few researcher-led demonstrations on the farmers' fields with all or most of the inputs provided to them to get them to participate in the program. For promoting CA this methodology is not very appropriate. Demonstrations should be farmer-led and backed by intensive knowledge. It is our experience that Asian farmers most often progress in the adoption of innovations in small steps. Farmer-to-farmer exchange of technology and information invariably gives them greater satisfaction and raises their confidence in the technology (which is backstopped by additional research information). To this effect, organization of travelling seminars of CA stakeholders provides a unique opportunity to overcome 'mindset problems' and to champion farmers who have infectious new ideas to communicate to the fence sitters, free riders and other people in two minds about the benefits of CA.

Dissemination of any set of best-bet practices is easier if they are extended to similar sites or zones elsewhere. For the effective promotion of RCTs and for targeting solutions to specific problems a well-organised database of the characteristics and limitations of the different technologies, the extent and distribution of land types and the NRM problems of the specific areas (salinity, waterlogging, moisture supply, flood events - their intensity and

duration etc.) is required. The application of remote sensing and GIS can help gather and synthesise important dynamic spatial information as an aid to pre-planning diffusion and targeting strategies for RCTs in different domains.

Policy and Strategy Implications for other Stakeholders

Section 3 discussed the policy and strategy implications for policy makers, it also discussed some specific issues which will often be priorities for different classes of stakeholders. This section discusses policy and strategy implications for other groups of stakeholders in the CA machinery input supply chain, namely: manufacturers, importers and retailers; machinery hire service providers; machinery repair and maintenance service providers; and farmers.

Manufacturers, Importers and Retailers

Demand Creation

Manufacturers, importers and dealers should be proactive in increasing the demand for agricultural machinery; that is they should not simply respond to demand but participate in its creation. This group is typically better educated than the majority of their potential farmer clients and they have access to more sources of information. They should take advantage of this to ensure that they keep abreast of current advances in mechanization for CA systems in similar agro-ecosystems around the world. One good example would be the outstanding success of conservation agriculture in Brazil and the current efforts to introduce farmers in several African countries to the benefits of this kind of labour saving crop production system. At the same time this group should make itself aware of current worldwide concern with climate change and the implications that this has for environmental protection. Again CA has an important role to fulfil.

Manufacturers who involve themselves with the vanguard of innovation introduction can expect to benefit from batch orders of equipment for pilot projects. These will usually be funded by governments or development organizations and can remove the risk associated with production for direct sale to farmers who may have poor purchasing power and equally poor access to credit supplies. The experience gained from this kind of pilot activity puts both manufacturers and dealers in a good position to judge the farmer demand for the product. It also gives an excellent opportunity to master the manufacturing processes required and to assess the cost the production process.

Although it is true that costs and benefits will be uppermost in manufacturers' minds, they are also capable of philanthropic actions. Technology transfer to African countries through in-house training is one example that has been proposed by Brazilian manufacturers¹¹. It should, however, be pointed out that technology transfer in the form of joint venture manufacture in developing countries is only likely to be successful when a mature market demand has been built up for the technology in question.

Synergistic Associations

By associating with other stakeholders promoting relevant innovations (such as international development organizations like FAO and IFAD, trade associations, national extension services and rural finance institutions) manufacturers can take a lead in promotion and demand creation through participation in on-farm trials and demonstrations, field days and other opportunities for practical demonstrations.

Participation in Machinery Testing Programmes

Manufacturers are key stakeholders in programmes of farm machinery testing. As noted above with reference to policy makers, manufacturers and importers must be included, along with end users, in any testing scheme. On-farm testing during the prototype development phase is an essential, but an often underestimated activity. By including representatives of farmer user groups at an early stage of product development, it is more probable that the finished article will enjoy a higher level of acceptance than a product introduced without consultation and participation.

¹¹During a three day trade mission seminar with Brazilian and East African manufacturers in Londrina, PR, Brazil, May 2008

Improve Business Management

The business management of larger scale manufacturers, importers and dealers is of high quality almost by definition as poor performance in this area would quickly lead to financial failure. However there is evidence that smaller scale actors are deficient in their business management. Training in the subject is often necessary and this group should actively seek out sources of information. The most likely provider of appropriate services will be a government sponsored training centre, but NGOs and credit institutions may also play important roles in the supply of relevant orientation and training.

Staff Training Programmes

There is an increasing awareness on the part of many developing country governments that to achieve environmental protection through the application of sustainable farming practices, there is a crucial need for more and better mechanization services for farmers. This means that the technology available will become more sophisticated for many countries as their economies become more integrated with the global market. In this situation staff will need to have access to programmes of continuous training (both for production and sales personnel) to improve staff morale and keep them up to date with innovative techniques and practices.

Attain and Maintain Competitive Advantage

To achieve market share and competitive advantage, manufacturers need to pay attention to a series of factors (according to successful companies). These include:

- Quality control, perhaps even to the extent of compliance with ISO 9000¹² standards.
- Provision of technical assistance to dealers and users. In this context it is important to avoid 'over selling', that is selling more machines than can be afforded the needed technical backup in terms of training and replacement parts.
- Good geographical coverage with the distribution network.
- Competitive pricing of the product.
- A policy of continuous product improvement.
- Investment in technology innovation.

Machinery Hire Services

Coordination with other Stakeholders

The business of providing machinery hire services for CA should be developed in close coordination with other stakeholders (especially farmers) to define needs and select the most appropriate solutions. It makes little sense, for instance, for a machinery hire service to be offering disc ploughs and harrows when the extension service is recommending reduced cultivation to cut energy requirements for agricultural production and to protect the environment. Farmers cannot adopt new practices if the service is not available, so that hire service providers need to liaise with manufacturers and importers to have access to the more profitable (for farmers) and more environmentally friendly technologies of CA.

Business Management

Public sector machinery hire services have proven to be notoriously unprofitable and therefore, in the long term, unsustainable. It is difficult, in the current free market climate, to endorse public sector machinery services. This means that the services offered must be profitable and experience has shown that the ability to calculate charging rates that reflect their real costs is often lacking. This is probably the most important aspect for private sector service providers and they will need to be trained in this discipline, just as was recommended for small-scale equipment manufacturers.

¹² Adherence to ISO 9000 standards does not of itself ensure product quality, but rather that consistent business processes are being applied (http://en.wikipedia.org/wiki/ISO_9000)

Quality Control

Whereas there is some evidence that farmers are frequently satisfied with cheaper services of inferior quality, this is unlikely to be the best service to offer for long-term sustainability. Maintaining high standards of quality in the work done requires tight quality control and will also require rigorous operator training.

In-service Training for Operators

The need for continuous in-service operator training follows from the previous point. It is also important in the dynamic environment of changing and improving the technologies being demanded. New practices require new approaches and, in the case of CA, novel machinery to implement them. It is not realistic to expect operators to reach acceptable levels of proficiency without the appropriate training.

Maintenance and Servicing

There is abundant evidence of poor servicing at machinery hire centres and this is manifested in machines lying idle through breakages and lack of parts. Again, training is required in parts control and adherence to servicing schedules.

Machinery Repair Services

Machinery repair services in developing countries are frequently under-capitalized and operate out of inadequate premises with insufficient tools and equipment. Many of the points mentioned above in the case of hire service providers also apply to repair service providers. In particular improvements are widely required in the following areas:

Business Management

This is needed especially for the calculation of accurate operating costs and, therefore, profitable charging rates. Current practices tend to charge according to perceived ability to pay, or by comparison with prices charged by other service providers (which may also undervalue the costs of work done).

In-service Training for Technical Staff

As has been mentioned in the cases of other stakeholders in the supply chain, a dynamic technological situation (of CA adoption, for example) will give rise to specialist repair needs which are best acquired through thorough technical training rather than by trial and error. Manufacturers and importers may play a role in this process, but in most developing country situations there is likely to be a need for a partnership between these stakeholders and the public and NGO sectors for the provision of the appropriate training.

Farmers

Large-scale farmers (rather like the larger-scale manufacturers and importers) are quite capable of managing their finances, providing training for their operators, gaining access to credit lines, keeping abreast of innovations and are fully integrated into the commercial market. On the other hand smaller-scale farmers may often require some assistance and orientation to become integrated into the market economy. In the process of becoming more commercially oriented, many of these farmers will need to acquire CA mechanisation services through hire or purchase.

Business Expertise

Farmers need information on how to choose between machinery options and for this they will need training in cost calculations, cash flow management and budgeting (especially partial budgeting).

Knowledge of Innovations

Smaller-scale farmers will usually not have easy access to knowledge of innovations (via the internet for example). This knowledge has to be supplied by the extension service, by NGOs, by regional knowledge brokers such as the African Conservation Tillage Network (ACT), or through development projects funded by international organizations.

Farmer Groups

When farmers organize themselves in groups they will usually find themselves in a better position to control their businesses in comparison with individual farmers working on their own. A farmer group with a bank account will clearly have better possibilities of gaining access to rural finance providers. They will also be better placed to acquire technology for enhancing the value of their products (by the purchase of a mill, for example, or other processing technology). However group ownership of farm machinery that is highly seasonal in its use cannot always be recommended. A tractor and NT planter will be needed by all, or most, group members at the same time and allocating access to the equipment may be divisive. For this kind of technology, experience indicates that better service is provided by individual entrepreneurs (typically larger-scale farmers) who then offer a custom hire service.

How farmer groups might be integrated in the machinery input supply chain is shown in Figure 13. The Figure indicates how financial institutions may channel credit for farm power input acquisition via farmer group savings schemes (which could be supervised, for example by the Village Organization in the Pakistani situation). The Financial institution then links with the machinery supplier which can supply equipment directly to the farmer group, or via an equipment service provider. The appropriate extension messages, relevant to the proposed technology and delivered by competent, well trained extensionists, are supplied to the CA machinery suppliers, service providers and farmer groups.

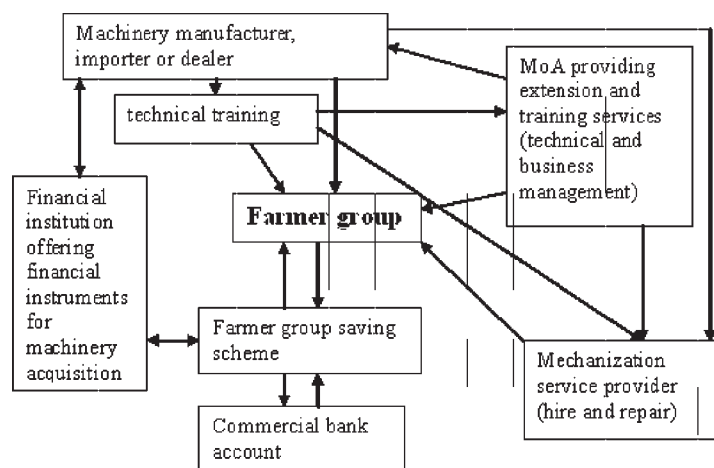


Figure 13. Possible interrelationships in the farm power input supply chain to farmer groups

Conclusions

CA for Environmental Protection

Worldwide many policy makers are justifiably concerned about tackling environmental degradation, reducing pollution, saving energy and limiting global warming. Promoting CA to achieve more widespread adoption is an important and increasingly attractive way to contribute to these goals. A major constraint to CA adoption, particularly among smallholder farmers in developing countries, is the acquisition of appropriate equipment; and especially equipment that is locally made and well adapted to local conditions.

CA policy should be compatible with other policy initiatives and so should ideally form part of a coherent national policy on agricultural improvement, and particularly mechanisation strategies. This should consider the present and desired situations and map out the measures needed to move from one to the other.

Improving the Quality and Supply of CA Equipment

Where there is no track record of manufacture of CA equipment then this can be a major hurdle for CA promotion. Policy options to encourage local manufacture include the following:

- Tax relief on raw materials if these attract import duty when finished agricultural machinery does not. This will need imagination and determination; it will not help to hold that raw materials favoured in this way may be deviated to other, non-agricultural, uses.

- Batch purchase of novel equipment for resale to end users via public sector institutions such as the extension service.
- Collaborative R&D. R&D is expensive, agricultural research institutions and universities can play an important role in partnership with the private sector (both manufacturers and farmers).
- Machinery testing is closely allied to the previous point. Collaborative testing programmes involving manufacturers, test engineers and farmers would ensure that testing is relevant to the needs of all stakeholders and does not become an academic exercise with few, if any, beneficiaries. Comparative testing of a range of makes and models in an on-farm environment is one attractive option.
- Training manufacturers and other stakeholders in skills such as business management and manufacturing techniques for modern equipment (plastic moulding, for example) would fill a felt need for the industrial sector. Training farmers in CA techniques and equipment use and management are also useful roles for the public sector.

Encouraging Farmer Adoption of CA

Farmers in many developing countries may be unaware of the benefits of CA, they may be reluctant to make the change from traditional practices to CA or they may not wish to risk isolation, or even ridicule, in their communities by embarking on radically different practices. Some of the ways that policies and institutions can help are:

- Providing a well trained and knowledgeable extension service. It is the unfortunate case that many extension services are not able to attract well qualified experts who may often be less knowledgeable than their farmer clients. Such a change requires long-term public sector commitment to improving the quality of the service offered and a more thorough penetration of the agricultural sector. Training and refresher courses at all levels are needed.
- The extension services are required to train farmers to adopt and adapt CA practices with the goal of 'beating the heat' and accommodating agricultural practices to climate change. TV, radio and print media must reach the farmers. One suggestion would be to create science TV channels with the express purpose of explaining to farmers (and indeed many policy makers) the long term consequences of their current practices.
- Extension services need to be empowered to capture farmer knowledge on how they fine tune different elements of CA and RCTs to cope with location specificity. Farmerto-farmer exchange visits between sites would be synergistic in this respect. Farmertofarmer extension systems also need to be promoted since farmers are less wary of and more willing to listen to other farmers when adopting new technology. Documentation, publication and dissemination of results are critical components for upscaling CA.
- Creating knowledgeable personnel for extension and R&D programs will also require another gap to be filled. Currently formal university and agricultural college training pays scant regard to CA practices, systems and potential. This appears to be an important constraint.
- Finance options for smallholder investment in agricultural technology are typically few and far between. Private sector finance service providers (usually banks) are often reluctant to extend finance options to farmers whom they view as resource poor and a risky market. The extension of subsidized rural credit may not be a panacea unless accompanied by wider rural development initiatives such as rural infrastructure and support for commercialized agriculture.

Revision of Obsolete Policies

Many government policies have been formulated over the years and can now be seen to be distorting the situation with regard to adopting environmentally friendly and cost saving technologies (like CA). Such policies should be carefully reviewed and ruthlessly pruned when they are seen to be inappropriate for today's situation of increasing population growth and environmental degradation where the need is for greater protection and more productive agriculture. Box 2 gives some examples from the situation in Asia.

Land Tenure and Payment for Environmental Services

Land tenure systems as they stand today provide no incentives for tenants to farm land sustainably and to use CA practices. This results in a lose-lose scenario for both owner and tenant. Policies are needed to protect a tenant's investment in land improvement. This issue could be resolved by providing incentives to tenants through

direct payments for environmental services such as improved soil health, reduction in greenhouse gas emissions and carbon sequestration credits in addition to ensuring the tenant's rights to farm the land continuously.

References

- Abbas, S.G. 2007. Case study on farm equipment related enterprises: availability, skills and services provided to farming communities in two selected districts of Pakistan (Rawalpindi and Sheikhpura). An unpublished report prepared for AGST, FAO, Rome. 82p.
- Amjad, N. 2004. Country report: Pakistan. Hanoi, Vietnam. Third session of Technical Advisory Committee (TAC) of the Asian and Pacific Centre for Agricultural Engineering and Machinery (APCAEM). 13-14 December. <http://unapcaem.org>.
- Casão Junior, R. and Guilherme de Araújo, A. 2008. Study to highlight lessons to be learnt for the development of equipment, manufacture, supply and technical support related to increasing farmers' adoption of CA practices in Tanzania and Kenya. Produced for the FAO project Conservation Agriculture for Sustainable Agricultural and Rural Development.
- Derpsch, R. 2005. The extent of conservation agriculture adoption worldwide: implications and impact. *In: Linking Production, Livelihoods and Conservation: Proceedings of the Third World Congress on Conservation Agriculture*, Nairobi, Kenya, 3-7 October 2005 (CD).
- Derpsch, R. 2008a. No-tillage and conservation agriculture: a progress report. *In: Goddard, T., Zoebisch, M.A., Gan, Y.T., Ellis, E., Watson, A. and Sombatpanit, S. (eds) 2008. No-till farming systems. Special publication 3. World Association of Soil and water Conservation. Bangkok. ISBN: 8789-974-8391-60-1. 544 p.*
- Derpsch, R., 2008b. www.rolf-derpsch.com
- FAO. 2008a. www.fao.org/ag/ca
- FAO. 2008b. www.fao.org/ag/ags/subjects/en/farmpower/mechanization/strategy.html
- Giller, K.E., Witter, E., Corbeels, M. and Tittonell, P. 2008. Conservation agriculture and smallholder farming in Africa: The heretic's view. Submitted to *Field Crops Research* (July 2008).
- Gupta Raj and Ken Sayre . 2008. Conservation Agriculture in South Asia - Some Lessons Learnt. Professional Alliance for Conservation Agriculture, ((PACA) , News Letter, 3: 1-3. New Delhi .
- Harrington, L.W. and P.R.Hobbs. 2009. The Rice-Wheat Consortium and the Asian Development Bank: A History. IRRI, Philippines. (To be published in 2009.).
- Higgins, D.R. and Reganold, J.P. 2008. No-till: the quiet revolution. *Scientific American*. June 30 pp70-77.
- Hobbs, P.R. and R.K. Gupta. 2003. Resource Conserving Technologies for Wheat in Rice-Wheat Systems. *In J.K. Ladha, J. Hill, R.K. Gupta, J. Duxbury and R.J. Buresh. (eds) Improving the productivity and sustainability of rice-wheat systems: issues and impact. ASA, Spec. Publ. 65, chapter 7: 149-171. ASA Madison, WI. USA*
- Hobbs, P. R. 2007. Conservation agriculture: what is it and why is it important for future sustainable food production? *Journal of Agricultural Science, Cambridge* 145, 127–138.
- Hobbs, PR, Sayre KD & Gupta, RK. 2008. The Role of Conservation Agriculture in Sustainable Agriculture. *Philosophical Transactions of Royal Society B (UK)*: 363: 543-555
- Hollinger, F., Odogola, W. and Sims, B. 2007. Financing improvements in farm mechanization in Uganda. Kampala. GTZ – SIDA Financial System Development Programme. 59 p.
- Lal, R. 1995. Global soil erosion by water and carbon dynamics. *In: Lal, R., Kimble, J.M., Levine, E. and Stewart, B.A. (eds), Soil and global change. CRC/Lewis, Boca Raton FL: 131-141.*
- Morgan, R.P.C. 2005. Soil erosion and conservation. Blackwell Publishing Ltd. ISBN: 13:978-1-4051-1781-4. 304 p.
- Rudenko, I., U. Grote, J. Lamers (2008): Using a Value Chain Approach for Economic and Environmental Impact Assessment of Cotton Production in Uzbekistan. *in: Jiaguo Qi, et al. (eds). Environmental Problems of Central Asia and Their Economic, Social and Security Impacts. Springer, AK/NATO Publishing Unit.*
- Sayre, K.D., and P.R. Hobbs. 2004. The Raised-Bed System of Cultivation for Irrigated Production Conditions. *In R. Lal, P. Hobbs, N. Uphoff and D.O. Hansen. (eds). Sustainable Agriculture and the Rice-Wheat System. Chapter 20: 337-355. Ohio State University. Columbus, Ohio, USA.*
- Sims, B.G., Kienzle, J. and Friedrich, T. 2007. Optimizing land and water use the role of equipment and input supply. *In: Sims, B.G., Kienzle, J., Cuevas, R and Wall, G (eds) Addressing the challenges facing agricultural mechanization input supply and farm product processing. Proceedings of an FAO workshop held at the CIGFR World Congress on Agricultural Engineering, Bonn, Germany, 5-6 September 2006. Rome. Food and Agriculture Organization of the United Nations. Agricultural and Food Engineering Technical Report 5. pp 23-26. ISBN 978-92-5-105784-1.*

The Tragedy Is On, The Tragedy Is Over: Pastoral Challenges and Opportunities for Conservation Agriculture

Michele Nori* and Constance Neely

¹*Independent Consultant on Agro-pastoral Livelihoods; Via Casine, 10 – Firenze, Italy*

²*Vice President for Global Initiatives and Advocacy; Heifer International, Arkansas, USA*
(*Email: MNori69@ominiverdi.com)

Drylands traditionally represent harsh environments where production without harming the underpinning ecosystem processes has proven difficult over the long term. Pastoral societies have been practicing sustainable land management for millennia, yet they have been poorly recognised for that. Instead national policies and development investments have often aimed at reshaping pastoral resource management patterns, seriously undermining their livelihoods and contributing to degrading their environments. As the natural resource became further degraded and advancing agriculture and tenure arrangements impeded grazing strategies that reduced grassland recovery times, conflicts between sedentary agriculturalists and mobile pastoralists have increased. Recently, deeper investigations in rangeland ecological dynamics and in pastoral socio-economic patterns are helping redress wrongly conceived and misinformed development paradigms for these systems. The ecological principles behind conservation agriculture and sustainable livestock keeping are complementary; however policy dimensions and options must be redefined to ensure opportunities for both pastoralists and agriculturalists. Building grazing land resilience as well as managing the livestock-cropland interface to the advantage of pastoralists and agriculturalists can provide an important opportunity for improving relationships, efficiency, equity, and the environment in drylands.

Key words: Pastoralism, drylands, livelihood, mobility, new range ecology, nutrient cycling, conservation agriculture, holistic management

Pastoralism Today

Pastoralists are people who rely on mobile livestock rearing as the main source of their livelihood, involving a continuous symbiotic relationship and ecological balance between pastures, livestock and people. Extensive pastoral production occurs in some 25% of the global land area, from the drylands of Africa (66% of the total continental land area) and the Arabian Peninsula, to the highlands of Asia and Latin America. The World Initiative on Sustainable Pastoralism¹ currently gives an estimate of 100 million to 200 million pastoralists worldwide; IFAD is currently working with a figure of 200 million. A multi-donor study of 1997 (Pratt et al.) talks of ‘an estimated 100 million people in arid areas, and probably a similar number in other zones, [for whom] grazing livestock is the only possible source of livelihood’, possibly including extensive mixed crop-livestock systems. For sub-Saharan Africa estimations vary from 22.5 million pastoralists (NOPA, 1992)² to its double (Markakis, 2004). Swallow (1994) further estimated that in Africa there were 216 million, almost 10 times as many, agropastoralists deriving significant quantities of feed from natural pastures. It is always a sensitive issue to quantify pastoral populations as to where a line is drawn between pastoralism and agro-pastoralism.

Overall pastoral systems are important to global society as they support herders’ subsistence, provide large quantities of food and non-food products which play a major role in ensuring local food security, and contribute significantly to the national economies of poor countries (cfr. Nori & Davies, 2007). These contributions accrue from areas where soil, rainfall and temperature conditions provide limited effective options for alternative land uses. Furthermore pastoralists’ capacity to enhance protection and regeneration of the natural resource base compared to other land uses is also being increasingly acknowledged.

There are strong commonalities in livelihood strategies of these groups exploiting distant and diverse drylands or highlands of the world, from Sub-Saharan African dry lowlands to cold Asian plateaux, from the tropical savannah to the cold northern steppe – a feature that is much less evident among other population groups across the globe. Pastoral groups inhabit environments characterised by resource-scarce, climatically marginal and highly variable agro-ecological conditions, where mobile livestock rearing has a natural comparative advantage and other land uses have been shown to be ineffective (Cossins, 1984; Hubl, 1985). The constraints posed by the physical and agro-ecological set up are critical in shaping the socio-economic livelihood patterns of pastoral communities, which

¹<http://www.iucn.org/wisp/index.html>

² “Nomadic Pastoralism in Africa”, A major review and research project funded by Unicef and the UN Sudano-Sahelian Office

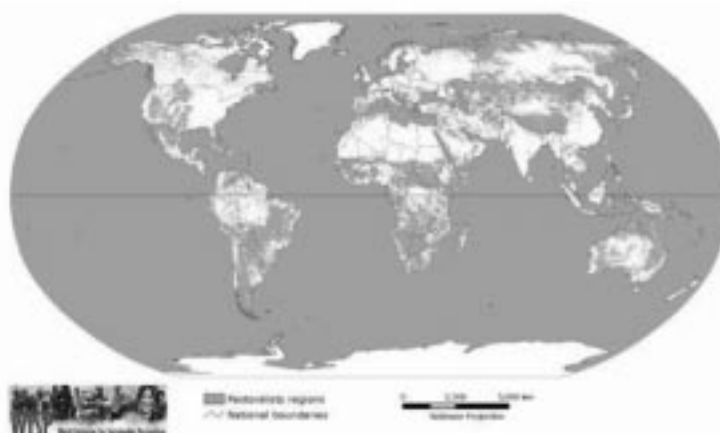


Figure 1. Global distribution of pastoralists (source: Nori & Davies, 2007)

hinge upon strategies that continuously adapt to a limited, highly variable and unpredictable resource endowment. Diverse pastoral societies are characterised by different animal species (Table 1). Studies have established the relationships between the animals characterising a pastoral society and the related agro-ecological and socio-political implications³.

Table 1. Regional zonation of pastoral systems (Blench, 1999)

Zone	Main Species	Current Status
Sub-Saharan Africa	Cattle, camel, sheep goats	Declining due to advancing agriculture
Mediterranean	Small ruminants	Declining due to enclosure and advancing agriculture
Near East and South-Central Asia	Small ruminants	Declining in some areas due to enclosure and advancing agriculture
India	Camel, cattle, sheep, goats	Declining due to advancing agriculture but peri-urban livestock production expanding
Central Asia	Yak, camel, horse, sheep, goats	Expanding following de-collectivisation
Circumpolar	Reindeer	Expanding following de-collectivisation in Siberia, but under pressure in Scandinavia
North America	Sheep, cattle	Declining with increased enclosure of land and alternative economic opportunities
Andes	Llama, alpaca	Contracting llama production due to expansion of road systems and European-model livestock production but expansion of alpaca wool production

Currently, the majority of these zones are under pressures related to advancing agriculture which may be further exacerbated with expanding biofuel production.

The Lasting Peril Of Wrong Advice

Amongst the many specific features that characterise pastoral populations, one deserves peculiar attention: the highest rate of dramatic failures of development policies and investments (Sandford, 1983; Waters-Bayer & Bayer, 1994). The history of development initiatives in pastoral environments is a dramatic sequence of misconceptions, wrongdoings and ineffective investments. Already by the end of the 1980s Harrison quotes a World Bank survey that records 300 failed projects in Africa, partly or wholly concerned with livestock developments (1987:226), with the African pastoral sector experiencing the greatest concentration of failed development projects in the world.

The development discourse that has been driving interventions in these regions was triggered by the idea that herding societies had not been able to develop institutions capable of regulating the ecological balance between

³Reference is made to the journal *Man*, volumes 4 to 7, 1969-1972.

people, livestock and vegetation. Despite their existence and evolution in marginal and harsh environments for millennia, pastoralists have been perceived and pictured as economically irrational (Hardin, 1968), willfully ignorant (Bennett, 1988), self-destructive (Anderson et al., 1999), engaged as they seem in threatening peaceful neighboring communities and pillaging the natural environment (Haaland, 1977; Livingstone, 1977). By constructing the negative myths of overstocking, desertification and insecurity these theories paved the way to conceiving pastoralism as economically inefficient, ecologically dysfunctional and socially backward. Extreme drought events in the Sahel and the Horn of Africa during the 1970s and 1980s (which added to the infamous Dust bowl experience in US during 1930s) and increasing conflict in pastoral regions further supported this vision, that pastoral resource management was at the root of unsustainable livelihood patterns and processes of desertification.

Conceiving pastoralism as 'wrong, destructive, or backward' called for deep reforms both as a natural resource management and as a livelihood system. The rationale of these strategies was to make pastoral productive systems more profitable to the national economy, either by converting their lands to farming (and lately into natural parks), or by incorporating pastoralists into the market economy (Galaty, 1980; Talle, 1988). In that sense pastoral development was conceived as increase in the livestock productivity - with more livestock products available for local and export markets - rather than improvements in the welfare of pastoralists (Sandford 1983) and the recognition of their role in land stewardship (Lane, 1988). With this intent overall development policies and investments in pastoral areas have followed a progression that initially addressed technical solutions targeting the productive aspects of pastoralists' main commodity (livestock), then moving to a wider approach targeting the tenurial and managerial aspects of pastoral natural resource base (rangelands). The illusion that development in such context was to be brought through material improvements aimed at enhancing productivity levels turned soon into the recognition that such interventions in the longer term proven unable to improve people's livelihoods but rather undermined their ecological as well as socio-political fabrics (Gunn, 1990).

Table 2. The three main stages of development interventions in pastoral areas

Period	1950s to 1970s	1980s to 1990s	More recently
Focus	technical aspects of the livestock production system	efforts aimed at readdressing range management	enabling environment for effective pastoral management
Actions	new breeds, forage production, feeding supplementation, animal health / veterinary systems, water availability	grazing reserves, group ranching, land titling, herders' organizations,	policy reforms, institutional change, conflict resolution, regional mobility, credit provision, information systems

Unsuccessful efforts have led to dismantled livelihood strategies and degraded land health which created a cycle of increasing social and environmental impoverishment. To break this cycle, the development focus is now on enabling environments for effective pastoral management, policy and institutional change, conflict management and enhanced services for mobile livelihoods.

Threats, Promises And Root Causes

Although it is here acknowledged that the dualistic distinction between farmers and herders is of limited value - due to the dynamism and the interconnectedness of such systems which often rely on both crops and livestock production in complementary ways - and a wide range of agro-pastoralists do exist in practice, we utilise these terms here for simplification purposes to address interactions between communities who mainly rely allocate most of their time in crop or extensive livestock production. An extensive debate on this vanishing dualism can be found in Hussein, K. (1998).

Conflict stemming from competing for limited natural resources tends to be recurrent in pastoral areas (Blench, 1996; Hussein et al., 2000). Conflicts among mobile pastoralists and agriculturalists have been on record for hundreds of years where the two groups either co-exist, where pastoralists move onto sedentary farmland due to climatic factors and lack of forage or where farmers block access to pastoral resources (Umar, 2002; Nori et al., 2007; UNDP, 2007; SoS Sahel, 2008). Watering spots and grazing reserves in the dry season are often a matter of survival however these critical resources are typically located in expanding mixed rain-fed or irrigated farming systems (Pedon, et al. 2006; SoS Sahel, 2008). While it is well documented that most pastoral rangelands are unsuitable for large-scale agriculture, policies at national and regional levels have continued to encourage sedentary

farming or ranching, which reinforces the misguided view that pastoralists are traditionally unproductive and open the floor for conflictive relationships and unsustainable resource management.

Although conflictive relationships are often recorded, field reporters seem often less keen in assessing and describing the wide range of cooperative and synergistic relationships between migratory herding communities and the settled agriculturalists with whom they interact. Mutually dependent, their survival and prosperity depend on each other (Nori, 1998; van Driel, 2001). Pastoralists historically have capitalized on the presence of crop residues on farmers' fields at the beginning of the dry season after crops are harvested, when pasture available for animal grazing starts declining; farmers benefit from the nutritional value on animal residues, on their side. Exchanges between livestock protein-rich products and cereal crops are beneficial for both communities, and sedentary farming communities benefit in a number of ways from the environmental wealth of well-managed pastoral areas, as they provide for alternate food stocks which can be drawn upon in times of food crisis (i.e. edible nuts, roots).

Pastoralism and agriculture must be thus viewed from an interdependent landscape and livelihoods perspective in the drylands in order to attend to root causes of emergent conflict, poverty and food insecurity.

Box 1 - The Karo and Hamar groups: access rights and bond friendship

Bond friendship can be discussed with respect to the Karo and Hamar pastoral groups. The Karo and Hamar groups inhabit the south-western tip of Ethiopia bordering Kenya. The Hamar inhabit a mountainous area that is free of tsetse fly infestation, while the Karo live in the lowlands, where tse-tse flies are widespread. On the other hand, the Karo area is suitable for the cultivation of sorghum. The Karo gain access rights to grazing lands in the Hamar highlands through the institutions bond friendship and reciprocal gift exchange. The system works as follows: during the dry season, the Karo people keep their cattle with bond friends in the Hamar area. In exchange for the grazing land and their labour, the Hamar households keep most of the butter and milk for themselves.

The Karo families regularly visit their bond friends in the Hamar area. On their way, they engage in marketing activities. They sell products, like honey, and buy goods, like coffee and bullets. Upon arrival at a bond friend's home, the Karo families inspect their cattle and stay at their host's house for days and even weeks. The host often gives his guest sheep and goat. In addition to the gift, the Karo family takes home some butter produced by its own cows kept with the Hamar family. The Hamar family, in turn, visits its bond friend in the Karo area and returns home with sorghum obtained as a gift from the Karo family. Resource-based conflicts often flare up between the Karo and Hamar people. However, conflicts rarely go out of control because the two peoples have developed mechanisms to manage disputes. Whenever a conflict arises, elders from both sides convene and settle the issue. As usual, the reconciliation process is part of an elaborate family accompanied by the ritual of goat slaughtering⁴.

This paper will focus on addressing two causal dimensions that have impeded sustainable livelihoods and landscapes in the drylands - through a) improving the ecosystem health (land health) that underpins all production systems and b) reframing access to the natural resource base.

Landscaping Herds For Non-Equilibrium Systems

Properly managed rangelands provide plants for human food, wood, thatching, shade and medicine, and represent important elements for nutrition, health and the general welfare of rural communities. Healthy rangelands provide important ecosystem services in the form of improved biodiversity of plant species, ground cover that increases water infiltration and storage, and carbon storage in soil organic matter (Savory and Butterfield, 1998; Batjes, 2004; Neely and Bunning, 2008; Neely and Hatfield, 2008). Many of these landscapes were maintained for millennia through animal impact and grazing as large herds of wild ungulates and pack hunting predators moved with seasons. Grasslands and grazers have co-evolved over millions of years and grasslands need grazers to facilitate energy flow and recycling of nutrients (McNaughton, 1979).⁴ A deeper understanding of historical grass and grazer interdependence dispenses with the long held notion that livestock and overgrazing, as typically understood, are the causes of land degradation (Savory and Butterfield, 1998). During the late 1980s and early 1990s through longer-term controlled studies, quantitative methodologies and sharper analytical tools (Gunn, 1990:29), scientists from the New Range Ecology approach were able to reverse the negative picture attached to pastoralists, by assessing and demonstrating that raising livestock through seasonal migration is a uniquely efficient way to draw the maximum well-being out of marginal areas unsuitable for other forms of agriculture – such as mountains or drylands - while also ensuring a good degree of environmental conservation, as the biodiversity, robustness and resilience of rangelands attest.

⁴ Petros, 2000, quoted in Nori et al., 2007

New range ecologists showed that arid and semiarid environments are inherently unstable, meaning that populations or other components are not in long-term balance with other elements of the system. Climate variability is so high and unpredictable that it represents the primary cause of complex ecosystem dynamics (Scoones, 1994; Ellis, 1994); livestock and vegetation do not control each other, and external shocks (i.e. drought) rather than endogenous processes (i.e. animal population pressure) determine livestock numbers and the state of vegetation (Ellis and Swift, 1988). The new model depicts semi-arid ecosystems as rarely reaching equilibrium, due to a number of bio-physical factors, compared to which management plays a limitedly significant role, so de-emphasising the effects of stocking rate on future productivity. Change in non-equilibrium environments does not occur gradually, does not follow successional models and does not show the classical feedback regulatory mechanisms. Non-equilibrium systems are fundamentally resilient in that rangeland plants rapidly recover when rain comes. In this perspective concepts such as 'climax vegetation', 'overgrazing' and 'carrying capacity' are accordingly highly problematic as they fail to recognize the variability and patchiness of arid lands ecology (Behnke 1994, Behnke & Scoones 1992, Behnke et al. 1993, Coughenour et al. 1985, Ellis & Swift 1988, Homewood & Rodgers 1991). Drought and desertification trends are viewed more the result of long-term climatic oscillations/patterns rather than of detrimental local land use patterns/human activities – as the recent Climate Change debate is also demonstrating.

By challenging some basic, and often deeply embedded, concepts of naturalness, balance, and order, non-equilibrium dynamics indicated new ways to think about resource management and policy. Externally-led development based on equilibrium and predictability concepts proved unable to understand and support pastoral resource management which became increasingly recognised as a complex dynamical pattern of behaviour, fine-tuned to non-equilibrium and thus unpredictable ecosystem functioning (Ellis, 1994).

This revised understanding of range dynamics brought fresh elements in the analysis of pastoral societies, contributing to acknowledge that pastoralists a) do care about the conditions of the natural resource base (on which they depend), b) they have thus developed institutions accordingly and that c) these institutions are tailored and suited to the local environmental set up. Concepts of space and time variability and non-linear system interactions shed new light and provided a fresh view on pastoral mobility and overall management of complex rangeland ecosystems, which has in turn stimulated a more constructive approach towards pastoral resource management, and triggered a more comprehensive understanding of pastoral livelihoods (Behnke and Scoones, 1993; Nori, 2004).

Unmanaged grazing or complete exclusion from grazing will often lead to desertification and loss of biodiversity in all but high rainfall areas (Jones, 2006). In medium to low rainfall areas grasses which are not grazed can become senescent and cease to grow productively (McNaughton, 1979). Savory and Butterfield (1998) articulated key insights that inform how livestock can be used in non-equilibrium systems in a way that mimics historical herds and regenerates degraded lands through animal impact. These insights recognize a) the advantage of the behaviour of bunching animals that are continuously moving in order to distribute dung and urine, trample the plant residue, and chip the soil surface to enhance water infiltration; b) that overgrazing is a function of time (allowing appropriate recovery periods) and not numbers of animals; and c) that land and plants respond differently to different management practices (fire, grazing, animal impact, etc) depending on the distribution of moisture throughout the year. Based on these insights, a planned grazing method was developed and is currently being put into practice world wide. The livestock grazing management results in improved soil cover, increased water infiltration/retention, improved plant diversity and biomass, controlled time that plants are exposed to grazing, increased animal density and trampling, distributed dung and urine, and improved livestock quality and productivity. Principles and practices that are in line with those of Conservation Agriculture.

Niamir-Fuller, 1999 notes that grassland productivity is dependent on mobility of livestock and herders, the length of continuous grazing on the same parcel, the frequency with which the patch is regrazed, dispersion of animals and herds around the camp and interval during which the patch is rested. Further, she points out that pastoralists can maintain higher populations of herbivores in a given area if they have ensured and flexible access to the different habitats and resources. A greater number of cases are emerging that demonstrate that grazing strategies that use animal impact and allow for an appropriate recovery times can lead to improved land health. If such approaches are implemented at a landscape level, livestock can positively influence ecosystem health of rangelands leading, among others, to increased feed supplies and refurbished ground water supplies for crops and grazers thus reducing one of the causes of conflictive relationships – degraded or scarcity of the resource base.

Unmanaged grazing or complete exclusion from grazing will often lead to desertification and loss of biodiversity in all but high rainfall areas (Jones, 2006). In medium to low rainfall areas grasses which are not grazed can become

senescent and cease to grow productively (McNaughton, 1979). Niamir-Fuller, 1999 notes that grassland productivity is dependent on mobility of livestock and herders, the length of continuous grazing on the same parcel, the frequency with which the patch is regrazed, dispersion of animals and herds around the camp and interval during which the patch is rested. Further, she points out that pastoralists can maintain higher populations of herbivores in a given area if they have having ensured and flexible access to the different habitats and resources.

Righting The Rights Issue

Mobility is this critical for extensive livestock rearing through continuous tracking of critical feed, water and other pastoral resources through time. Swift has recently classified mobility according to its main purpose, whether related to production or exchange or escape purposes (Swift, 2008)⁵. Other classifications rely on the geographical dimensions of mobility and the applied patterns (refer to Nori et al., 2005). Extensive livestock keeping can exist for much of the year on arid lands so long as they have secure access to water and higher value forage (such as browse) during the dry season, and the ability to move to wet season pastures during the rains and access salty soils and medicinal plants at certain times of the year. In more temperate environments, the seasonal movements between summer highland and winter lowland pastures play a similar role. Secure access to drought refuge areas is also essential (e.g. forest areas, swamp lands) while forest resources such as fuel wood and wild fruits also complement dietary and income-generating patterns. The interdependence of arid lands with other ecosystems (such as forests or wetlands) thus creates opportunities for resource extraction across several different and complementary ecological niches.

Exchange-related mobility is also critical importance within pastoral livelihood patterns and indications are that its relevance is on the increase, as the market integration of pastoral livelihoods seems a characterising feature of most dryland environments (Nori, 2009). This form of mobility aims at enhancing opportunities to establish and develop reciprocal and interdependent relations with neighbouring sedentary communities (farmers, urban dwellers, etc.), to access different market opportunities (to sell own products and to purchase staples and inputs such as veterinary drugs), and to search for complementary livelihood sources. Exchange-related mobility is not necessarily finalised to generate an income per-se, but rather to access markets and products from other land users, to acquire or share information, to participate to wider networking.

Apart from the human and social capitals it hinge upon (i.e. indigenous skills over climate, environment and livestock functioning as well as extended networks and information systems) mobility also implies and involve access to a large set of resources. Misconceived development paradigms, traditionally unfavourable land and food policies and increasing land competition generated by growing population pressure have been increasingly squeezing herders' land rights and shrinking the scope of their moves.

As predicted by some theories (Boserup, 1965, 1981; Demsetz, 1967 and others), and indeed as pushed by most governments and international agencies (Kirk, 1999), growing population pressure, market development, and improved technology have in time lead to increased incentives to individualize access to resources (Kisamba-Mugerwa et al., 2006) largely contributing to increasing the insecurity and vulnerability exposure of herding communities.

Although pastoral resource tenure and control mechanisms are typically defined as 'communal', it is indeed difficult to find a concept that translates the complexity of these sophisticated access rights systems (Swift, 1994;), as their *fuzzy* nature implies overlapping claims to resources, shifting assertions of rights and continuous contestation and negotiation of access rules that dominate tenure arrangements in uncertain environments (Scoones, 1994; Deveraux, 1996). What is of relevance to herders is the option to access specific land resources at different times of need, rather than the formal control over a sporadically productive piece of land. While critically accounting for the conditions of the resources (whose value changes seasonally and inter-annually), a major concern is thus allocated to the user, as rangeland utilisation patterns have to adapt to herds' needs. It is the way a resource is utilized within a specific livelihood pattern that defines the claims and rights over it.

In this context individualization and privatization might not be not necessary for either efficiency or sustainable resource management (Bromley & Cernea, 1989; Ostrom 1990), while it seems increasingly clear that individualization can lead to inequitable outcomes, increased conflicts, natural resource degradation and reduce pastoralists' ability

⁵Swift also mentions a third class under 'escape mobility', which is not considered here.

to cope with risks through spatial mobility – thus critically affecting their livelihood (Behnke, et al. 1993; Swallow 1994; Scoones 1995; van den Brink, et al. 1995; Platteau 1996; Kirk 1999; Niamir-Fuller 1999; Nori, et al., 2008).

Of Residues and Reconnections

Conservation agriculture (CA) maintains the fundamental principles of permanent vegetative cover, rotating or inter-planted crops, and minimal soil disturbance (FAO, 2007a). As it has advanced among large scale commercial crop producers, conservation agriculture is more and more being taken up by small scale and limited resource farmers in many parts of the world including 15 African countries. In Zambia, for example, some 200,000 smallholder farmers are practicing CA (FAO, 2007a). In many countries increased yields have been reported as well an enhanced capacity to produce a crop in drought years indicating an important adaptation strategy relevant to climate change.

In Sub-Saharan Africa, adaptive applications of conservation agriculture have met with constraints relative to planting equipment alongside continued competition for plant residues for fuel or livestock feed (FAO, 2007a). This comes as little surprise in regions populated by millions of pastoralists and where more than half of the agricultural population subsists on farming systems in which livestock are a major component (Swallow, 1994; Dixon et al. 2001). FAO (2006) reports that livestock can be fully integrated into conservation agriculture, by exploiting the recycling of nutrients. They note that agriculturalists can augment the crop rotation by introducing forage crops for soil cover and fodder and, at the same time, reduce pest problems. For example, Brazil has introduced 'integrated crop-livestock zero tillage systems' (ICLZT) which aims to produce high yielding pastures while limiting deforestation. In these larger scale sustainable intensification systems livestock and pasture are incorporated into zero tillage systems (FAO, 2007b). However, while integrated livestock-conservation agriculture applications are viewed as beneficial, in the drylands, conflicts around the use of organic material for animal feed or soil cover have not diminished.

In his overview of crop-livestock systems in West Africa, Powell (2003) notes that at low population densities, crop and livestock production systems often operate as separate enterprises while at higher densities, functionally linked interactions increase between the crop and livestock production systems, building upon exchanges of grain, crop residue, water, genetic resources and manure (McIntire et al, 1992, Hoffman, XXXX). In these systems Powell (2003) identified animal manure as the most important soil fertility amendment and now, with fertilizer and energy prices high, it is likely that fertility of croplands will increase in its dependence on nutrients supplied from rangeland in the form of manure. In Southern Africa, some farmers and pastoralists are currently innovating with using livestock to enhance the nutrient content and the minimum tillage using animal impact of the crop fields (Box 1).

Box 2. Managing the interface in Zimbabwe

Community members in the Hwange communal lands near Victoria Falls, Zimbabwe have experimented with kraaling livestock overnight on their maize fields during the dry season. In this scenario, the livestock are herded in one herd/mob and grazed on rangeland through the daylight hours using a grazing plan to ensure animal impact and time of recovery of plants on the rangelands. At night, during the dry season, the animals are brought back to individual cropping fields, which have movable (and lion proof) kraals on small portions of the fields. The cattle have room to lie down and are only in the kraal for seven nights or less. The kraals are subsequently moved around the crop field. The benefits of this method include even distribution of nutrients but also some disturbance of crop field surface from the hoof action that serves as soil preparation for the subsequent crop – providing a resulting minimum tillage effect. On the crop fields where this has taken place, maize yields have been reported to be as much as 14 times the conventionally managed maize yields. On most fields other crops have also been intercropped which enhances agro- biodiversity and biomass production⁶.

As argued by Blench (1996), it is likely that the complex patterns of cooperation characterizing the multiple uses of many African wetlands would have probably never developed without initially conflictive relationships. The challenge is thus to disentangle the interconnectedness of existing rights and claims over contested resources and develop common institutional frames where a mutual benefit can be obtained through their sustainable management in a shared way. Within this frame, the difference existing between rights and claims over land and livestock resources are to be critically assessed and understood.

⁶ Cfr. African Centre for Holistic Management; www.holisticmanagement.org

Cattle, Canaries and Crops

After decades of oblivion, extensive livestock rearing is gaining back priority concern on the agenda of international development agencies. A deleterious mix of misunderstanding and neglect has contributed to turning herders from a group considered as the better off amongst rural communities into the most vulnerable and food insecure. The climate change debate with its concern for communities residing under marginal climatic patterns, has turned societal attention back to herding societies, possibly with a 'canaries in a coalmine' syndrome - using them as indicators of what would be for the others under current trends of increasing temperatures and rainfall unpredictability.

In truth where climatic conditions become more variable extensive livestock production has the potential to sustain populations. Pastoralism may in fact provide food resources and secure a viable livelihood alternative where the climate change and other pressures on ecosystems result in enhanced unreliability of farming and the transformation of forest into savannah. Pastoralists seem thus better positioned than other societal groups in tackling the Climate Change challenges – as mobility and flexible resource access rights prove to be important assets vis-à-vis the adaptability requirements which are increasingly important in a changing environment. Indeed mobile livestock rearing can represent the best way to mitigate against climatic risk, particularly in marginal lands (Nori and Davies, 2007).

What we witness in the current context is that mobile livestock rearing already represents a growing activity in many marginal areas of the world. Many rural communities are increasingly rearing livestock in an extensive way as a strategy for diversifying their assets, as a response to the increase in variability and uncertainty that is associated both with the socio-economic environment as well as the climate, in India as elsewhere. Conversely, some pastoralists are themselves seeking ways to diversify their livelihood base by incorporating other production systems, as evidenced by the increase in farming amongst West African Fulani. Enhanced interactions and synergies between the two production systems seems a promising way to make best possible use of resources under variable climatic endowments. Indeed, the appreciation for pastoral resource management will even increase once governments, development agencies, scientists and private sector will accept to recognize the carbon sequestration potential of good grassland management on extensive land areas (Neely and Bunning, 2008), together with the other environmental services which pastoralists provide (and that the EU has started to remunerate accordingly).

The perception of herders as those amongst the most exposed and vulnerable to Climate Change dynamics is thus in a way contradictory, and seems to relate rather to the policy environment which is unfavourable to herders, rather than to pastoralists' inadequacy to adapt to changing environmental conditions. In recent decades while in fact shifting rainfall patterns have been recorded, with more intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics (IPCC, 2007: 8), these have been paralleled by an increasing limitation posed to pastoralists to move through different territories, to access critical livelihood resources, to trade across borders, to benefit from appropriate investments, to participate in relevant policy decision-making, thus affecting herders' capacity to anticipate, cope with, resist to and recover from the impact of such changes.

Fruitful options to strengthen collaborative links and mutually beneficial exchanges and contaminations between farming and herding groups are thus to be developed, especially in drylands areas, so to enhance the capacity of these communities to diversify their livelihood options and to enhance their adaptability vis-à-vis a globalising society and a changing climate. This process has to start from the acknowledgement and the recognition of the root diversity of the mechanisms and structures that govern resources access rights in these complementary systems (land and livestock).

Acknowledgments

The authors are grateful to the Marie Curie program of the European Commission and to the CERES program of Wageningen University for the funds provided through the 'Milking Drylands' research program. Collaborations with *World Initiative for Sustainable Pastoralism*, *International Land Coalition*, *SoS Sahel* and *International Institute for Environment and Development* are also acknowledged.

Reference

Anderson, D.M. & Broch-Due V., 1999. *The poor are not us: poverty and pastoralism in Eastern Africa*. Oxford, James Currey

- Batjes, N.H. 2004. Estimation of soil carbon gains upon improved management within croplands and grasslands in Africa. *Environment, Development and Sustainability*, 6:133-143.
- Behnke R. 1994. Natural resource management in pastoral Africa. *Dev. Pol. Rev.*12(1):5-27
- Behnke R.H. and Scoones I., 1993. Rethinking range ecology: implications for rangeland management in Africa. International Institute for Environment and Development & Overseas Development Institute. London
- Behnke RH, Scoones I. 1992. Rethinking Range Ecology: Implications for Rangeland Management in Africa. *Env. Work. Pap.* 53. Washington, DC: World Bank
- Behnke R.H., 1992. New Directions In African Range Management Policy. Pastoral Development Network paper 32c. Overseas Development Institute, London
- Bennett JW. 1988. The political economy and economic development of migratory pastoral societies in Eastern Africa. In *Power and Poverty Development and Development Projects in the Third World*, ed. DT Attwood, TC Bruneau, JG Galaty, pp. 31-60. Boulder: Westview
- Blench R., 1999. Extensive pastoral livestock systems: issues and options for the future. FAO. Rome
- Blench R., 1996. Aspects Of Resource Conflict In Semi-Arid Africa. ODI Natural Resource Perspective # 16
- Boserup E. 1981. *Population and technological change*. University of Chicago Press, Chicago, Illinois, USA.
- Boserup E., 1965. The conditions of Agricultural Growth. EarthScan, London
- Bromley DW, Cernea MM. 1989. *The Management of Common Property Natural Resources: Some Conceptual and Operational Fallacies*. Washington, DC: World Bank
- Brink van den R., Bromley D. W., Chavas J.P., 1995; The economics of Cain and Abel: agro-pastoral property rights in the Sahel – *Journal of Development Studies*, 31/3
- Coughenour MB, Ellis JE, Swift DM, Coppock DL, Galvin K, et al. 1985. Energy extraction and use in a nomadic pastoral ecosystem. *Science* 230:619-25
- Cossins, NJ 1984. The productivity and potential of pastoral systems
- Demsetz H., 1967. Towards a Theory of Property Rights. *The American Economic Review*. Volume 57, Issue 2. May, 1967, 347-359
- Devreux, S. 1996. *Fuzzy Entitlements and common property resources: struggles over rights to communal land in Namibia*. IDS Working Paper 44. Brighton, U.K.: Institute of Development Studies.
- Dixon, J.; Gulliver, A., Gibbon, D., Hall, M. 2001. Farming Systems and Poverty, FAO and World Bank
- Ellis J, Swift DM. 1988. Stability of African pastoral ecosystems. *J. Range Manage.* 41:450-59
- Ellis J., 1994. Climate variability and complex ecosystem dynamics: implications for pastoral development. In: Scoones I. Ed., 1994. Intermediate Technology Publications Ltd., London
- Ellis J., Swift D.M., 1988. Stability of African pastoral ecosystems. *J. Range Manage.*41:450-59
- FAO, 2006. Conservation Agriculture (<http://www.fao.org/Ag/magazine/0110sp.htm>) cited December 2008.
- FAO, 2007b. Tropical crop-livestock systems in conservation agriculture: The Brazilian experience Rome, Italy
- FAO, 2007a SARD And Conservation Agriculture In Africa. Sustainable Agriculture and Rural Development (SARD) Policy Brief No. 18. Rome, Italy
- Galaty, J., 1980. "Organizations for Pastoral Development Context of Causality, Change, and Assessment." In *The Future of Pastoral People: Proceedings of a Conference Held in Nairobi, August 4-8, 1980*, by the Institute of Development Studies. Nairobi: I.D.S., 284-291.
- Gunn, S.E. 1990. Development in a nomadic society : a study of indigenous and exogenous change in Northern Somalia University of Colorado, Boulder
- Haaland, G. "Pastoral Systems of Production: The Socio- cultural Context and Some Economic and Ecological Implications." In *Land Use and Development African Environment Special Report 5*, ed. Phil O'Keefe, and B. Wisner, 179-193. London: International African Institute, 1977.
- Hardin G. 1968. The tragedy of the commons. *Science* 162:1243-48
- Harrison, P. 1987. The greening of Africa. International Institute for Environment and Development — Earthscan, Paladin, London, UK. 380 pp.
- Hoffmann, I. 2002. Case Study Number 2. Biodiversity Management in West African Pastoral and Agro-Pastoral Systems. FAO. Rome, Italy
- Homewood KM, Rodgers WA. 1991. *Maasailand Ecology: Pastoralist Development and Wildlife Conservation*. Cambridge: Cambridge Univ. Press
- Hussein, K., Sumberg, J., and Seddon, D., 2000, "Increasing violent conflict between farmers and herders in Africa: Claims and the evidence" *Development Policy Review* Vol 17
- Hussein, K. (1998). Conflict between farmers and herders in the semi-arid Sahel and East Africa: A review. Pastoral Land Tenure Series No. 10. Drylands Programme. International Institute for Environment and Development & Overseas Development Group. London
- IPCC 2007. Working Group I: the physical basis of climate change. <http://ipcc-wg1.ucar.edu/wg1/wg1-report.html#foot-1>
- Jones, C. 2006. Grazing Management for Healthy Soils. March 24, 2006, (Available at <http://grazingmanagement.blogspot.com/>).
- Kirk M., 1999. 1999. *Land tenure, technological chance and resource use in African agrarian systems*. Frankfurt am Main, Germany: Peter Lang Verlag.

- Kisamba-Mugerwa, W., J. Pender, and K. Edward (2006) Impacts of Individualization of Land Tenure on Livestock and Rangeland Management in Southwestern Uganda. IFPRI
- MacIntire, J., D. Bourzat, and P. Pingali. 1992. Crop-livestock interactions in sub-Saharan Africa, World Bank, Washington, D.C. *Man* journal, volumes 4 to 7, 1969-1972.
- Markakis J., 2004. Pastoralism on the Margin. Minority Rights Group International, Nairobi
- McNaughton, S.J. 1979. Grazing as an optimization process: grass-ungulate relationships in the Serengeti. *American Naturalist*, 113: 691-703.
- Neely, C. and S. Bunning. Review of Evidence on Dryland Pastoral Systems and Climate Change: Implications and opportunities for mitigation and adaptation. FAO – NRL Working Paper. Rome, Italy.
- Neely, C. and Hatfield, R. 2007. Livestock Systems. In Scherr, S. and J. McNeely. *Farming with Nature*. Island Press. Washington, D.C.
- Niamir-Fuller, M. 1999. Managing mobility in African Rangelands: The Legitimization of Transhumance. London, UK, Intermediate Technology Publications Ltd.
- NOPA. 1992. *Pastoralists at a crossroads: Survival and development issues in African pastoralism*. UNICEF/UNSO project for nomadic pastoralists in Africa, Nairobi
- Nori M., Taylor M., Sensi A., 2008. *Browsing on fences: pastoral land rights, livelihoods and adaptation to climate change*. IIED Drylands Series #148, London <http://www.iied.org/pubs/display.php?o=12543IIED>
- Nori M. and Davies J., 2007. *Change of wind or wind of change ? Climate change, adaptation and pastoralism*. Report form an electronic conference. World Initiative for Sustainable Pastoralism, Nairobi www.iucn.org/WISP/publications
- Nori M., Kenyanjui M. B., Mohammed Ahmed Yusuf, Fadumo Hussein Mohammed, 2006. *Milking Drylands: the emergence of camel milk markets in stateless Somali areas*. *Nomadic People Magazine* 10.1
- Nori M., 2006 *Mobile livelihoods, patchy resources & shifting rights: approaching pastoral territories*. Thematic paper for the International Land Coalition, ILC. Rome;
<ftp://ext-ftp.fao.org/AG/Data/Upload/ANGR/DAD-Net/pastoralistpaper.pdf>
- Nori M., Switzer J. and Crawford A., 2005. Herding on the Brink: Towards a Global Survey of Pastoral Communities and Conflict - An Occasional Paper from the IUCN Commission on Environmental, Economic and Social Policy; Gland (Ch) <http://www.iisd.org/publications/pub.aspx?id=705>
- Nori M., 1998. From sharing to market exchanges. Livelihood connections between the Arsi herders and the Silte farmers in the Ethiopian Rift Valley, Ziway area. Report drafted for IIED on a EC-funded research project. Unpublished
- Ostrom E., 1990. *Governing the Commons: the Evolution of Institutions for Collective Action*. Cambridge University Press
- Peden, D., A. A. Freeman, A. Astatke, A. Notenbaert, 2006 Investment options for integrated water-livestock- crop production in sub-Saharan Africa. ILRI, Working Paper No. 1
- Platteau, Jean-Philippe. 2000. *Institutions, Social Norms, and Economic Development*. Amsterdam: Harwood Academic Publishers.
- Powell, J. M., R. A. Pearson, and P. Hiernaux, 2003. Crop–Livestock Interactions in the West African Drylands
- Pratt, D. J. De Haan, C. and Le Gall, F. and, 1997. Investing in Pastoralism: Sustainable natural resource use in arid Africa and the Middle East. World Bank Technical Paper 365. Washington
- Sandford S. 1983. *Management of Pastoral Development in the Third World*. Chichester: Wiley
- Savory, A. and J. Butterfield. 1998. *Holistic Management: A new framework for decision making*. Island Press, Washington, D.C.
- Scoones I. Ed., 1994. *Living with Uncertainty: new directions in pastoral development in Africa*. Intermediate Technology Publications Ltd., London
- SoS Sahel, 2008. *Herding and farming in the Nuba: agro-pastoral livelihoods in the Kordofan region*. In: *Securing pastoralism in East and West Africa Pastoral mobility* IIED & SoS Sahel; Warren Buffet Foundation
- Swallow, B. M. 1994. *The Role of Mobility within the Risk Management Strategies of Pastoralists and Agro-pastoralists*. Gatekeeper Series 47. International Institute for Environment and Development. London
- Swift J.J., 2008. Draft paper on mobility presented at the workshop on Securing pastoralism in East and West Africa Pastoral mobility IIED & SoS Sahel; Warren Buffet Foundation. Addis Ababa, November 2008
- Swift J.J., 1994. Dynamic ecological systems and the administration of pastoral development. In: Scoones I. Ed., 1994. Intermediate Technology Publications Ltd., London
- Talle Aud, 1988. Women at a Loss: Changes in Maasai Pastoralism and their Effects on Gender Relations. SSSA, University of Stockholm
- Umar, Bello Farouk (2002). *The Pastoral-Agricultural Conflicts in Zamfara State, Nigeria* Presentation for the International Farming Systems Association, Florida, USA
- UNDP (2007). *Between A Rock And Hard Place: Armed Violence In African Pastoral Communities*.
- van Driel A., 2001. *Sharing a Valley: the changing relations between agriculturalists and pastoralists in the Niger Valley of Benin*. African Studies Center 64/2001. Leiden
- Waters-Bayer A, Bayer W. 1994. *Planning with Pastoralists: PRA and More. A Review of Methods Focused on Africa*. GTZ, Eschborn

Theme 3: Environment

Session 3.1: Climate Change

Conservation Agriculture Protocols for Greenhouse Gas Offsets in a Working Carbon Market

Tom Goddard¹, Karen Haugen-Kozyra² and Andy Ridge³

¹Alberta Agriculture and Rural Development, #300, 7000-113 Street, Edmonton, Alberta, Canada T6H 5T6

²#930, 10303 Jasper Avenue, Climate Change Central, Edmonton, Alberta, Canada T5J 3N6

³Alberta Environment, 12th floor, 10025 - 106 Street, Edmonton, Alberta, Canada T5J 1G4

The global carbon market is growing rapidly and is currently valued at over \$100 B USD. In some jurisdictions, companies can offset their emissions by purchasing offset credits or contracts from others who have reduced their greenhouse gas emissions or can sequester carbon. Conservation agriculture projects can provide offsets to large emitters of greenhouse gases. In North America, Alberta created the first compliance-based, multi-sector carbon regulatory framework with an accompanying offset system in 2007. Following stringent international standards of protocol development, we have developed a range of agriculture protocols. Offset projects using these protocols have been purchased by large emitters in the first compliance period and we expect this interest to grow. Key enablers in the market besides the enabling policy include an agency to facilitate the market and an aggregator business model that gathers many small amounts of carbon offsets into large projects that appeal to the buyers. The four phases of the process of protocol development is introduced and a tillage reduction protocol (No Till) is described in more detail to illustrate issues of additionality and project scale. Offset protocols need a combination of science and policy development to provide assurance to markets. We show how we have “learned our way” into the development of a viable offset market inclusive of conservation agriculture protocols so that others may learn from us.

World interest in reducing greenhouse gas emissions is increasing. The World Bank estimated the 2007 global carbon market at \$64 B USD - double the value from a year earlier and a six fold increase from 2005 (Capoor and Ambrosi 2008). Recently, Point Carbon reported that the value of the market in 2008 had grown to \$125 B USD, more than double that of 2007 (Point Carbon, 2009). Most of that value is from the European market which tracks sales and volumes largely based on permit trading. Trading occurs where companies desire to reduce emissions but cannot in the short term, so they purchase government issued permits or project-based offset credits from others to meet compliance. The former typically occurs from regulated companies who have excess permits to sell, over and above their regulatory requirement, and the latter being created from unregulated companies who are able to reduce their emissions or sequester carbon through changes in management practices.

In regulated systems, there needs to be a clear set of rules and standards to enable trading of project-based offsets to the regulated sectors for compliance purposes. In North America, Alberta has created the first compliance-based, multi-sectoral carbon regulatory framework with an accompanying offset system in 2007 (Alberta Environment 2007a). To date, the Alberta system has the largest number of agriculture-based greenhouse gas (GHG) standards than anywhere in the world, and a large contribution of agricultural offsets created as a result (primary agriculture is a non-regulated sector). The contribution that the agriculture sector can make to reducing GHG emissions is substantial, and a well-defined Offset Policy can drive farmer uptake in conservation practices, and result in many sustainable co-benefits along the way.

The Alberta Emissions Context

Alberta has the highest greenhouse gas (GHG) emissions of any province in Canada (235 Mt CO₂e in 2006) and it is projected to increase to 305 CO₂e Mt by 2020 (Alberta Environment 2007b). Alberta has 10% of the national population but a vibrant oil/gas resource extraction industry and coal based thermal electrical generation mix result in the province comprising 33% of the total national inventory of GHGs (Environment Canada, 2008).

On a national basis, agriculture produces 7% of Canada’s greenhouse gas emissions (Environment Canada, 2008). Agriculture in Alberta produces 31% of the national agriculture emissions due to the size of the agriculture industry. Alberta has nearly one third of the agriculture land in Canada and more than half the national beef cow herd.

The 2002 Alberta Climate Change Emissions Management Act (CCEMA) required companies of a certain emission output (over 100 kt of total GHGs) to record and file statements of annual GHG emissions since 2003. Alberta had a total of 115 Mt of 2006 greenhouse gas emissions recorded under the auspices of the Specified Gas Reporting Regulation (Alberta Environment 2007b) about 100 facilities in all.. Nearly half of the total regulated industrial emissions are from coal-based power companies and one third are from oil and gas. Fourteen percent of the total emissions are classed as “other” which includes refining, cement, manufacturing, forest products and fertilizer industries. The combined total emissions of fertilizer plants were 4.5 Mt of CO₂e but they were responsible for nearly half of the total N₂O emissions. The top 30 companies are responsible for 87% of the total 2006 emissions.

Enabling Legislation and Policy

Alberta was the first province in Canada with a climate change action plan in 2002 and an enabling act to address emissions management (Climate Change and Emissions Management Act, CCEMA, amended 2007). As part of that legislation, reporting and emission reduction target regulations were introduced that required industries with emissions (CO₂e) greater than 100 kt per year to report and reduce their emissions to established targets.

Alberta chose an emission intensity basis for emission reduction targets. The emission intensity approach (GHG emissions/unit of production) made sense for Alberta because it was the first jurisdiction in North America to implement a carbon constraint on its economy, without other jurisdictions bearing this burden. From a competitiveness point of view, and Alberta being so export-focused in agriculture and energy products, particularly with the USA – this more economically friendly way of reducing emissions is important. Later, Alberta will have to evaluate its regulatory approach as talk of a North American wide cap and trade system materializes into more concrete action in the 2013-2014 timeframe.

Thus, under Alberta’s GHG regulatory system, companies are motivated to become more energy efficient in their production as well as cutting GHG emissions. Absolute caps tend to limit or reduce economic activity (companies fold or move). Alberta believes that implementation of new technologies will reduce emissions in the long term. In the meantime, market based instruments such as offset credit trading have a role to play as we move toward the longer-term goal.

In early 2007 the Climate Change Emissions Management Act was amended to require companies with total GHG emissions of over 100 kt CO₂e per year to reduce their emissions intensity by 12% from their baseline (an average of 2003-2005 emissions intensity). Newly constructed facilities (past 2000) have a three year grace period due to the fact that they will have installed the newest technology and in order to create a baseline (Alberta Environment 2007).

As mentioned, just over 100 companies qualify in the “over 100,000 tonne club”. Under the Act they have three options to reduce emissions to come into compliance (i.e. for those who weren’t able to achieve their 12% reduction in a particular year).

1. Emission Performance Credits. Obtain performance credits (buy, trade, etc) from other regulated companies that have reduced their emissions beyond their 12 % target;.
2. Technology Fund Credits. Pay into the Climate Change and Emissions Management Fund at a set price of C\$15/tonne CO₂e. Funds collected are to be used to develop or invest in Alberta based technologies, programs, and other priority areas; and,,
3. Emission Offsets. Companies may offset their emissions by purchasing emission reduction offsets from unregulated companies who voluntarily undertake Projects to reduce emissions. The Alberta Offset System operates under a set of policies, rules, standards (known as Offset Quantification Protocols) and Guidance Documents to ensure that offsets are of the highest rigour and quality to ‘offset’ regulated companies requirements.

Companies account for their emissions on a calendar year and have until the end of the following March to reconcile their account. Since the Act was amended in the spring, the 2007 year started on July 1st so companies initially had only have half a year for compliance. Starting in 2008, compliance cycles are a full year. Alberta Environment estimates that if all companies paid their current emission intensity liability into the Fund it would amount to about \$177 M on an annual basis. At \$15 per tonne that works out to about 12 Mt of liability. Therefore, there will not be enough offset credits to satisfy the demand on an annual basis..

Key Enablers

In order for a carbon market to function well, the science of GHG accounting by emission factors and agreed to quantification formulae, or the generation of policy, are by themselves not enough. Seeding the market place with science-based quantification protocols for different Offset project types, developed transparently with significant technical review, helps to provide certainty to buyers and sellers and reduce transaction costs. In Alberta, two key entities have helped in protocol development, setting up market standards and infrastructure and, enabling the market to function. They are Climate Change Central - a non-government organization (NGO) created in 2000 to enable climate change programming across all sectors in Alberta. The second is the various aggregator companies that group together tonnage created from offset projects on different farms and deliver the offsets to market.

Climate Change Central (C3) is a partnering agency with the Alberta Government to develop the needed tools and infrastructure to help Albertans generate offsets. C3 provides a meeting ground for market regulators, protocol developers and aggregators. The private sector is encouraged to develop draft protocols in Alberta, according to the ISO 14064-2 project based accounting standard, and C3 coordinates an open, transparent technical and stakeholder review process on behalf of the Alberta government. Further, C3 runs the project-based registry where project developers can register their projects, post their reports and verification statements and serialize their tonnes of carbon offsets – necessary steps in the creation of a compliance-based offsets¹. This ensures transparency, no double accounting and confidence to buyers that the proper oversight on the creation of the offsets has occurred. In Alberta, compliance-based offsets can only be generated through the use of a government-approved quantification protocol.

Aggregators are companies that create offset magnitudes of a size that interest the buyers. Individual farms do not have sufficient volumes of carbon offsets to interest the larger industrial buyers – the regulated companies are seeking offset packages of between 50,000 to 100,000 tonnes or more.. Enabling characteristics of aggregators include:

- May have staff that can review protocols in the final stages of development.
- Create interest amongst the offset suppliers (farmers)
- Explain protocols and requirements to clients.
- Provide data support to clients.
- Create a quality aggregation business model that withstands third party verifications.
- Allows farms with small amounts of offsets to participate in the market.
- Provide entrepreneurial skills and innovations for the offset market to work smoothly.
- Provide feedback to protocol developers and market regulator.

These two important partners in the carbon offset market facilitate the development and operation of a market without a heavy burden upon government of additional staff and infrastructure. In addition, they play a pivotal role in reducing transaction costs so that individual farms can participate in the carbon market and generate revenues – thereby driving increased conservation practice uptake. C3 has facilitated a carbon offset suppliers association where aggregators can share information, develop common contract terms and ensure each other's activities are adhering to collective business standards. These key enablers help identify and fill in the holes on the carbon market highway and make the market “real” for suppliers and buyers.

Offset Quantification Protocols

Protocol development has been a long and involved task, requiring significant science coordination and peer-based technical review. The credibility of a protocol development process is vital to the long-term viability of an Offset system. The protocol development process in Alberta is based on the ISO 14064-2:2006 standard that includes expert engagement, defensible scientific methodologies, a rigorous peer review process, and documented transparency to ensure a robust offset system that delivers real greenhouse gas reductions and net environmental benefits.

When Alberta began developing protocols first at the provincial level (circa 2002) and then later in a federal-provincial-territorial process, there had been little experience and even lesser expertise in the area. We have relied on learning our way into protocol development and application. Early work in protocol development in a federal-

¹ See www.carbonoffsetsolutions.ca for the Alberta Emission Offset Registry, approved quantification protocols, and all other relevant information related to the Alberta Offset System.

provincial-territorial context began on a pork protocol. National support and cooperation continued with other protocols up until 2006.. Many federal, provincial and academic scientists and technical experts collaborated on these protocols. The last protocol to be worked on by a federal-provincial initiative was the soil tillage management protocol. A change in federal government stalled further development until 2008. Alberta continued protocol development on a unilateral basis during the two-year stall in federal interest as protocols were needed for the 2007 amendment to the Alberta Climate Change and Emissions Management Act which created the compliance market.

The development of a new protocol may require the coordination of relevant scientific research and/or technical data related to the GHG reduction or removal activity and/or the baseline approaches. These take the form of technical seed document(s) (TSDs).² The TSDs are working documents that identify the potential practices/technologies that will lead to the emission reductions/removals and draw upon Best Practice Guidance to identify relevant activity data, emission factors and formulae to arrive at quantification approaches. To develop these, engagement of federal, university and other specialists from across Alberta other provinces, the USA, and sometimes overseas, is needed.

The TSDs are the underpinning technical resources that guide adaptation of technical elements into the ISO 14064-2 Alberta Protocol template. They make up the scientific basis of the GHG quantification approach and therefore should represent the best available science relating to the project activity. The strength of a protocol ultimately relies on the extent to which the TSDs have been developed from science review and coordination of expert judgement on the subject matter. TSDs should contain the most recent and relevant science from well-established sources, and ratify the link between practice change or new technologies, and quantified GHG reductions. Typically, workshops of relevant experts are held to collectively decide on the synthesis science and technical issues under the discipline of the ISO 14064-2 principles.³ Agricultural protocols typically proceed in a series of phases of collective decision-making about the certainty of the science at hand.(see points below).

The Alberta development process is currently a 10-step process that can take anywhere from 8 to 20 months (Figure 1) –the more complex the protocol, the longer it takes and land-based agricultural protocols can take the longest depending on the availability and robustness of consensus and synthesis science. An August 2008 call by the federal environment agency for existing protocols to be adapted for the soon to be developed National Offset System has rekindled interest. Over half of the protocols on the federally approved “fast track”eligibility list are Alberta government protocols. They will be adapted into the national offset system.

Standards, such as ISO, can be used to provide a consistent framework for quantifying project-based GHG offsets. They provide a policy-neutral, non-sectoral, verifiable template or specifications upon which a protocol can be customized to the regulatory requirements of the jurisdiction at hand. Using a standard promotes consistency and transparency in GHG quantification, monitoring, reporting and verification.

The ISO 14064-2 standard provides a template and a process to ensure quantification protocols (1) are based on a streamlined life cycle assessment for project and baseline conditions; (2) evaluate all potential baseline scenarios; (3) identify the relevant GHG emissions controlled by the project, and identify impacts upstream and downstream of the project, and (4) decide which sources and sinks are material to the quantification methodologies.

Some key points in the Alberta protocols are:

- Alberta Government approved quantification protocols are developed on an ISO 14064 Part 2 framework. Third party verification of offset projects follows the ISO 14064 Part 3 standard.
- Scientific/technical data and standards are all considered. The value of coefficients may depend upon the level of scientific data available, uncertainty, expected variability of application (soils, landscape, livestock classes, climate, etc).
- Protocols account for all GHGs (CO₂, N₂O, CH₄ and consideration of all 21 gases listed in the Act).
- Protocol rely on Best Practice Guidance – IPCC Guidance, WRI GHG Protocol, Canada’s National Emissions Inventory methodology; applicable standards and procedures; other System methodologies and protocols.

² Technical Seed Document (single or multiple documents) are the series of technical foundation pieces that support the GHG quantification and approaches in an eventual protocol.

³ This may only be relevant for activity based protocols or where the relationship between GHG impacts and the practice at hand is less robust.. Using the principles of completeness and conservatism in the ISO 14064-2 standard are applied here.

- Verification and harmonization or linkage factors are considered. It will be more valuable if it is compatible with future national or other provincial protocols. Where possible, the protocols are applicable across Canada.
- Verification is completed after the credits have been created (*ex poste*). There is no project approval or validation step, so well articulated protocols are critical to the function of the marketplace.
- The more rigor in producing offset quantification protocols should yield more of a blue-chip protocol that produces a higher value offset.
- Alberta has the largest suite of compliance-quality agricultural protocols than anywhere in the world, including soil carbon sequestration protocols.
- The Agricultural Protocols are the most complex to develop and require substantial technical and scientific coordination and review. They proceed in 4 Phases to prepare the technical seed documents that form the foundation of the protocol:
 - o Phase 1 – Compilation and synthesis of available scientific information (4 to 8 mos)*
 - o Phase 2 – Development of a Science Discussion Paper for consultation (3 to 4 mos)
 - o Phase 3 – Science Coordination Workshops (1 to 2 mos)
 - o Phase 4 – Standardize into Alberta ISO 14064-2 based Template (1.5 mos)
 - o Enters the Alberta Protocol Review Process (2 to 6 mos)

*Note – at end of this stage, the technical steering committee may decide that the science is not robust enough and stop the process.

Currently 10 of 23 approved protocols are of interest to agriculture:

Afforestation	Biofuel	Energy efficiency
Beef feeding edible oils	Biogas	Pork
Beef days on feed	Biomass	Tillage management
Beef life cycle		

Current protocols in the development cycle are:

Nitrous Oxide Reduction Protocol
 Reducing summerfallow
 Beef Residual Feed Intake
 Conversion to Perennial Forage
 Soil amendment protocols
 Native Rangeland Management
 Pasture Management
 Wetlands Management

The Alberta regulation states the rules that determine an eligible offset in Alberta:

1. They result from actions taken on or after Jan 1, 2002 (where applicable due to the nature of the protocol). This acknowledges the signals sent in 2002 with the Climate Change and Emissions Management Act and gives credit for early actions.
2. They are real, demonstrable, quantifiable, and measurable – they must be net of all relevant GHG sources and sinks stated in the Act. Suppliers, buyers and the public must be confident in what is being created and sold.
3. They occur at a place other than a regulated facility and from actions not otherwise required by law.
4. Ownership is established and clear.
5. They are only counted once for compliance purposes (they are unique).
6. They are verified by a qualified third party (engineer or an accountant).
7. Credits occur from Alberta-only projects.

Note that the Alberta Offset System defines additionality or 'beyond business as usual activities' at the regulation level as 'after 2002' activities only, and surplus to regulation. Additionality criteria are further satisfied through the identification of the baseline condition as defined in the protocol.

Details of not only protocols and all the development information, but also calculators and Government guidance documents are available on the C3 Carbon Offset Solutions website specially set up for the Alberta offset market

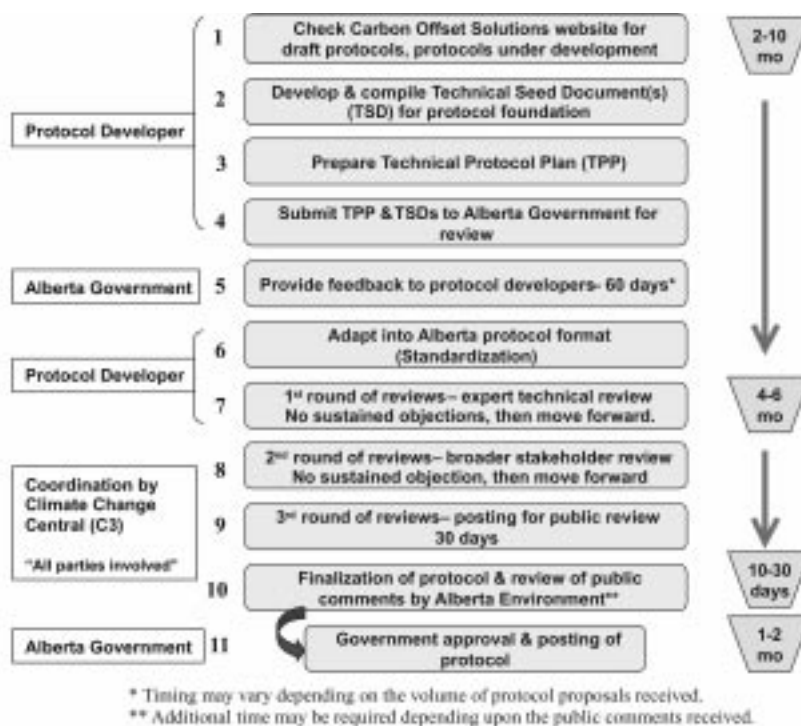


Figure 1. The Alberta protocol development process

(www.carbonoffsetsolutions.ca). In addition the website contains many items such as the Registry, a listing of aggregator companies, verifiers and brokers operating in the Alberta market and their contact information. It's essentially the "one-stop shop" for all things related to the Alberta carbon market.

Tillage System Management Protocol

The Soil Tillage System Management Protocol was the most sought after project type and so far, has constituted the most offsets sold in the market (to date over 1 million tonnes of offsets in Alberta since July 1, 2007 when the system began). This is largely due to the ease of implementation of the Tillage management protocol. The protocol is based on Canada's National Emissions Inventory Tier II methodology. The methodology develops carbon sequestration coefficient(s) based on model output, developed and validated with research data (eg. Century 4.0 for soil carbon; Figure 2). N2O and Energy CO2 emissions are also derived from the national inventory Tier II quantification. The protocol presents a simplified way of accounting for changes in these gases through providing emission factors. Data collection at the project level requires monitoring and verification of the type of tillage activity – not direct measurement of gases. This minimizes administration costs and treats large groups of farmers the same. It's cheaper to monitor/verify activity than direct GHG impacts.

Farmers are allowed to sell their soil carbon accumulations back to 2002 provided that conditions adhere to the protocol (dated farm operational records and evidence of purchase of reduced tillage equipment).

Typically, eligible actions for offsets in Alberta or under any existing offset system must be new and additional to business as usual. Since reduced and no tillage practices are being adopted already in western Canada, this proved particularly challenging, since there was a desire at the policy level to have these sink-creating practices continue. The solution was to develop a 'moving baseline' to accommodate early adopters as well as late adopters of the practice. Essentially the sequestration coefficient was discounted for the slope of the increase of no-till and reduced till adoption as accounted for by the national agriculture census taken every 5 years.

More specifically, the tillage system protocol uses unique approaches to meet additionality and permanence criteria of the Offset System. To satisfy additionality, the quantification science uses a discounted or 'adjusted baseline' to subtract out carbon accrued (ie before the 2002 start year of the offset eligibility criteria) from current adoption rates of zero or reduced tillage from a region – deriving regional discounted baselines.. In this manner, only

Methods of Soil Carbon Quantification

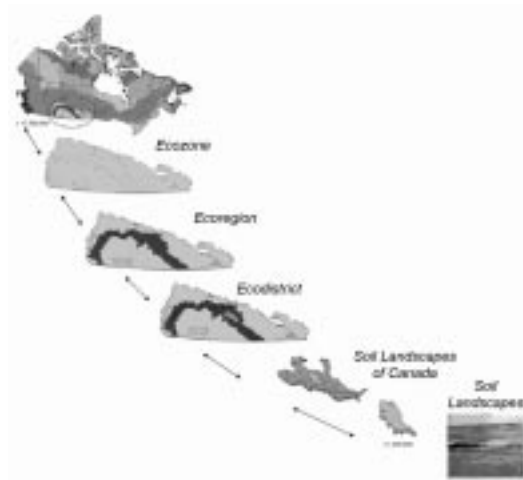


Figure 2. Canada’s methodological approach to C accounting Nation—wide

the additional or incremental carbon going forward from 2002 onwards due to the continuation of the practice post 2002 is allowed to count as an offset credit. Thus, the adjusted baseline, is only applied to activities that sequester carbon on a go-forward basis (Figure 3). In this manner, all tillage management projects get a ‘haircut’ off their carbon tonnes, but early adopters are allowed to participate to maintain the practice, and late adopters get a smaller coefficient (laggards get less?). The discount rates can be high - coefficients in some regions are nearly zero due to high rates of adoption, or discounted by 40 to 60% in others. The federal government’s cross-ministry Working Group on Offsets in December 2006 adopted this policy as a fair and equitable means to recognize early adopters in activity based projects where practices that create sinks could be reversed quite easily. It was recognized that maintenance of the sink *is as important* as the creation of a larger sink by farmers from their tillage practices on the prairies.

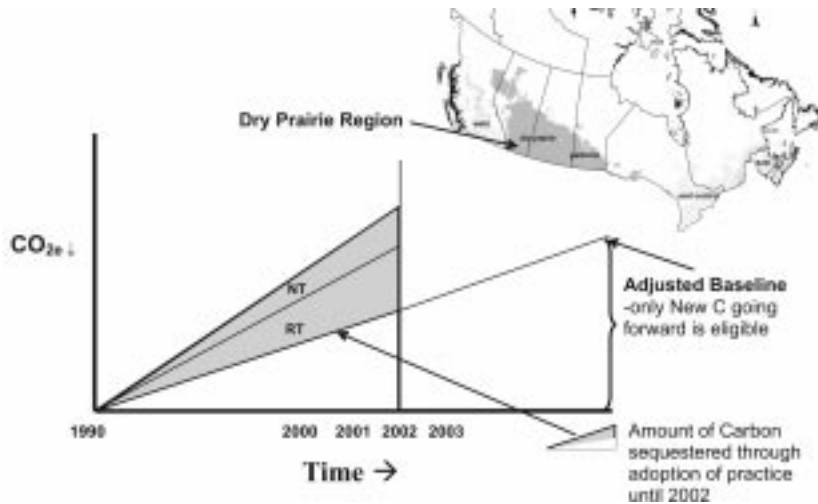


Figure 3. Schematic of the Adjusted Regional Baseline for the for Dry Prairie Region - discount based on adoption rate of reduced till (RT) and no-till (NT) practice for the Baseline Year (2002)

The permanence of sequestered soil carbon for no-till projects in Alberta is ensured by a government-backed policy approach known as an “Assurance Factor”, which is applied to every tonne of carbon offset created under the protocol. Development of the ‘assurance factor’ relies on a risk-based assessment of the probability of a reversal of a no till or reduced till practice occurring over a set period of time. The risk-assessments were conducted by

polling agricultural extension specialists and examining industry practice surveys over the last couple of decades, deriving a reversal risk percentage projected into the future. The Alberta prairies have over 20 years of experience with reduced tillage management and experts who do not have a market interest (government and not for profit extension staff), were consulted to derive the assurance factors.

In essence, each coefficient is discounted by the reversal risk percentage derived for a given region in Alberta and set aside by the government (e.g., 10% discount on every verified tonne creates a set aside, resulting in 0.1 t CO_{2e} collected by the government for each verified tonne). This pool of carbon is used to cover the risk of a reversal. This reserve assures against carbon lost to the atmosphere via reversals in the future – it functions as a reserve holdback that is operationalized through government policy. To date, with tillage management offsets approaching 1 Million tonnes, the reserve has grown to 100,000 tonnes to ensure against any reversals that occur (Figure 4). Project developers need to disclose when a sink practice is reversed, and they do not create credits for that year. Alberta has found that this approach allows for more flexibility in management and contracting; with a discounted approach to address liability, annual contracts can be used.

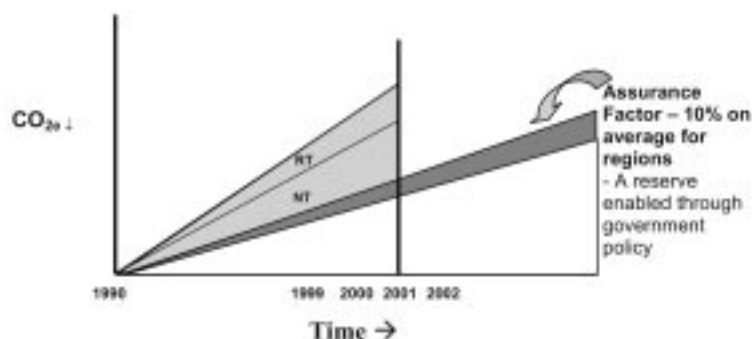


Figure 4. Schematic of the Assurance Factor for Tillage System Management Protocol in Alberta

Alberta recognizes that soil carbon sequestration occurs at different rates according to agro-climatic zones (following the development work of the national tillage management protocol, 2006). In that protocol process, two regions were delineated for the dry and moister prairie zones. A minor adjustment of the boundary line between the two regions was made in Alberta to be more consistent to soil property zone boundaries. Aggregator companies underlined the need for a simple application of the boundary. Was it to be a transition zone of an intermediate value reflecting the natural fuzziness or gradation of soil carbon? Should it be a hard line that can be envisioned on the ground? Consultations soon determined the best approach was a line that is one fence post wide, a distinct line across the province. A listing of the land parcels (“quarter sections”) which contained the boundary line was released to aggregators and a clarification document produced.

The definition of No-Tillage, based on the degree of soil disturbance, surfaced early on in the application of the protocol. The working definition in the original protocol was not specific enough and would vary depending up individual soil and equipment circumstances. A maximum disturbance percentage, which would still yield the same carbon sequestration values, was adopted based upon the ratio of seed row opener width to shank spacing. A clarification document was produced. Interestingly, farmers considering new equipment purchases made certain the equipment configuration would meet the definition and purchased equipment that perhaps provided even less soil disturbance than originally intended.

Verification costs are another area of complexity. There is very limited experience in the world of verifying carbon projects. It often merges several disciplines together such as accountants working with agronomists and/or engineers and/or livestock specialists, according to ISO 14064-3:2006 and ISO 14065 standards... Physical inspection of facilities or farms needs to be kept to a minimum in order to reduce verification costs down, thus risk-based sampling of aggregated projects such as reduced tillage projects is the norm.. Verification costs should reduce as prototypes and templates are developed and confidence, testing and learning increases.

The tillage system management protocol now has five accompanying documents on the carbon offset solutions website to provide further guidance and clarification. Seven tillage projects are underway in Alberta at the date of this publication.

Carbon Market Performance to Date

The first commitment period of the compliance regulation (6 months) ended December 31, 2007. Over that half year period industry in Alberta chose to settle two-thirds of their liability by payments into the technology fund, one-quarter of their liability settled by purchasing offsets and the remainder by trading emission performance credits. Of the offsets purchased, just over half of them came from agriculture sources – all from the soil tillage management protocol. Sale prices ranged from C\$6 to C\$12 per tonne CO₂e. Transaction costs were in the 30-40% range. To date, over 1 million tonnes of reduced tillage offsets have been verified and created – far and wide the most popular project in Alberta.

However, a number of submitted tillage offsets did not pass verification in the first commitment period because ownership could not be proven to the satisfaction of the verifier (land tenure rates are 50% or higher in the Prairies). Some landowners are not resident in the province and it takes extra time and effort to obtain a release of ownership of the sequestered carbon contracts. Some landowners also need explanations on what ownership is being verified and what it all means. The offsets can be resubmitted for the current compliance period once the paperwork is in order.

Extension meetings were held across the province in the fall of 2007 and 2008 to inform farmers and industry of the rules of the market, available protocols, roles of aggregators and economic opportunities. The mornings were presentations and discussions. The afternoons were mock trading sessions. These are very popular with participants and part of making sure market information is available to all. – a level playing field is important.

What did Alberta learn from the first cycle of the market? A survey of market participants was conducted along with a review meeting held in July 2008 with all parties to document our learnings. Key learnings include:

- Alberta's offset system proved the aggregator model works.
- Intense interest in biosequestration projects – the protocol and it's policies works.
- The market is now competing on reduced transaction costs.
- More project documentation templates are required.
- Verification standards are needed for more complex projects (e.g. tillage).
- Ownership issues – barred up to 40% of tillage offsets for some projects in the first period.
- Less bureaucratic red tape also means more market uncertainty – there's a balance.
- Accreditation of verifiers may be warranted.
- Unanticipated business costs found on the project developer side will lead to more diversification of projects (\$15 technology fund essentially a price ceiling for the market).

Driving Conservation Agriculture through Carbon Offset Policies

Through international discussions of emissions trading and flexibility mechanisms within the Kyoto Protocol, and subsequent finalization of the Treaty, agricultural soil sinks and Land Use and Land Use Change and Forestry activities were enabled through Articles 3.3 and 3.4. Several existing and developing Offset systems in North America have identified agricultural and forestry offsets as eligible and they will need accompanying quantification protocols to enable them. However, at an international level, the progress under the Clean Development Mechanism or of other offset-based systems is slow for agricultural crop and livestock initiatives.

Alberta and Canada have focused much energy and resources towards accounting for GHG at the national and GHG project level. The uptake of reduced tillage projects in Alberta is high and driving a continuing increase in the rate of adoption of reduced tillage. The existence of the pork, beef, bioenergy, afforestation on marginal lands and energy efficiency protocols should provide more opportunity for increased conservation management in Alberta. Several more protocols that cover a range of different management practices are in the development cycle. The nitrous oxide reduction protocol, scheduled for released in 2009 should be applicable to other jurisdictions.

Offsets have green value for the agricultural sector, not only as a new commodity to be marketed and sold on it's own right, but the quantification of reduced GHGs of agricultural products can be used as a 'green brand' for

marketing purposes. Reduced methane emissions from beef products and a reduced nitrous oxide profile for crops can have ripple effects along the commodity value chain, and some buyers are already seeking these attributes. In addition, the reduced energy footprint and production efficiency gains for some of these activities will be important in the future – and revenue from offsets may provide that additional incentive to convince a farmer to try a new management system.

Today we are at a project-based or modular approach to calculating GHG offsets, but as our knowledge grows and through targeted research to increase our understanding of the scientific relationships between different management systems and all three GHGs, farm-level quantification may be possible.

Conclusions

Our experience in developing and supplying tillage system offset protocols to the Alberta compliance offset market has illustrated to us the need for a comprehensive systems approach integrating the science, policy, theory and agribusiness realities. The best learning occurs when we work with all parties that have an interest in the market. Considerable effort and resources are needed and distribution of efforts across government departments and NGOs negates the need for a large administration in any one institution. In addition to protocol development, guidance documents are required, information centres and extension of the system as well as technologies required for both sellers and buyers. Aggregators help bring sellers (farmers) to the market and can alert the regulator to adjustments that are needed. We have found buyers and sellers willing to participate in tillage carbon offsets. The system works.

References

- Alberta Environment. 2002. Climate change and emissions management act. Alberta Queen's Printer, Edmonton, Alberta. http://www.qp.gov.ab.ca/documents/Acts/C16P7.cfm?frm_isbn=077974697X
- Alberta Environment 2007a. Climate Change: Alberta's Credit Trading System – facts at your fingertips. Factsheet 1p. http://environment.alberta.ca/documents/Credit_Trading_System.pdf
- Alberta Environment 2007b. Alberta Environment Report on 2006 Greenhouse Gas Emissions. 81p. http://www3.gov.ab.ca/env/air/documents/2006_GHG_Report.pdf
- Alberta Environment. 2007c. Specified gas emitters reduction regulations. <http://environment.alberta.ca/631.html>
- Alberta Government. 2007. Climate Change and Emissions Management Amendment Act, 2007. <http://www.assembly.ab.ca/bills/2007/pdf/bill-003.pdf>
- Capoor, K and Ambrosi, P. 2008. State and Trends of the Carbon Market 2008. World Bank, Washington D.C. 71p. <http://siteresources.worldbank.org/NEWS/Resources/State&Trendsformatted06May10pm.pdf>
- Climate Change Central. 2008. (various listings, protocol documents in pdf format) <http://www.climatechangecentral.com>, <http://www.carbonoffsetsolutions.ca>
- Environment Canada. 2008. National Inventory Report 1990-2006 greenhouse gas sources and sinks in Canada. Environment Canada, Ottawa. 615 p.
- Point Carbon. 2009. Carbon market monitor: A review of 2008. January 2009.

Carbon Sequestration Opportunities with Smallholder Communities: Forestry, Agriculture and Agro-Forestry

Louis V. Verchot^{1*} and Viendra P. Singh²

¹Center for International Forestry Research, P.O. Box 0113 BOCBD, Bogor 16000, Indonesia

²World Agroforestry Centre, 1st Floor National Agricultural Science, Complex (NASC),
Dev Prakash Shastri Marg, Pusa, New Delhi, 110 012, India

(*Email: lverchot@cgiar.org)

Agricultural lands, comprising arable land, permanent crops and pasture, occupy about 40% of the earth's land surface¹, and these lands are expanding. Most of the agricultural land is under pasture (~70%), and only a small percentage (<3%) are under permanent crops. Over the past four decades, an average of 6 million ha of forest and grassland has been converted to agriculture annually. Agricultural lands will continue to increase in the coming decades, with large increases expected in Latin America and Africa (see Rosegrant et al., 2001; IPCC, 2007).

It is particularly difficult to estimate actual GHG emissions from agriculture and other land uses because of the high degree of both spatial and temporal variability associated with the underlying causes of these emissions. The spatial variability has to do with both the variation in the biophysical environment and variation in farm management. This is particularly problematic for estimation of the non-CO₂ GHGs like nitrous oxide (N₂O) and methane (CH₄), both of which present large variation across landscapes and regions (Verchot et al., 1999; 2000; Davidson et al., 2000; Davidson and Verchot 2000). Temporal variability is driven to a large extent by inter-annual variations in local weather and how farmers respond to these variations.

To standardize all gases for comparison in this paper, we use the global warming potentials (N₂O = 310 and that of CH₄ = 21) to calculate the effect of emissions on atmospheric forcing in terms of carbon dioxide equivalents (CO₂e). Thus, for example, one tonne of N₂ emitted will be equivalent to 310 tonnes of CO₂.

Our best estimate is that agriculture accounts for about 10-12% of the total global anthropogenic emissions of GHGs or between 6 and 8 GtCO₂e per annum. Emissions are increasing rapidly in agriculture and between 1990 and 2005; these increases are estimated to have been on the order of 17%. Emissions are expected to continue to increase due to increased demand for food as populations grow, and shifts in diets as societies in developing countries become wealthier and meat consumption increases. There are two types of emissions directly attributable to agriculture:

- Non-CO₂ GHGs from management operations = 6.2 Gt CO₂e
- Energy related CO₂ emissions (including emissions from manufacture of fertilizer) = 0.6 Gt CO₂e

Land-use change is often for agriculture, but there are other drivers of deforestation and conversion of natural ecosystems to other land uses. Global emissions from this source are equal to 7.6 Gt CO₂e; the portion attributable to agriculture is generally not separated out in global estimates (Houghton, 2007). We will deal with opportunities to alter this flux through carbon sequestration in agricultural systems in this paper.

Energy related emissions are small from the sector both in absolute magnitude and as a percentage of the emissions from the sector and will not be discussed here. Non-CO₂ GHG emissions are an order of magnitude greater than the energy emissions. Emission from land-use change often associated with agriculture are also large.

Non-CO₂ Greenhouse Gases

Agriculture accounts for between 59 and 63% of the world's non-CO₂ GHG emissions (USEPA 2006a, b). This sector accounts for 84% of the global N₂O emissions and 54% of the global CH₄ emissions (USEPA, 2006b). These emissions are principally from six sources:

- N₂O from soil
- N₂O from manure management
- CH₄ from enteric fermentation

- CH₄ from manure management
- CH₄ from rice cultivation
- CH₄ from other sources
 - o Savannah burning
 - o Burning of agricultural residues
 - o Burning from forest clearing
 - o Agricultural soils (CH₄)

Nitrous oxide emission from soils is the most important emission for the sector, followed by CH₄ from enteric fermentation (Table 1). CH₄ from rice cultivation is the third largest source. The driver of emissions from this sector is production, which will increase in the near future to keep pace with the growing population, particularly in tropical developing countries. A change in diet preferences and increased consumption of meat as societies become more affluent is also an important driver, particularly for emissions from enteric fermentation. By 2030, non-CO₂ GHG emissions from agriculture are expected to be almost 60% higher than in 1990 (Verchot 2007).

Table 1. Non-CO₂ GHG emissions (Mt CO₂e) by source in the agricultural sector

Source	Year			
	1990	1995	2000	2005
N ₂ O Soil	2284	2405	2610	2782
N ₂ O manure	196	199	205	219
CH ₄ enteric fermentation	1772	1804	1799	1929
CH ₄ manure	223	225	225	235
CH ₄ other	268	274	455	456
CH ₄ rice	601	621	634	672
Global total	5343	5528	5928	6291

There are numerous opportunities for mitigating non CO₂ GHGs in agriculture. GHG emissions can be reduced by managing carbon and nitrogen more efficiently in agricultural ecosystems (Bouwman, 2001; Clemens and Ahlgrim, 2001). Carbon can be sequestered from the atmosphere and stored in soils or in vegetation, for example in agroforestry systems (Verchot et al., 2007; Lal, 2004; Albrecht and Kandji, 2003). Crops and residues from agricultural lands can be used as a source of fuel to displace fossil fuel combustion, either directly or after conversion to fuels such as ethanol or diesel (Schneider and McCarl, 2003; Cannell, 2003). In the following sections we examine some promising options.

Mitigation of Non-CO₂ GHGs

There are a large variety of mitigation options for agricultural gases. In many cases there are production or cost tradeoffs that need to be understood in order to design proper incentives for uptake of these practices. Mitigation measures include agronomic measures such as improved crop varieties, fertility management, erosion control, irrigation management, and increased use of cover crops and crop rotation. Some soil management measures including improved nutrient management and reduced tillage will reduce emissions and sequester carbon. Better residue and water management in rice can yield significant reductions of CH₄ emissions. For livestock, there are a wide range of practices associated with grazing land management, manure management, and feeding that can reduce emissions and increase carbon sequestration.

Emissions of N₂O from croplands are often associated with applying fertilizer in excess of crop demands. One mitigation goal might be to reduce excess fertilizer application while maintaining high yields. Several mitigation options could be considered:

- Split fertilization: Application of the same amount of fertilizer as in the baseline, but divided into three smaller increments.
- Fertilizer reduction to match crop needs.
- Application of nitrification inhibitors and the use of slow release fertilizer formulations reduce the conversion of ammonium to nitrite and limit N₂O emissions.

In intensive animal production systems manure decomposes under anaerobic conditions and result in a fermentative digestion process with the production of CH₄ rather than CO₂. The composition of manure can influence

the amounts of N₂O emitted. Up to 90 per cent of the CH₄ emitted by anaerobic manure management systems can be captured and combusted. For the case of composting, 10 to 35 per cent of the emitted CH₄ can be reduced. Reductions in N₂O emissions in intensive systems can be achieved through improved manure application to soils. Regional mitigation potentials for manure management application practices according to Smith et al. (2007) are provided in Table 2 below.

Table 2. Mitigation potentials through manure management practice (tCO₂e ha⁻¹ yr⁻¹)

Climate Zone	CO ₂	CH ₄	N ₂ O
Cool-dry	1.34 (-3.19–6.27)	0.02 (0.01–0.02)	0.00 (-0.17–1.30)
Cool-moist	2.79 (-0.62–6.20)	0.00	0.00 (-0.17–1.30)
Warm-dry	1.54 (-3.19–6.27)	0.00	0.00 (-0.17–1.30)
Warm-moist	2.79 (-0.62–6.20)	0.00	0.00 (-0.17–1.30)

Source: Smith et al. (2007).

Note: Values in parentheses correspond to low and high mitigation potential. Positive values represent CO₂ uptake which increases the soil carbon stock, or a reduction in emissions of N₂O.

Methane emissions from enteric fermentation can be reduced in a number of ways. (Smith et al; 2007). Improved feeding can provide an enriched diet to animals, which improves their digestion efficiency and lowers enteric CH₄ emissions. Grain supplementation can be costly and is appropriate for confined animals. Choice of forages can also reduce emissions: use of forages with higher nutritional quality; use of forage from plants containing natural methanogenic depressors, such as condensed tannins; mineral supplementation to overcome possible nutrient deficiencies; and improvement of the sanitary condition of the drinking water to avoid parasitic diseases and improve animal health would all reduce the CH₄ emissions (Smith et al, 2007; DEFRA, 2007; de Klein and Eckard, 2008). Reductions can also be achieved through breeding or through dietary additives like ionophores.

In rice systems, water management can reduce soil CH₄ emissions. Different strategies of flooding and draining the field such as pre-harvest drainage, early single or dual drainage, midseason drainage, late dual drainage, and alternate flooding/drainage all reduce emissions. Management of organic inputs can reduce emissions through the use of composted rice straw, mulching, and removal of rice stubbles from the fields. Mineral inputs can also be used to reduce emissions through the application of phosphogypsum, ammonium sulphate, and tablet urea. Direct seeding is also recommended for establishing rice fields with reduced methane emissions.

Cost of Non-CO₂ GHG Mitigation

This section draws very heavily on the USEPA report ‘Global Mitigation of Non-CO₂ Greenhouse Gases’ (USEPA 2006b). The USEPA constructed marginal abatement curves for different regions and different sectors by estimating the carbon price at which the present value benefits and costs for each mitigation option equilibrates (present value of benefits = present value of cost). This produced a stepwise curve that reflects the average price and reduction potential if a mitigation technology were applied across the sector within a given region.

Costs included capital, or one-time costs, and operation and maintenance costs, or recurring costs. The calculation included a tax rate of 40% and used a 10% discount rate. Benefits included the intrinsic value of CH₄ as either a natural gas or as fuel for electricity or heat generation, non-GHG benefits of abatement (e.g. improved nutrient use efficiency), and the value of abating the gas given a GHG price. The breakeven price calculations do not include transactions costs. All calculations were in US\$ from the year 2000. More details on the construction of these curves can be found in the report.

Most of the abatement curves indicate negative costs for some level of abatement. This means that some GHG emission reduction is already feasible and cost effective. These activities have not yet been implemented because there are non-monetary barriers that need to be overcome. These opportunities are often referred to as “no regret” options. The curves all become very steep or even vertical at around \$30. Thus, for this analysis, we will assume that this is the maximum economic level of abatement and we will calculate the abatement potentials at this level of cost.

Regional abatement curves were generated as was a globally aggregated abatement curve. These curves were used to generate the summary of net reductions at different carbon prices for croplands and livestock that is

Table 3. Potential total reductions (MtCO₂e) of emissions from agriculture for selected countries and regions with carbon prices at \$0 and \$30 per tCO₂e, with constant herd size. Table adapted from USEPA (2006b)

Country/Region	2010		2020		2030	
	\$0	\$30	\$0	\$30	\$0	\$30
Africa	5.8	13.1	6.0	15.1	6.9	17.4
Annex I	136.5	222.6	140.1	210.1	147.3	221.0
Australia/New Zealand	7.3	10.4	7.7	11.3	7.8	11.5
Brazil	9.3	16.9	10.1	18.3	11.3	20.5
China	61.7	111.5	55.2	106.0	60.5	116.3
Eastern Europe	7.2	9.7	7.1	10.2	7.6	10.9
EU-15	24.0	38.5	23.9	36.4	24.5	37.2
India	7.1	41.9	7.2	44.6	7.7	47.6
Japan	1.3	7.6	1.4	7.8	1.4	7.9
Mexico	3.5	5.6	4.3	6.8	4.1	6.6
Non-OECD Annex I	38.1	62.0	38.4	43.0	41.2	46.2
OECD	97.5	162.1	100.4	168.5	105.5	176.9
Russian Fed	36.6	60.5	37.0	41.5	39.4	44.2
South & SE Asia	71.6	115.4	82.6	131.1	87.8	139.3
United States	49.8	80.4	51.1	86.6	53.3	90.3
World	313.6	552.1	323.1	559.4	350.2	606.3

presented in Table 3. Significant opportunities for abatement exist in Annex 1 countries and in China. In Africa and other least developed countries (LDCs), only moderate possibilities exist for abatement of emissions due to soil management and enteric fermentation. Projected abatement for 2030 was based on the 2020 abatement curve and an estimated baseline emission from constant rates of emission increases between 2010 and 2030. We summarize emissions reductions potentials at no cost and potentials at costs less than \$30/tCO₂e.

Land-use Change

Emissions of GHG from land use change in tropical countries (~7.6 Gt CO₂-eq) exceed emissions from all other agricultural sources combined and continue to grow as areas of cropland and pasture land increase. In 2005, agricultural lands occupied 49.7 million km², having increased by 4.7 million km² since the early 1960's². Pasture land accounted for 65 per cent of the increase and arable and permanent croplands accounted for the remaining 35 per cent.

Since 1965, land under row crops and permanent crops have increased in Sub-Saharan Africa (37 per cent), West Asia and North Africa (28 per cent), East, South and Southeast Asia (23 per cent), Latin America and the Caribbean (48 per cent) and Oceania (32 per cent). Recent trends suggest that land area for cropping is levelling off in Latin America. Likewise, the area under meadow and pasture is increasing in West Asia and North Africa (40 per cent), East, South and Southeast Asia (24 per cent), Latin America and the Caribbean (48 per cent) and Oceania (32 per cent). Short-term trends suggest that growth pasture area may be levelling off in all regions, with the exception of sub-Saharan Africa³.

Mitigation through Carbon Sequestration

Agricultural ecosystems have significant potential to increase carbon storage, thereby reducing atmospheric concentrations of CO₂ by sequestering C in soils and vegetation (Lal, 2004; Albrecht and Kandji, 2003). Agricultural lands also remove CH₄ from the atmosphere by oxidation, though less than forests (Tate *et al.*, 2006; Verchot *et al.*, 2000), but this effect is small compared to other GHG fluxes (Smith and Conen, 2004). Increased carbon stocks can be achieved through a change in land use to one with higher carbon stock potential, usually revealed by a change in land cover or through management practices. The IPCC Special Report on Land Use, Land-Use Change and Forestry (2000) identified a number of categories of activities on agricultural lands that generate benefits:

- Conservation tillage to maintain higher levels of soil organic matter. This practice promotes sequestration of soil carbon, but tends to increase N₂O emissions. The carbon sequestration potential of this practice is controversial.

- Agroforestry (including conversion from forests to slash-and-burn to agroforests after deforestation, conversion from low-productivity croplands to sequential agroforestry, integration of trees into farming systems and agricultural landscapes).
- Improved grassland management (including improved grazing management, fertilization, irrigation and use of improved species and legumes).
- Restoration of severely degraded lands (including salt-affected soils, badly eroded and desertified soils, mine spoils, and industrially polluted sites).

Carbon accumulation from a change in land use and management is not be sustained indefinitely. Eventually, inputs and losses balance, and carbon stocks approach a new, higher equilibrium (Davidson and Ackerman, 1993; IPCC 2000). The effect of the land-use change on atmospheric GHGs must be determined from a whole system point of view. In many “managed” ecosystems, there is significant removal of carbon in harvested products, some of which may accumulate in long-term storage pools (e.g., wood products), while some carbon rapidly returns to the atmosphere via respiration. Additionally, increases in soil organic carbon are often associated with increases in N₂O emissions (Li et al., 2005). In wetlands, the effects of changes in land-use on soil CH₄ emissions also need to be considered.

Conservation tillage is any tillage method that leaves sufficient crop residue in place to cover at least 30% of the soil surface (Lal, 2003). These practices have been increasingly used throughout the world. Given that soil disturbance is thought to stimulate soil carbon losses through enhanced decomposition and erosion, reduced- or no-till agriculture often (but not always) results in soil carbon gain in the surface portions of the soil. Reduced- or no-till practice may affect N₂O emissions but the net effects are not well-quantified and understood. Smith et al (2007) estimated the potential of this mitigation practice to sequester carbon and reduce N₂O emissions under different climate zones is presented in Table 4.

Table 4. Mitigation potential through improved tillage and residue management (tCO₂e ha⁻¹ yr⁻¹)

Climate Zone	CO ₂	N ₂ O
Cool-dry	0.15 (-0.48–0.77)	0.02 (-0.04–0.09)
Cool-moist	0.51 (0.00–1.03)	0.02 (-0.04–0.09)
Warm-dry	0.33 (-0.73–1.39)	0.02 (-0.04–0.09)
Warm-moist	0.70 (-0.40–1.80)	0.02 (-0.04–0.09)

Source: Smith et al. (2007)

Note: Values in parentheses correspond to low and high mitigation potential. Positive values represent CO₂ uptake which increases the soil carbon stock, or a reduction in emissions of N₂O.

More recently the potential of this practice to sequester carbon has been challenged (Baker et al., 2007). All studies that purport to observe increases in soil C stocks limit sampling to 30 cm depth or less. In fact, half of the studies surveyed by West and Post (2002) sampled to 20 cm or less. However the rooting system of many crops, maize for example can extend to up to 2 m in depth. A survey of studies from Canada (Vanden Byggart et al., 2003) showed that a majority of studies that were sampled to greater than 30 cm depth reported a net loss of SOC in the soil profile. Thus, it appears that conservation tillage affect the distribution of SOC and does not promote sequestration. This is perhaps a challenge to scientists working in developing countries to undertake research to determine whether C sequestration can be achieved through reduced tillage in tropical systems and if so, under what conditions. The research must take this redistribution phenomenon observed in temperate soils into account and examine the entire rooting zone that is likely to be affected by changes in tillage.

Two other types of land management in the agricultural sector offer significant opportunities for carbon sequestration (Figure 1; IPCC 2000): improved grassland management and agroforestry. For improved grasslands, high rates of sequestration can be achieved through introduction of more productive grass species and legumes. Improved nutrient management and irrigation can also increase productivity and sequester more carbon. About 60 percent of the grazing lands available for carbon sequestration are in developing countries. Grazing land management, despite the low carbon densities in these lands, has a high potential because of the large amount of land susceptible for this improvement (3.4 billion ha).

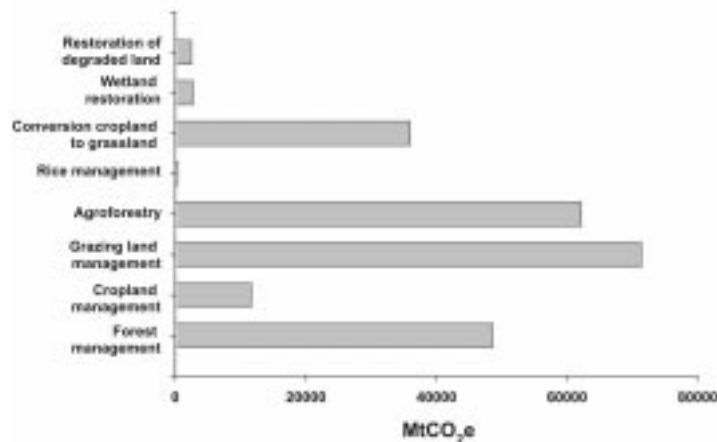


Figure 1. Potential for carbon sequestration of different land use and management options over a 30 year period (adapted from IPCC 2000)

Agroforestry has such a high potential because it is the land use category with the second highest carbon density, after forests and because there is such a large area that is susceptible for the land use change. Agroforestry also offers the potential for synergies between expanding the role of agroforestry in mitigation programs and adaptation to climate change (Verchot et al., 2007). In many instances, improved agroforestry systems can reduce the vulnerability of small-scale farmers to inter-annual climate variability and help them adapt to changing conditions. Other options such as rehabilitation of degraded land and wetland restoration have low potentials, globally, to contribute to mitigation, although locally their potential may be significant. These low values are the combined result of low area availability and slow carbon accumulation rates.

Costs of C Sequestration in Agricultural Landscapes

A rigorous analysis of costs and mitigation potential does not presently exist in the literature and there is no basis to develop this at the moment. For conservation tillage, there is generally a savings to farmers due to reduced use of tractors to till soils. These are somewhat offset by higher herbicide costs to reduce weed problems. However, since the carbon benefits of this practice remain doubtful, we will not pursue this further here.

Clearly in developing countries, the greatest potential for climate change mitigation in rural landscapes are associated with reducing deforestation emissions and creating sinks through community forestry and agroforestry practices. Others have reviewed the costs to farmers of reducing deforestation and forest degradation emissions and these costs are around US\$1 to 5 per tCO₂e (Stern 2007; Swallow et al., 2007). In this paper, we will provide a novel analysis of the potential costs of community forestry and agroforestry options.

Individual countries present very different institutional situations and institutional costs associated with setting up monitoring and verification services, extension services to farmers and transparent benefit and risk sharing services will vary from country to country. Assessing these costs and the sources of variation in these costs is beyond the scope of this paper. However, we can assess the likely costs to farmers in very approximate terms as a means of establishing a likely “farm-gate price” for carbon sequestration.

The IPCC (2000) Special Report presented two illustrations of the potential of carbon sequestration to contribute to climate change mitigation through agroforestry and through improved grassland management. We propose an expansion of the IPCC Special Report scenario, which will illustrate the potential for carbon sequestration in the agricultural sector and the costs of achieving that sequestration. The results of this analysis will only be semi-quantitative, but it is reasonable to expect them to be indicative of the order of magnitude of the potentials and costs

The IPCC scenarios suggested that it would be possible, with considerable international effort, that 10 percent of the land available for improved pasture management could be under this improved management by 2010 and that as much as 20 percent could be under improved management by 2040. Likewise for agroforestry, the report suggested that 20 percent of the available land could be under this land management practice by 2010 and 40

percent by 2040. These suggested targets have not been achieved and we are at almost the same state of land availability as we were in 2000, when the report was written, so we will use these values in this exercise.

For this analysis, consider an example of a moderately intensive community forestry system, which has been modelled using the ENCOFOR decision support Carbon Model (www.joanneum.at/encofor; Figure 2). The system produces timber, with some cash crops grown in the understorey or non-timber products produced in the plantation. Examples of this system might be the rotational woodlots of Tanzania, the pine-coffee-banana systems of central Java, Eucalyptus and Poplar based agroforestry systems of the Indo-Gangetic Plain (Bekele-Tesemma, 2007).

In this system, the trees are harvested after 12 years, and regenerated. The ENCOFOR model suggests that the average annual accumulation in this example over 30 years is 1.26 tonnes C per ha and over 60 years, this average figure drops to 0.52 tonnes per ha per year. The IPCC Special Report suggested an average carbon accumulation rate in an agroforestry system was about 3.1 tonnes per ha for a 30 to 50 year time horizon. These values are appropriate for a multi-strata system that is kept in place over a long period of time, such as the home garden systems of Africa or the jungle rubber agroforestry systems of Indonesia.

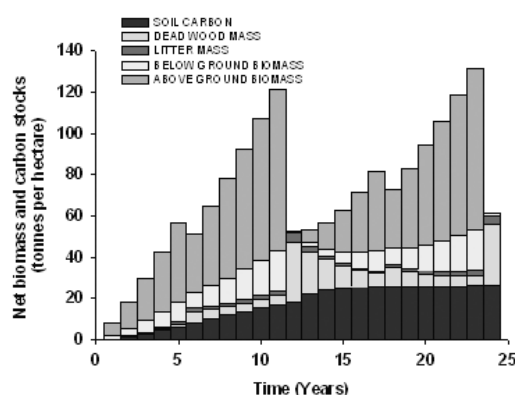


Figure 2. Projection of carbon accumulation in a multi-strata agroforestry system.

These two examples are used because they provide useful bounds to our calculations. In the community forestry case we have a system which is regularly harvested and therefore has lower annual accumulation rates because the aboveground biomass is regularly brought back to zero. In the multi-strata agroforestry case, we have a permanent tree-based production system.

Carbon sequestration potential can be calculated by taking the time frame proposed in the IPCC Special Report, taking the projections of area of land adopting the improved practices, and using both the IPCC and ENCOFOR projections for carbon accumulation rates, and the IPCC projection for grassland management. Table 5 presents the scenarios for agroforestry and Table 6 presents one for grassland management. If we take the sum of the annual accumulation rates over the next 30 years, the results suggest that the total potential sequestration is on the order of 12 to 19 Gt of carbon or 45 to 70 Gt of CO₂e. This does not account for the carbon sequestered in harvested wood products from the agroforestry plantations.

Costs of tree planting projects include those associated with plantation establishment, maintenance costs like pruning, and measurement and monitoring of the carbon sequestered. In many cases, extension and farmer education is required to teach farmers about new agroforestry systems. To calculate these costs, the ENCOFOR financial analysis tool was used. Values are in 2005\$. Establishment costs include the purchase of seedlings, labour for site preparation and planting, and costs of protection (fencing, guarding, etc).

The cost of establishing these agroforestry plantations comes to around US\$780 for the two rotations of a 1 ha plantation of 1000 trees. Operating costs include weeding, thinning and pruning the trees, which come to \$440 per ha. Additional costs of preparing documentation for carbon crediting under the different types of systems that currently exist come to \$60 per ha and the costs of monitoring and verifying are \$190 per ha. Thus, the total cost in this scenario is \$1470 per ha. From the example above, an agroforestry plantation contains an average 80t of biomass over its lifetime or 40 tonnes of C per ha in 5 carbon pools (aboveground biomass, belowground biomass, deadwood, litter, and soil carbon). The costs of establishment and maintenance of these plantations comes to US\$36.75 per tonne of carbon, or \$10.02 per tonne of CO₂e.

Table 5. Estimates of potential C sequestration in agricultural landscapes through forestry practices over 30 years. Two scenarios are presented, one based on the IPCC (2000) LULUCF report and one based on the projections of the ENCOFOR Carbon Model

Time (years)	Land area available (M ha)	Adoption/ conversion of area(%)	Permanent agroforestry (IPCC)		Community Forestry(ENCOFOR)	
			Rate of C gain (tC ha ⁻¹ y ⁻¹)	Carbon (Mt y ⁻¹)	Rate of C gain (tC ha ⁻¹ y ⁻¹)	Carbon (Mt y ⁻¹)
10	630	20	3.1	391	1.26	159
15		23		456		186
20		27		521		212
25		30		586		239
30		33		651		265

Table 6. Estimates of potential C sequestration in grasslands over 30 years. The scenario presented is based on the IPCC (2000) LULUCF report

Time (years)	Land area available (M ha)	Adoption/ conversion of area (%)	Rate of C gain(tC ha ⁻¹ y ⁻¹)
10	3400	10	238
15		12	278
20		13	317
25		15	357
30		17	397

However, not all of these costs need to be borne by the international community or by outside investors. Agro- or community-forestry systems are profitable in their own right. The example given here has a 22% internal rate of return. These systems vary considerably across regions and have varying income generation potential. This means that the costs of expanding the adoption of forestry activities do not have to be fully borne by external investors. Costs can be shared with rural farmers who will benefit from these profitable systems. In most cases agroforestry systems are more profitable than subsistence agriculture.

The idea of additionality in financing carbon sequestration is already embodied in the UNFCCC and its Kyoto Protocol. Additionality is the criteria for carbon offset projects to determine offsets that occur in addition to business as usual. Additionality is determined by analyzing barriers. Many barriers to adoption of these systems exist, and prevent them from contributing more fully to rural development, including:

- **Delayed returns on investments:** In most cases it takes 3 to 5 years to recoup initial investments in agroforestry systems. This is prohibitively long for smallholder, subsistence farmers. Alternative and shorter-term income sources are required to bridge the gap between planting and income generation.
- **Lack of knowledge:** In many instances farmers lack knowledge about how to grow trees and the potential for income generation of agroforestry systems. Rural extension systems, where they function, often do not have the information on these systems to pass along to farmers. Improvement of extension services is required to overcome this barrier.
- **Labour shortages:** Agroforestry systems are generally more labour intensive than cropping systems. Farming families in rural areas in the developing world often have labour shortages during rainy seasons and therefore are not capable of taking full advantage of these periods. In many areas, men and women have left to find employment in cities and send remittances back to the family that remains in the villages. Funding to purchase additional labour or lure family members back from the cities could help in overcoming this barrier.

Investments to facilitate wider adoption of higher carbon and higher profit production systems need to target removing these or other barriers that exist in rural areas. In the example above, one of the most important barriers for resource poor farmers to engage in this type of project is financial. Figure 3 shows that the cash flow for this type of plantation is negative for the first three years of the project. This is fairly common in agroforestry projects. A second barrier is lack of knowledge about agroforestry systems. Thus, despite the favourable internal rate of return resource poor farmers cannot undertake this type of production system because of the financial barrier early in the conversion phase to a new production system and because of the knowledge barrier.

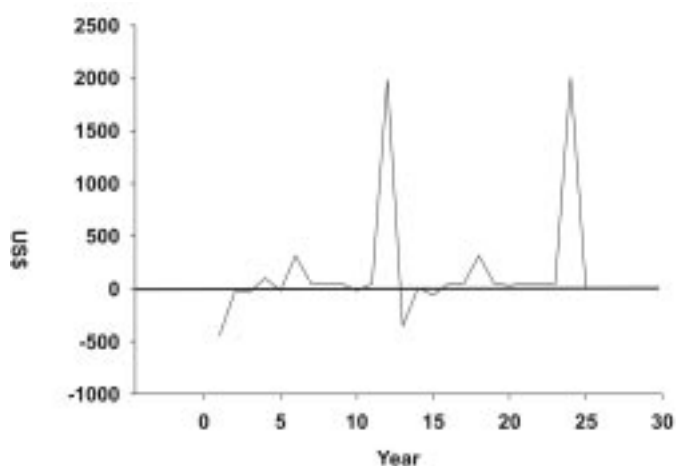


Figure 3. Cash flow over two rotations of a moderately intensive agro/community forestry plantation in the tropics. Values are in 2005\$.

If additional investments were to be made to overcome these barriers, wider adoption of agroforestry could occur. In this case, investments of US\$640 per ha would be required and the cost of sequestering the carbon would be only \$16.93 per tonne of carbon or \$4.62 per tCO₂e. For the case of permanent agroforestry, assuming similar establishment and operating costs, the cost per tonne C decreases to \$6.88 because of the higher productivity of the system. Assuming similar costs to overcome barriers for these types of plantations, the cost of removing the barriers would be only \$1.88 per tonne CO₂e. Finally, to put this in a global perspective, the technical potential C sequestration of this scenario is 30.8 GtCO₂e for a total cost of \$134.4 billion. The actual potential suggested by the IPCC scenario analyzed in Section 3.1 is given in Table 7. About 50% of the land-use change globally is occurs in Africa, thus, the continent could make a significant contribution to climate change mitigation through C sequestration in agricultural landscapes.

Greater consideration of these land-use mitigation options is warranted, as these types of activities can offer multiple benefits. If well designed, agroforestry, grassland management, land rehabilitation, and wetland rehabilitation projects can contribute to biodiversity conservation, watershed protection, reduction of desertification, sustainable land management, and poverty reduction.

Table 7. Calculations of actual sequestration and costs for agroforestry using the IPCC scenario for adoption/conversion. Costs are calculated using total costs per hectare and the values suggested for investments aimed at removing barriers only.

Time (years)	Adoption/ conversion of area	Sequestration potential		Implementation costs	
		Permanent agroforestry (MtCO ₂ e y ⁻¹)	Community forestry (MtCO ₂ e y ⁻¹)	Full (\$M)	Barriers only (\$M)
10	20	1,434	583	5,843	2,544
15	23	1,672	682	6,836	2,976
20	27	1,910	777	7,791	3,392
25	30	2,149	876	8,783	3,824
30	33	2,387	972	9,739	4,240

Conclusion

There are useful opportunities for mitigating non-CO₂ GHG and soil carbon emissions in agriculture. Emissions can be reduced by managing carbon and nitrogen more efficiently in agricultural ecosystems. The most promising option for the continent is carbon sequestration from the atmosphere and storage in soils or in vegetation, for example in community forestry or agroforestry systems. The opportunities and investments required are summarized in Table 8. In the foregoing analysis, values for abatement of non-CO₂ GHG were in 2000\$ whereas carbon sequestration values were in 2005\$. To make these values comparable a 4 percent discount rate was used and all values are presented in \$2000.

There are opportunities for small emissions reductions at a net benefit or at zero cost, and these need to be pursued. There is potential for abatement of all sources, but with current technologies and the prevailing economic conditions these potentials are all low. The analysis presented here suggests that 11-13 percent of non-CO₂ GHG and soil carbon emissions could be abated at reasonable costs.

Sequestration offers the most significant and cost effective means of reducing atmospheric concentrations of GHGs. There are large potentials in a number of practices in agriculture. In the examples worked out in this report on agroforestry, total costs for sequestration were on the order of \$10 per tCO₂e and the estimates of global feasibility are between 0.7 and 2.1 GtCO₂e per year. Many of these practices are economically beneficial, but do not occur due to a number of barriers. Investment targeted at overcoming these barriers is much less than the total cost, and therefore, there are opportunities to share costs with other beneficiaries. The analysis suggests that the cost associated with overcoming these barriers is less than \$4.50 per tCO₂e.

Table 8. Summary of mitigation opportunities and additional costs in the agriculture sector. Cost values are in 2000\$

Source	Cost \$/ tCO ₂ e	2010		2020		2030	
		MtCO ₂ e	\$million	MtCO ₂ e	\$million	MtCO ₂ e	\$million
Non-CO ₂ GHG							
Croplands	0	128	0	130	0	140	0
	30	183	5,478	168	5,037	180	5,392
Rice	0	109	0	114	0	116	0
	30	226	6,789	238	7,137	243	7,298
Livestock	0	76	0	83	0	92	0
	30	143	4,281	158	4,731	175	5,257
Total	0	314	0	323	0	350	0
	30	552	16,564	559	16,781	606	18,190
C sequestration							
Agroforestry (IPCC)	4.5			1,672	6,836	2,149	8,783
Agroforestry (ENCOFOR)	10			682	6,836	876	8,783

Abatement costs are significant compared to current and projected rates of global investment in agriculture. Improved abatement options likely require increases in public research funding. Investments, particularly in developing countries, need to increase. Reductions in investment by developing countries and reduction in the share of ODA for agriculture over the past three decades have led to land degradation and extensification of subsistence agriculture systems, as populations have grown. This has led to large-scale losses in carbon from natural ecosystems. Investments aimed at sequestration and intensification of agricultural systems can reverse this trend.

References

- Albrecht A and Kandji ST 2003, Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystems and Environment*. **99**: pp.15-27
- Baker, J.M., T.E. Ochsner, R.T. Venterea, T.J. Griffis. 2007. Tillage and soil carbon sequestration- What do we really know? *Agriculture, Ecosystems and Environment* 118: 1–5.
- Bekele-Tesemma A. 2007. Profitable Agroforestry Innovations for Eastern Africa. RELMA World Agroforestry Centre, Nairobi, Kenya.
- Bouwman A. 2001, *Global Estimates of Gaseous Emissions from Agricultural Land*. Rome: Food and Agriculture Organization (FAO)
- Cannell MGR. 2003. Carbon sequestration and biomass energy offset: theoretical, potential and achievable capacities globally, in Europe and the UK. *Biomass & Bioenergy*. **24**: pp. 97-116
- Clemens J, and Ahlgrimm HJ. 2001. Greenhouse gases from animal husbandry: mitigation options. *Nutrient Cycling in Agroecosystems*. **60**: pp.287-300
- Davidson EA and Ackerman IL. 1993. Changes in soil carbon inventories following cultivation of previously untilled soils. *Biogeochemistry* **20**: pp.161-193
- Davidson EA and Verchot LV. 2000. Testing the hole-in-the-pipe model of nitric and nitrous oxide emissions from soils using the TRAGNET database. *Global Biogeochemical Cycles*. **14**: pp.1035-1042

- Davidson EA, Verchot LV, Cattânio JH, Ackerman IL and Carvalho JEM. 2000. Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazonia. *Biogeochemistry*. **48**: pp.53-69
- de Klein, C.A.M. and R. J. Eckard. 2008. Targeted technologies for nitrous oxide abatement from animal agriculture. *Australian Journal of Experimental Agriculture*, 2008, 48, 14–20.
- DEFRA, 2007. *A review of research to identify best practice for reducing greenhouse gases from agriculture and land management*. Defra Project AC0206, London, UK.
- Houghton, R.A. 2007. Balancing the Global Carbon Budget. *Annu. Rev. Earth Planet. Sci.* 2007.35:313-347.
- Intergovernmental Panel on Climate Change (IPCC). 2000. *IPCC Special Report on Land Use, Land-Use Change and Forestry*. Cambridge: Cambridge University Press
- IPCC 2007. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Lal R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science*. **304**: 1623-1627
- Lal, R., 2003. Global potential of soil carbon sequestration to mitigate the greenhouse effect. *Crit. Rev. Plant Sci.* 22 (2), 151–184.
- Li C, Frohling S, and Butterbach Ball K. 2005. Carbon sequestration in arable soils is likely to increase nitrous oxide emissions, offsetting reductions in climate radiative forcing. *Climatic Change*. **72**: pp.321-338. doi10.1007/s10584-005-6791-5
- Rosegrant M, Paisner MS, and Meijer S. 2001. *Long-Term Prospects for Agriculture and the Resource Base*. The World Bank Rural Development Family. Rural Development Strategy Background Paper #1. Washington DC: The World Bank
- Schneider UA and McCarl, BA. 2003. Economic potential of biomass based fuels for greenhouse gas emission mitigation. *Environmental and Resource Economics*. **24**: pp.291-312
- Smith KA and Conen F. 2004. Impacts of land management on fluxes of trace greenhouse gases. *Soil Use and Management*. **20**: 255-263
- Smith P, Martino D, Cai Z, Gwary D, Janzen HH, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes RJ, Sirotenko O, Howden M, McAllister T, Pan G, Romanenkov V, Schneider U, Towprayoon S, Wattenbach M, and Smith JU. 2007. Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society, B*.
- Stern, N. 2007. *Stern Review: The Economics of Climate Change*. Cambridge University Press, Cambridge, UK. pp. 575.
- Swallow, B., van Noordwijk, M., Dewi, S., Murdiyarto, D., White, D., Gockowski, J., Hyman, G., Budidarsono, S., Robiglio, V., Meadu, V., Ekadinata, A., Agus, F., Hairiah, K., Mbile, P., Sonwa, D.J., and Weise, S., 2007. Opportunities for Avoided Deforestation with Sustainable Benefits: An interim report of the ASB partnership for the Tropical Forest Margins. Nairobi, Kenya.
- Tate KR, Ross DJ, Scott NA, Rodda NJ, Townsend JA, and Arnold GC. 2006. Post-harvest patterns of carbon dioxide production, methane uptake and nitrous oxide production in a *Pinus radiata* D. Don plantation. *Forest Ecology and Management* **228**: pp.40-50
- US Environmental Protection Agency (USEPA). 2006a. *Global Anthropogenic Non-CO₂ Greenhouse Gas Emissions: 1990-2020*. Washington DC: USEPA
- US Environmental Protection Agency (USEPA). 2006b. *Global Mitigation of Non-CO₂ Greenhouse Gases*. Washington DC: USEPA
- VandenBygaart, A.J., Gregorich, E.G., Angers, D.A., 2003. Influence of agricultural management on soil organic carbon: a compendium and assessment of Canadian studies. *Can. J. Soil Sci.* 83, 363–380.
- Verchot LV, Davidson EA, Cattânio JH, and Ackerman IL. 2000. Land-use change and biogeochemical controls of methane fluxes in soils of eastern Amazonia. *Ecosystems*, **3**: pp.41-56
- Verchot LV, Davidson EA, Cattânio JH, Ackerman IL, Erickson HE, and Keller M. 1999. Landuse change and biogeochemical controls of nitrogen oxide emissions from soils in eastern Amazonia. *Global Biogeochemical Cycles*. **13**: pp3146
- Verchot LV, van Noordwijk M, Kandji S, Tomich T, Ong C, Albrecht A, Mackensen J, Bantilan C, Anupama CK, and Palm C. 2007. Climate change: Linking adaptation and mitigation through agroforestry. *Mitigation and Adaptation Strategies for Global Change*, **12**: pp.1381-2386. DOI 10.1007/s11027-007-9105-6
- Verchot, L.V. 2007. Opportunities for Climate Change Mitigation in Agriculture and Investment Requirements to Take Advantage of These Opportunities. *A report to the UNFCCC Secretariat Financial and Technical Support Programme*. url: http://unfccc.int/files/cooperation_and_support/financial_mechanism/application/pdf/verchot.pdf
- West, T.O., Post, W.M., 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. *Soil Sci. Soc. Am. J.* 66, 1930–1946.

Mitigating Climate Change and Better Ensuring Agriculture's Adaptation for Impending Climate Change through Conservation Agriculture

Des McGarry

*Land and Environment Consultant, Brisbane, Australia
(Email: desmcgarry@optusnet.com.au)*

Global climate change (CC), as assessed by the 4th Assessment Report of the IPCC, is already occurring and the potential impacts are regarded to be ever-worsening. Agriculture, though occupying 40-50% of the Earth's land surface, contributes "only" 10-12% of total global anthropogenic greenhouse gas (GHG) emissions (5.1 to 6.1 GtCO₂-eq/yr in 2005). However, agriculture contributes 47% and 58% of total anthropogenic emissions of N₂O and CH₄, respectively. CO₂ has large annual exchanges between the atmosphere and agricultural lands but the net flux is estimated to be approximately balanced, so accounts for less than 1% of global anthropogenic CO₂ emissions. Agricultural CH₄ and N₂O emissions have increased by nearly 17% from 1990 to 2005; 32% of the increase from Non-Annex I ("least developed countries") countries who were responsible for ~75% of all agricultural emissions. The Annex I countries, collectively, showed a decrease of 12% in GHG emissions.

Several agencies (eg IPCC) already recognise that the agriculture sector (globally) has developed several documented and tested strategies with strong potential to impact on CC through reduced GHG emissions (mitigation), and achieve readiness of the agricultural sector for CC (adaptation), with concurrent benefits (co-benefits) of attaining more sustainable land management practices, generally, and food and water security, and rural poverty mitigation, specifically. The common term for these strategies is Conservation Agriculture (sometimes termed "low input agriculture") that though non-prescriptive and requiring local fine-tuning to ensure practicality and widespread success, does have three core themes: (a) maintaining a permanent organic cover over the soil (b) minimising soil disturbance (no till) and (c) practising crop rotations for organic matter and biodiversity enrichment. Further, inter-related practices to further enhance CC mitigation and achievement of sustainable systems include biogas (CH₄) production from animal wastes, inter-cropping, the use of biofuels and site specific nutrient management for balanced fertiliser usage.

Required for wide and successful implementation of these initiatives will be the close linking of CA and related actions to the on-going development activities of existing International and National CC and sustainable development initiatives, such as the content of IPCC reports, the targets of National Development Strategies and Millennium Development Goals, the Marrakech Process, the National Communications (NC) and National Adaptation Programs of Action (NAPA) of several Non-Annex I countries that already mention such actions in brief. Additionally, placement of these initiatives within higher level policy implementation will help achieve attractiveness of the revised sector management initiatives. Concurrently, implementation of bottom-up, country driven, regionally networked, cross-sectoral approaches will ensure multi-level stakeholder benefits for land, water and biodiversity protection within several key agricultural systems, as well as increased farm profitability towards rural poverty reduction, through lessened input:output ratios.

Selected examples of current CA and related strategies and their role in CC mitigation will be presented. A current aim is the creation of a "framework" of good practices and their role in mitigating CC. Foreseen is that this framework will continue to be populated and enriched with time, to ensure multiple examples of good practice across a wide variety of environments.

The purpose of this Paper is to commence discussion of a range of inter-linked, practical strategies already known and practised within some sections of the agriculture sector¹, (mainly Conservation Agriculture and related practices), to aid the mitigation of climate change (CC) while decreasing vulnerability of the agriculture sector to impending future changes, and increasing the adaptation to CC of natural resources generally and agriculture and rural livelihoods specifically. Concurrent co-benefits are also achievable, eg increased economic sustainability (via reduced input:output ratios) towards poverty reduction, and food and water security. The implementation and attainment of these multi-level wins is most guaranteed through holistic, multi-level scenarios, based on sound and acceptable (to end users) practices that are inter-agency and cross-cutting, firmly research (science) based/tested/monitored and supported by necessary policy changes. The desired outcomes are widespread farm-level uptake of these strategies for significant CC gains and co-benefits of improved yields, food and water security, sustainable land management, and reduced rural:urban socio-economic inequities.

¹ Defined by the IPCC as "lands used for agricultural production, consisting of cropland, managed grassland and permanent crops including agro-forestry and bio-energy crops"

This paper will focus on the concepts and practicalities of two inter-related questions: “What can agriculture do to lessen CC?” and “What can agriculture do to ensure adaptation to impending CC” As such, these questions are different to most considerations of CC being addressed in today’s literature. These have tended to focus more on the predicted future impacts (direct and indirect) of CC on the agriculture sector, or, in other words the risk to agriculture of CC in terms of cause, magnitude, nature and geographic variability of the predicted changes in climate.

By necessity, this script tends to be academic. However, from the outset it will be stated that the aim or outcome of these deliberations is the *implementation* of the themes and actions addressed herein. In this way, it is hoped the content of this paper can be used to support and develop *actions* in both loan-funding scenarios (eg World Bank, Asian Development Bank) and grant-funding applications (eg GEF). To these ends, this script will present the bigger, global picture of agriculture and CC, but the final aim will firmly be the addressing of CC issues locally; this being the most implementable scenario. The goal is to achieve workable and executable scenarios; ones that certainly improve the “lot” of rural communities and individual farmers and concurrently aid/support higher level scenarios (Governmental and International aid agencies) in such areas as food and water security, land degradation and urban expansion, in the ever changing scenario of population growth, rising oil and fertiliser prices, dietary changes and CC.

At this early stage, this paper does not claim to provide an exhaustive breakdown of every component of the current subject matter. Rather, a prime aim, herein, is the creation of a framework that establishes the main components of the debate on “what agriculture can do for CC and adaptation of agriculture for CC”, towards the (more important) pragmatic implementation of the parts. To these ends, the framework will consist of several, sequential and inter-related topics, towards achieving several, integrated outcomes: (i) a critical review of the literature - to aid clarification (for persons wishing to further investigate this theme) of the diverse content of the myriad of publications on CC currently being produced, in order to separate out those themes relevant to the prime topic addressed here; (ii) a review of the recent past and current works of governmental, international agency, NGOs and individuals investigating or funding work on CC, again to separate out the relevant works to the current theme; (iii) utilising the (i) and (ii) reviews (that by the nature of CC work will be active and ongoing for some years) highlight both the concepts (eg scientific writing on the scales of the problem and expected influences of altered practices on CC) as well as seek out and present already-implemented field-based examples of the major mitigating strategies across a wide range of scales and environments, while concurrently (iv) seeking interested parties to form partnerships of inter-agency, -country, -disciplines etc for information sharing (successes and failures), implementation scenarios, adoption pathways, inter-institute support and training packages, and costs/benefits/barriers at farm, regional and global scales with the aim of achieving upscaling of the relevant agriculture strategies for widespread benefits.

Points (ii) to (iv), above show cognisance that success in these endeavours will be far more assured through linkages with existing strategies both directly on the current theme as well as cross-cutting with related subject areas.

These same points also show that there has been, to date, a certain amount of discussion and some on the ground activities on the themes being addressed here. Written materials (reviewed below) include IPCC and UNFCCC documents, national development plans (e.g. poverty reduction strategy papers), national sustainable development strategies, Millennium goals, country National Communications (NC) and National Adaptation Programs of Action (NAPA) of several Non-Annex I countries. However, these documents mostly provide only general information on Agriculture’s role in mitigating CC and fall short in presenting practical, farm-level interventions, or implementable policies, or required capacity building/training etc formulated towards actually achieving the on the ground, CC mitigation/adaptation activities. The specific “on the ground” activities that have been conducted for some decades tend to be specific to individual farmers, farmer associations, and crop-oriented growers’ groups (eg Australian cotton and grains groups). Many of these conduct agriculture practices that have strong potential to be CC mitigating strategies, termed Conservation Agriculture (CA). However, at present these are conducted for reason of cost- and input-reduction, and drought and erosion proofing, rather than CC mitigation and preparedness.

Required, therefore, and as such defines the focal point of this paper and the works that emanate from it, is a set of definitive advisory statements of strategies (practical, farm-level interventions) to achieve the mitigation/adaptation to CC. And the link to and support gained from associated supportive policies, as well as the requirements for capacity building/training, networking etc - again formulated to achieve farm level activities. Subsequent steps

include pathways for upscaling and replication of these strategies to achieve widespread impacts on both CC and concurrent sustainable use of the environment.

Previous and Current Works

A start will be made to review current literature and activities in the subject area. The aim is to seek out relevant texts and activities, towards supplementing and enriching the information they provide. Eight of the more major ones will be reviewed here. The content of this list is dynamic and it is expected that others will come to light, for incorporation in future drafts of this paper.

- (i) The Pew report² (Paustian et al 2006) stated that though the agriculture sector (including land use change) contributes about 1/3rd of the total human-induced global warming effect (the remainder mainly being CO₂ emissions from fossil fuel combustion), "...agriculture is unique in that it can bring several, inter-related and synergetic strategies to the mitigation of global warming that also provide multiple co-benefits, that by themselves justify the new practices and provide means whereby agriculture can adapt or improve readiness against CC". In such ways, the agriculture sector has the potential to reduce its own emissions and concurrently both offset and reduce emissions from other sectors through removing CO₂ from the atmosphere *via* photosynthesis and storing carbon in plants and soils (every tonne of carbon added to and stored in plants or soils removes 3.6 tonnes of CO₂ from the atmosphere), as well as providing biofuels to displace fossil fuel use, and through the adoption of agricultural best management practices (that in themselves aid global, environmental condition and aid adaptation of the sector to CC) reduce emissions from agricultural soils (N₂O), from livestock production and manure (CH₄), and from on-farm energy use (CO₂).
- (ii) The Marrakech Process began in 2003 to build political support for the implementation of sustainable consumption and production (SCP) and to prepare input for negotiations at CSD 18-19³. The Marrakech Process is a global initiative to support the elaboration of a 10-Year Framework of Programs on SCP, as called for by the WSSD Johannesburg Plan of Action. Its goal is to assist countries in their efforts towards sustainability, to green their economies, to help corporations develop sustainable business models, and to encourage consumers to adopt more sustainable lifestyles. The more specific report within the Marrakech Process on "SCP in Agriculture and Rural Development"⁴ discusses achieving more sustainable consumption and production in the agricultural sector that gives a less input intensive and more resource efficient agriculture as a means to strengthen the competitiveness of the agricultural sector. The report urges the promotion of good environmental practices in agricultural production for sustainable agricultural development and poverty reduction, and rehabilitating degraded, over-used lands through CA practices. The report also notes that biofuel production can assist the agricultural sector contribute to mitigating GHG emissions.
- (iii) Of direct relevance to the subject matter herein, are the writings of Professor Julian Cribb⁵; a strong advocate of Agriculture's role in positively influencing current global problems of food security and rising prices with impending CC. He argues the important role that the world's farmers can have in aiding the rescuing of civilisation from the multiple, additive problems currently effecting the globe, including: the lowest levels of world food security in 50 years, rising food prices (eg rice has risen from \$400 to \$1000 a tonne), world population growth (projected 9.1 billion by 2050), increased demand for protein food (especially in China and India), total world food demand forecast to rise 110% by 2050, a global water crisis (cities now consuming half the water once used to grow food while groundwater levels are falling in every country where it is used for agriculture), reduced area of good arable land (from urban expansion, erosion and degradation), massive inflation in the prices of fuel, fertiliser and chemicals, biofuels fast-expanding into historic food production areas (that by 2020 are projected to consume 400 million tonnes of grain annually; the entire world rice harvest) all under the spectre of climate change (up to half the Earth projected to be in regular drought by the end of the century). His discourse is that world authorities need to recognise that "Agriculture Policy is Defence Policy", including and crosscutting as it does with policies in the subject areas of refugees, immigration, environment, health, food and economics. Required is a doubling of world food output, cognisant that there is no "silver bullet solution". Resolution must be achieved

² The Pew report: <http://www.pewclimate.org/docUploads/Agriculture%27s%20Role%20in%20GHG%20Mitigation.pdf>

³ See: <http://esa.un.org/marrakechprocess/roadmapcsd.shtml>

⁴ Download from: <http://esa.un.org/marrakechprocess/issuesagricultureandrural.shtml>

⁵ Adjunct Professor in Science Communication at the University of Technology, Sydney, Australia; see: <http://www.atse.org.au/index.php?sectionid=1207> and <http://www.sciencealert.com.au/jca.html>

using less land (increasingly lower quality land), far less water, far fewer nutrients with projections of ever-increasing drought. The requirements therefore are for integrated, cross-cutting actions on a global scale and by every human, government and international agency. Target areas include increasing water use efficiency (irrigation and rain) in all crops, the implementation of organic and low-input farming systems, raising vegetable production and consumption, replacing protein and carbohydrate based foods with lower input cost and “more direct” foods such as pulses and grains, the commitment to recycle all nutrients - on the farm (eg slurry from biodigesters), in the food chain or in sewage works (utilising urban sewage for methane production) - and the large scale introduction of ‘green cities’ that address the environmental impacts of urban development. Recognised is that these challenges are far from trivial. However, just as humanity overcame two previous global food crises with the first agricultural revolution and the green revolution, it is now called on to do so again, with the “sustainable food revolution”.

- (iv) The third volume of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007), goes further (in terms of IPCC reporting of CC) than the previous two volumes that considered “only” the physical science basis of climate change and the expected consequences for natural and human systems. More pertinent to the subject matter of this paper, the 3rd volume provides analysis of the technologies, costs, benefits and policy interventions required of different approaches to mitigating and avoiding climate change. Additionally, and again of direct relevance to the current paper, the third volume also analyses “how can climate mitigation practices and policy be aligned with sustainable development practices and policies?” There is a specific chapter (Chapter 8) on “Agriculture”⁶ that recognises that “a variety of options exist for (the) mitigation of GHG emissions in agriculture...(including) improved agronomic practices (nutrient use, tillage, residue management), restoration of organic soils (drained) and degraded lands for crop production, improved water and rice management, set-aside of land, land use change (eg conversion of cropland to grassland), agro-forestry, and improved livestock and manure management. Recognised, too is that many of these potential mitigation opportunities use current technologies so could be implemented immediately, but future technological development will be required for efficacy of additional mitigation measures.
- (v) An earlier report from the Pew Centre (Burton et al 2006) introduced the concept (again of direct relevance to the current paper) of “integrating CC adaptation considerations across the full range of Sustainable Development (SD)”. The report considered this as the most direct and effective means of discouraging investments that heighten climate vulnerability and promoting those that strengthen climate resilience. A development-centred strategy could closely complement the Convention-based approach, helping to ensure that national adaptation strategies prepared with Convention support are implemented, and could over time leverage far more resources than likely would be forthcoming under the climate regime. Proposed investments could be assessed for their own vulnerability to climate variability and climate change and for any broader effect on climate vulnerability within the host country. As with the environmental impact assessments now performed routinely by multilateral lenders, this would provide critical information to decision-makers. Projects in SD that substantially reduce climate vulnerability, or are identified as priorities in national communication and adaptation programs (see next two items) might be given preferential treatment.
- (vi) National Communications (NC) are the reports that parties to the UNFCCC must submit on implementation of the Convention to the Conference of the Parties (COP)⁷. The core elements of NCs for both Annex I and non-Annex I Parties are information on emissions and removals of GHG and details of the activities a Party has undertaken to implement the Convention. NCs usually contain information on national circumstances, vulnerability assessment, financial resources and transfer of technology, and education, training and public awareness; but the ones from Annex I Parties additionally contain information on policies and measures. Annex I Parties that have ratified the Kyoto Protocol must include supplementary information in their national communications and their annual inventories of emissions and removals of GHGs to demonstrate compliance with the Protocol’s commitments.
- (vii) More than 40 least developed countries (LDCs) have received funding under the UNFCCC to prepare National Adaptation Programmes of Action (NAPAs) that draw on existing information to address urgent needs in terms of CC variability, risk and adaptation, and identify priority actions with regard to adaptation to climate change⁸.

⁶ <http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter8.pdf>

⁷ See http://unfccc.int/national_reports/items/1408.php

⁸ http://unfccc.int/national_reports/napa/items/2719.php

The rationale for NAPAs rests on the limited ability of LDCs to adapt to the adverse effects of CC. In order to address their urgent adaptation needs with focus on enhancing adaptive capacity to climate variability. A NAPA takes into account existing coping strategies at the grassroots level, and builds upon that to identify priority activities with prominence given to community-level input, recognizing that grassroots communities are the main stakeholders. About 40 NAPAs have been produced to date.

- (viii) The Global Environment Facility (GEF) administers CC adaptation funding under the UNFCCC and allocates funds for implementation projects. As it has become more apparent that global warming is occurring, the Conference of the Parties' (COP) guidance to the GEF has emphasized the need to move from preparation to implementation. The GEF has responded by initiating four different paths to support adaptation activities: the Strategic Priority on Adaptation (SPA), the Least Developed Country Fund (LDCF), the Special Climate Change Fund (SCCF) and the Adaptation Fund (AF)⁹. Consistent with UNFCCC guidance, projects supported by these four avenues will seek to integrate adaptation policies and measures in all sectors of development including water, agriculture, energy, health, and vulnerable ecosystems. SPA aims to reduce vulnerability and to increase adaptive capacity to the adverse effects of climate change through supporting pilot and demonstration projects that address local adaptation needs and generate global environmental benefits in all GEF focal areas. LDCF addresses the extreme vulnerability and limited adaptive capacity of LDCs. LDCF initially supported preparation of National Adaptation Programmes of Action (NAPAs), as detailed in (vii) above. The NAPAs conclude with a list of prioritized project profiles to be subsequently implemented with support from the LDCF. The SCCF, established in response to guidance from the Conference of the Parties to the UNFCCC, was originally aimed at supporting activities in the following areas: adaptation, technology transfer, energy, transport, industry, agriculture, forestry, and waste management, and economic diversification. The AF will be financed from the share of proceeds on the clean development mechanism (CDM). Consequently, with the entry into force of the Kyoto Protocol, 2% of the share of the proceeds from CDM projects will be directed to an adaptation fund. Many of the projects funded under these GEF initiatives are quite recent and are being conducted, now. Of interest will be the outcomes of these projects in terms of the subject matter of this current paper; to be investigated as the GEF projects develop and produce outcomes.

The problem(s)

Why is there a need for Agriculture to aid in the mitigation of CC and concurrently better adapt itself for change? Some of the drivers have already been mentioned, as reviewed by Cribb (2008). The following list adds to those.

- (i) A first consideration is Agriculture's contribution to CC. Agriculture, though occupying 40-50% of the Earth's land surface, contributes "only" 10-12% of total global anthropogenic GHG emissions (5.1 to 6.1 GtCO₂-eq/yr in 2005)¹⁰. However, agriculture contributes 47% and 58% of total anthropogenic emissions of N₂O and CH₄, respectively; particularly important as it is known is that CH₄ and N₂O have 21 and 310 times the "global warming potential" of CO₂. CO₂ has large annual exchanges between the atmosphere and agricultural lands but the net flux is estimated to be approximately balanced, so accounts for less than 1% of global anthropogenic CO₂ emissions. Agricultural CH₄ and N₂O emissions have increased by nearly 17% from 1990 to 2005; 32% of the increase from Non-Annex I ("least developed countries") countries who were responsible for ~75% of all agricultural emissions. The Annex I countries, collectively showed a decrease of 12% in GHG emissions.
- (ii) In terms of food security, FAO estimates put the number of people suffering from chronic hunger worldwide in 2003-5 at 848 million, an increase of 6 million from the 842 million in 1990-2¹¹. Soaring food, fuel and fertilizer prices have exacerbated the problem. Food prices rose 52% between 2007-8, and fertilizer prices have nearly doubled over the past year.
- (iii) The diets of large sections of the world's population are changing, particularly in developing countries (Delgado 2003, FAO 2008a)¹² where there has been a pronounced shift away from staples such as cereals, tubers and pulses towards more livestock products, vegetable oils, fruits and vegetables. Total meat production in developing countries increased 5-fold (27 million tonnes to 147 million tonnes) between 1970 and 2005, and, although the

⁹http://www.gefweb.org/projects/focal_areas/climate/documents/GEF_Support_for_Adaptation_to_Climate_Change.pdf

¹⁰ IPCC (2007) <http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter8.pdf>

¹¹ From: <http://www.fao.org/newsroom/en/news/2008/1000923/index.html>

¹² FAO - "Current world fertilizer trends and outlook to 2011/12" <ftp://ftp.fao.org/agl/agll/docs/cwfto11.pdf>

pace of growth is slowing down, global meat demand is expected to increase by more than 50% by 2030. One report¹³ states that by 2020, developing countries will consume 107 million metric tons (mmt) more meat and 177 mmt more milk than in 1996-8, dwarfing developed-country increases of 19 mmt for meat and 32 mmt for milk in the same period. These increases require more feed (coarse grains and oilseed meals). One projection sees that this increase in livestock production will require annual feed consumption of cereals to rise by nearly 300 mmt by 2020 with concurrent increased demand for fertilisers. Conversion of grain areas to vegetable and fruit production will also translate into greater fertilizer demand as average application rates for the latter is about double those for grain crops.

- (iv) The recent GLADA report (Bai et al 2008) stated that land degradation is increasing in severity and extent in many parts of the world, with more than 20% of all cultivated areas, 30% of forests and 10% of grasslands undergoing degradation. An estimated 1.5 billion people, or a ¼ of the world's population, depend directly on land that is being degraded. This land degradation reduces productivity, impacts negatively on migration, food insecurity, damage to basic resources and ecosystems, and leads to loss of biodiversity. Additionally, land degradation has important implications for CC mitigation and adaptation, as the loss of biomass and soil organic matter releases carbon into the atmosphere and affects the quality of soil and its ability to hold water and nutrients. Importantly, the GLADA study shows land degradation since 1991 has affected new areas and some historically degraded areas were so severely affected that they are now stable having been abandoned or managed at low levels of productivity; all impacting on non-mitigation of CC through reduced soil organic carbon (SOC), decreased vegetative cover and often increased albedo effects, causing increased warming form increased reflectance.
- (v) Compounding the ever growing area of degraded land, the world is running out of farm land (Cribb 2008). The area of land where food is grown has declined from 0.45 ha per person in the 1960s to 0.23 ha currently and will continue to fall as population rises. This creates a need to increase output from smaller land areas. Or, increase productivity of what are currently considered marginal lands but only if conducted with sustainable practices or the situation (marginality / degradation) will worsen.
- (vi) Oil costs. From the mid-1980s to September 2003, the inflation adjusted price of a barrel of crude oil was <\$25/ barrel, rising to \$60 by August 2005, and then \$146 in June 2008, before falling back to \$110 by the start of September 2008. The price of oil impacts greatly on many areas of the agriculture sector; fuel for farm machinery is the most direct, but fertiliser price and haulage of farm products are also affected.
- (vii) Fertiliser prices. A multitude of recent developments have led to a dramatic increase in world fertiliser prices over the last 18 months¹⁴, causing fertiliser prices to rise more than oil or any other commodities in that period¹⁵. The world price of diammonium phosphate (DAP) in January 2007 was \$335 per tonne; in 14 months this price increased to \$1110 per tonne. Over the same period the retail price increased from \$610 per tonne to \$1220 per tonne. The world price for urea was relatively stable at around \$200 per tonne until mid-2004. Over the last six months of 2004 the world price for urea increased to around \$325 per tonne. It then fluctuated in the range between \$325 per tonne to \$400 per tonne until January 2008, after which it increased to above \$600 per tonne by May 2008.
- (viii) Ever growing population. Already the urban : rural ratio of land is increasing with some of the best agricultural land being taken for urban development From footnote 16 - In spite of world population growth slowing from 1.26% (1996-2005) to 1.10% (projected 2006-15), absolute annual increments continue to be large. It is anticipated that between 50 and 70 million people will be added annually to the world population until the mid 2030s. Almost all of this increase is expected to take place in developing countries especially the group of 50 LDCs. More food and fibre will be required to feed and cloth these additional people and to increase the daily food uptake of the still 830 million undernourished world wide (2002-04). There is thus significant scope for further increases in demand for food even as population growth slows down.
- (ix) Biofuels. High oil prices and the potential for future decline in mineral oil stocks are creating new markets for agricultural commodities that can be used as feedstock for the production of bio-fuels¹⁶. Bio-fuels are being promoted as contributing to a wide range of policy objectives, most notably as providing greater energy security

¹³ <http://jn.nutrition.org/cgi/content/full/133/11/3907S>

¹⁴ FAO - "Current world fertilizer trends and outlook to 2011/12" <ftp://ftp.fao.org/agl/agll/docs/cwfto11.pdf>

¹⁵ The Guardian newspaper (August 2008); <http://www.guardian.co.uk/environment/2008/aug/12/biofuels.food>

¹⁶ FAO - "Current world fertilizer trends and outlook to 2011/12" <ftp://ftp.fao.org/agl/agll/docs/cwfto11.pdf>

with regard to liquid fuels, increasing rural incomes, lowering greenhouse gas emissions and providing economic opportunities for developing countries. Currently there is ~14 million hectares or 1% of arable land planted with biofuel crops which provide some 1% of transport fuels. Some predictions see this area doubling to ~35 million hectares by 2030. This massive growth is causing alarm, in terms of possible negative impact on the food security of millions of people across the world, if biofuels are to be either utilising crops currently used as food (eg maize and sugarcane) or are grown on land currently used for food crops. Balance is required. Additionally, foreseen is the potential to grow certain biofuel crops (the more hardy and drought resistant shrub types) on what is currently deemed “marginal” land. With improved agricultural practices (detailed below) especially no till, stubble mulches and inter- and understorey cropping, these lands could be both made productive, be protected from degradation and achieve long term sustainability.

Linkages are known to exist between rising oil prices, increased fertiliser demand and biofuel production¹⁷. High oil prices have contributed to price increases for most agricultural crops by both raising input costs, and by boosting demand for agricultural crops used as feedstock in the production of alternative energy sources (biofuels). The combination of high oil prices and the desire to deal with environmental issues is driving the rapid expansion of the biofuels sector. This is likely to boost the demand for feed stocks such as maize, sugar, rapeseed, soybean, palm oil and wheat for many years to come. However, much will also depend on the supply and demand fundamentals of the biofuel sector itself. High oil prices could depress the use of oil-based fertilizers which have been behind much of the increase in farm production during the past half century.

- (x) Lessened water. Rural water usage is increasing, competition with industry and ever growing urban areas is increasing, and CC seems to forecast increasing drought in certain areas. Required are cropping practices that are far more water use efficient; of both rain and irrigation waters.
- (xi) Changing land use with CC. Some studies are predicting that with change in global climatic zones, population growth, dietary changes and biofuel demands vast areas of what are currently natural ecosystems will be converted into croplands. The example is given of vast areas of grasslands in East Africa, expected to be converted to ploughed fields over the next 40 years, as wetter conditions caused by climate change attract crop farmers to grazing grounds¹⁸.

Towards Solutions

- General

In the light of the above multitude of inter-linked and in many cases synergetic “pressures” on land, the environment and the agricultural sector, there recently have been many calls for “a change to the norm” in order to offset short term economic pain and long term “doom” of the world’s population. A major goal of each of these three initiatives is to guide and inspire many government and civil society personnel who though they may realise that action is needed, are not exactly sure what steps to take. Three examples will be given.

- (i) A recent publication by UNEP on “Planning for Change” (Matthew 2008)¹⁹ urged the global community, in the context of impending CC, to adopt more sustainable life-styles to both reduce the use of natural resources and CO₂ emissions. Coming out of discussions at the Summit on Sustainable Development (Johannesburg 2002), The UNEP report stated that it is becoming increasingly clear that the world cannot achieve sustainable economic growth with old fashioned consumption and production patterns. In accordance with the “Marrakech process” (a ten-year framework of national and regional initiatives on how to achieve SCP), these guidelines have been developed for governments and other stakeholders to establish national programs on “Sustainable Consumption and Production (SCP). Provided are 10 steps on how to plan, develop, implement and monitor a national SCP program. Discussed also are cross-cutting steps, aimed at linking the program to existing strategies such as national development plans (e.g. poverty reduction strategy papers) and national sustainable development strategies. For monitoring purposes a special focus has been made on the development and application of indicators to measure progress toward SCP. In addition, nine country case studies and other examples of good practice illustrating how governments are implementing SCP programs around the world are provided highlighting lessons learned.

¹⁷ FAO - “Current world fertilizer trends and outlook to 2011/12”<ftp://ftp.fao.org/agl/agll/docs/cwfto11.pdf>

¹⁸ From <http://www.scidev.net/en/news/climate-cropland-changes-raising-temperatures-in-e.html>

¹⁹ http://www.unep.org/pdf/UNEP_Planning_for_change_2008.pdf

- (ii) Smith et al (2007), in Chapter 8 “Agriculture” in the 4th Assessment Report of the IPCC, state that opportunities for mitigating GHGs in agriculture fall into three broad categories, based on the underlying mechanism: (1) reducing GHG emissions by more efficient management of carbon and nitrogen flows in agricultural ecosystems, (2) enhancing removals by correcting SOC losses through improved management, thereby withdrawing atmospheric CO₂, includes reduced crop residue burning and erosion for increased carbon sequestration, and practices such as agro-forestry, perennial plantings and no-till with crop residue retention to increase SOC; (3) avoiding (or displacing) emissions: eg using biofuels rather than fossil fuels as the carbon is of recent atmospheric origin.

More specific agriculture practices that may mitigate GHGs are:

- (a) cropland management (better yields, perennial crops, inter-cropping, legumes and crop rotations, with careful fertiliser regimes, give more SOC; minimal or no till reduces SOC losses from tillage and erosion, and builds SOC and soil fauna); improved irrigation practice can increase yields, hence SOC; draining wetland rice out of season to reduce CH₄ emissions; agro-forestry gives increased carbon sinks, reduced erosion; conversion of arable to grassland or perennial shrubs also aids SOC increase.
 - (b) grazing land management/pasture improvement; improved species and nutrition lead to better SOC and water use efficiency with reduced erosion; ceasing slash and burn reduces many GHGs and builds SOC.
 - (c) restoration of degraded lands; re-vegetation increases SOC and improves water use efficiency and erosion control.
 - (d) livestock management; main aim is CH₄ reduction from enteric fermentation; *via* feeding and dietary changes, and biogas production from collected animal waste.
 - (e) manure/bio-solid management; as (d).
 - (f) bio-energy production; biofuels; balance required of food and fuel production from arable lands.
- (iii) Conservation Agriculture has been practised in many countries and agriculture sectors for up to 40 years. One definition of CA is: “a concept (with very practical field-level outcomes) for resource saving agricultural ecosystem production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment as one of the promising ways of implementing SLM” (Unger 2006). CA varies in almost all situations, as it is not prescriptive. However, the common features are: (a) maintaining, a permanent vegetative cover over the soil provided by the leaves and stems of the current crop, including cover crops and intercrops, plus the organic matter provided by a mulch of retained residues from previous crops: (b) minimising soil disturbance by tillage, preferably eliminating inversion tillage altogether (no-till) and (c) practising crop rotations and combinations which contribute to increased SOC as well as maintaining biodiversity above and in the soil, and may help avoid build-up of pest populations and weeds.

Recently there has been a move to better orient the three CA principles with current challenges in the terms of agriculture, food security and CC (FAO 2008b). The workshop sought answers to the question: “Can plough-based farming be replaced with more sustainable systems in order to safeguard the world’s future food supplies?” Recognised is that the world’s food supplies will increasingly depend on raising production per unit area of farmed land. The need now, therefore, is for farmers to take up more sustainable, productive and profitable ways of production that do not damage the soil, land and environment. The workshop focused its attention principally upon CA based farming systems with their potential to be applied on a global scale (currently there are 100 million hectares of arable crops, grown annually without tillage) to ensure adequacy and security of the world’s food supplies while improving farmers’ livelihoods. Challenges recognised were how to accelerate the participatory adaptation and large-scale uptake of CA practices, wherever appropriate, and in forms fitted to the diversity of local conditions and constraints.

- More specific

Currently, there are several specific initiatives that appear to promise potential in mitigating CC, adapting agriculture for CC, and concurrently aid sustainable land management for food security and improved rural socio-economics. This will be particularly true with joint determination of these initiatives. Required for each of these is investigation for specific agricultural sectors, countries, regions etc of the requirements to implement and then

rapidly upscale (widen the uptake of) these initiatives to maximise local and global benefits, towards future (preferably) spontaneous uptake as widely as possible. Also worthy of investigation is the potential of developing Regional Networks, to accelerate the sharing of training and capacity building in the new techniques, sharing of ideas and technology breakthroughs, equipment, trained staff, laboratory facilities and results from monitoring sites, etc; towards developing a modality of the several initiatives, to aid transferability to other countries, regions, etc. Requirements of creating or developing associated, supporting policy development and capacity building (training) also will aid the wider and successful adoption of these initiatives.

Six examples will be presented here. This list is designed for future enriching and enlarging by others, to address specific needs for as wide an impact as possible.

1. **No till** (NT), also termed direct drilling or zero tillage, is an agricultural practice widely recognised as an important contributor to fixing carbon in the soil, thereby reducing the amount of CO₂ released into the air²⁰ as well as being a generally accepted “best management strategy” for reduced inputs, and land and environmental protection. Retention of plant residues with NT prevents soil erosion (reduced by up to 90%), builds soil biodiversity, decreases use of Nitrogen-based fertilizers (hence release of atmospheric N₂O), improves water infiltration (up to 60%) for future crop use, and requires less cultivation and animal draft (hence fossil fuel use and manure production with less CO₂ and CH₄ emissions). John Landers, who has promoted the technology in Brazil since the 1970s, states: “With the best NT systems you have >1 ton of carbon sequestered (in the soil) per hectare per year.” At present there is an estimated 100 million ha of NT, practised worldwide²¹, showing the very large potential of this practice to remove atmospheric CO₂.

The aim is to increase the uptake of NT (or reduced till) in the agriculture sector of many countries. Constraints and barriers to this strategy, however, are already well known. Rattan Lal (Lal 2007) has stated that “the adoption of NT farming in ...south east Asia...is practically negligible” with the predominance of NT uptake (and associated multilevel gains and spillovers) being in the Americas, Europe and the Indo-Gangetic plain. Resource poor and small size landholders of south east Asia have limited access to required inputs to NT (herbicides, seeding equipment) as well as having competing demands on crop residues (animal feed and fuel) that NT requires to be left in the field.

2. **Biogas** (Methane, CH₄) production (*ie* the controlled production of CH₄ in anaerobic digesters) presents a powerful, and apparently readily implementable and upscalable use of animal manures and other (waste) farm residues, that otherwise would either be kept in open ponds or spread on farms as raw materials (both recognized as strong emitters of CH₄). The aim is to gain far wider utilization of biogas production and use, particularly in rural and peri-urban areas of selected countries. And in this way follow the lead of the Peoples’ Republic of China (particularly over the last 20 years) where there are currently 1.3 billion people providing daily CH₄ inputs into mainly small (8 m³) but also some large (5200 large and mid size) digesters (end 2006 data) with annual production of 6.5 billion m³ of biogas, with the projection of 50 million people using biogas technology by 2010, producing 5.5 million kW at that time (DuByne 2008) and²². China is aiming for 25 billion m³ of biogas by 2020, providing energy to 25% of households in rural areas. Among the many benefits gained from biogas production, the reduction in CH₄ emissions is only one. Biogas usage also reduces the use of trees and crop residues for firewood, addressing not only smoky (unclean) air pollution which is seen as a particulate “GHG” (at all scales from individuals in family homes to country-wide emissions), but also impacts on the negative cycle of land denudation from tree clearing (for firewood) leading to reduced SOC and soil erosion and reduced-level farm production. Another positive is the use of digester residues (routinely pumped out) as bio-fertilisers for increased land productivity without the need for mineral fertiliser inputs.

Certain countries (eg Indonesia) have commenced investigation into the use of crop residues (in particular rice straw) that is in excess of requirements (particularly in two or three crops a year production cycles, where the mass of rice straw residues slow the next crop planting). The residues are mixed with a starter-catalyst (such as Urea or animal manure) to produce biogas. Prototype biodigesters have been produced, with great potential for upscaling, to reduce straw burning hence GHG production, and provide clean cooking fuel for rural dwellers. Investigations are also underway on the potential of utilising other urban wastes (particularly large amounts of waste vegetable matter

²⁰ From the “Science and Development Network”:

<http://www.scidev.net/Features/index.cfm?fuseaction=readFeatures&itemid=576&language=1>

²¹ From the www site of Rolf Derpsch (world no-till advocate): <http://www.rolf-derpsch.com/>

²² <http://www.i-sis.org.uk/BiogasChina.php>

from vegetable markets) for CH₄ production and urban energy provision. Waste paper is also being considered with co-benefits of greatly reducing landfill requirements or GHG from burning the paper.

3. Balanced fertilizer(s) usage is central to CC mitigation (principally N₂O reduction), as well as the achievement of more sustainable development, agriculture adaptation to CC (through reduced dependence on expensive inputs to maintain yields with more hostile climate) and the reduction of rural poverty. This practice is sometimes referred to as “site specific nutrient management” (SSNM) and has been well-researched from the mid 1990s in south east Asia. SSNM provides a field-specific approach for dynamically applying nutrients to crops as and when needed. This approach advocates optimal use of indigenous nutrients originating from soil, plant residues, manures, and irrigation water. Fertilizers are then applied in a timely fashion to overcome the deficit in nutrients between the total demand by rice to achieve a yield target and the supply from indigenous sources. Research in ASEAN countries show that more balanced fertiliser use leads to reduced losses ex-site, and increased yields with equal or reduced N₂O emissions. Investigation is required on the potential and requirements of applying the SSNM approach to other crops (including upland crops and agro-forestry).

In association with SSNM and to support its use at the farm level, several ASEAN institutes have developed and tested field (farmer usable) soil fertility testing kits and fertilizer field kits (the latter to test the quality of farmer-purchased fertilizers); further ensuring reduced fertilizer usage. The more widespread development of these field kits to a wide range of crops is required as too are the resources required (staff, laboratories, field trials, training, farmer field schools, etc) to develop and extend these.

5. Rotations. There are multiple, synergetic benefits of introducing diversified crop rotations (particularly with a legume phase), married together with reduced tillage and especially NT. Positive outcomes include increased soil productivity (from increased SOC and N status), improved soil aggregation (leading to increased water use efficiency of rain and irrigation from increased water entry, storage and release to plants) and increased soil micro- and macro- biology (in particular earthworms) with improved soil porosity and mixing of SOC to deeper soil layers. Fertiliser (mineral) inputs are also reduced with direct impacts on GHG emissions both from field applications and N₂O release, as well as GHGs in production of the fertilisers. Input costs, particularly with spiralling oil and fertiliser costs are reduced. Sequencing low residue crops like peas, lentils, mustard, and canola with greater residue cereals to reduce the trash loading is attractive in wetter climates. Including a deep-rooted legume like alfalfa or lucerne can help increase the rate of nitrogen cycling and help break through plough layer compaction. Possible also to grow allelopathic crops that cause adjoining plants to die or grow more slowly, that with careful selection can greatly assist weed control, hence reduce the need for (oil based) weedicides and the fuel required to apply them to the field. Smother crops, too, can be grown to achieve similar weed-kill or reduction, with the added bonus that these crops reduce erosion, enhance soil fertility and SOC when they naturally break down, and again help feed the soil biota.

6. Biofuels. Many possible scenarios remain to be investigated to ensure the correct balance of biofuel and food production, and the sustainable use of current arable land and (even more importantly) of land currently classed as “marginal”. If conducted correctly (that is firmly based on the CA principles of no-till, in conjunction with cover and rotation crops, with under and alley cropping and balanced fertiliser usage) the use of low fertility land to produce biofuels is a possible example of “win win win” technology. Currently underutilised or degraded land, that is commonly steep and erodible, can be used for fossil fuel replacement materials, with subsequent increase in local area employment and salary earning, as well as increasing the land quality and long term sustainability by organic matter and leguminous cover/row crops.

Conclusions

Most of the strategies whereby Agriculture can contribute to climate change mitigation and the adaptation of the agriculture sector to the, apparently, inevitable changes are already known. Fortunately, these same initiatives cross over with recognised practices to ensure long term sustainability of land, the agriculture sector and those dependent on its outputs. Stabilising food security in the light of increasing population, dietary changes, spiralling oil, commodity and fertiliser prices only strengthen the need for dramatic reductions in input:output ratios across all components of the Agricultural sector.

The challenge remains, however, of achieving the far wider implementation and “upscaling” of these strategies to ensure both a global impact on CC mitigation, as well as more assured food, water and livelihood security for the

world's population through local adaptations to CC. Rapid and more impacting effects will be gained with concurrent application of several of the strategies, rather than in isolation of each other. Countries should strive to work together on these approaches, most likely in comparable ecological/climatic zones, and build regional networks, to aim for commonalities in approach and cross-sharing of technologies, successes, training and capacity building to achieve regional homogeneity of practices, and provide a framework (modality) to carry these over to other regions for more assured global impacts. Immediate emphasis should focus on “what can be initiated now” with understood, in-place technology that has shown success elsewhere and which has been taken up by farming communities as their new “best practice and practice of choice”. One aim is to ensure widespread uptake within minimum or no risk scenarios. Benchmarking (pre-change), monitoring and evaluation of the impacts of the altered practices will be required, to demonstrate positives (and negatives) and provide the means to convince others of the need and the positive impacts of change. Economic, environment and social indices all need to be collected, to show the cross cutting nature of the altered practices.

References

- Bai ZG, Dent DL, Olsson L and Schaepman ME 2008. Global assessment of land degradation and improvement 1: identification by remote sensing. Report 2008/01, FAO/ISRIC – Rome/Wageningen. pp 59.
- Cribb, J. (2008). Tackling the world food challenge. Australian Academy of Technological Sciences and Engineering. Volume 151. August 2008. Available at: <http://www.atse.org.au/index.php?sectionid=1207>
- Delgado, C.L (2003). Rising Consumption of Meat and Milk in Developing Countries Has Created a New Food Revolution: *Journal of Nutrition*, 133, November 2003.
- DuByne, D. (2008). The Biogas Revolution. BBI Bioenergy Australasia. October 2008. p. 26-29.
- FAO (2008a). Current world fertilizer trends and outlook to 2011/12, Food and Agriculture Organization of the United Nations, Rome 2008
- FAO (2008b). Investing in Sustainable Agricultural Intensification the Role of Conservation Agriculture - *A Framework for Action*. Proceeding of a Technical Workshop, FAO (Rome). July 2008. Downloadable from: www.fao.org/ag/ca/
- IPCC, 2007: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Lal, R. 2007, 'Carbon management in agricultural soils', *Mitigation and Adaptation Strategies for Global Change* 12: 303–22.
- Matthew, B. (2008). Planning for Change - Guidelines for national programmes on sustainable consumption and production. United Nations [UN] Environment Program. Waterside Press. pp 106.
- Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko (2007) Chapter 8: Agriculture. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Unger, P.W. (2006) *Soil and Water Conservation Handbook – policies, practices, conditions and terms*. Haworth Food and Agricultural Products Press. London. p 248.

Greenhouse Gas Mitigation in Rice-Wheat System with Resource Conserving Technologies

H. Pathak

*Division of Environmental Sciences, Indian Agricultural Research Institute, Pusa, New Delhi, 110 012, India
(Email: hpathak.iari@gmail.com)*

The intensified rice-wheat system, evolved rapidly since the 1960s after the introduction of modern high yielding varieties, access to irrigation, fertilizer, and pesticides, provides staple grain for more than 400 million people in Asia (Ladha et al., 2003). During the last 4 decades the system has contributed tremendously towards the food security of South Asia. However, of late there has been a significant slow down of the growth rate in production and the sustainability of this system is at stake. Decline in soil productivity particularly organic C and N, deterioration in soil physical characteristics, delay in sowing of wheat, decreasing water availability and depletion of groundwater, increased soil salinity and water logging and increased pest incidence and evolution of new more virulent pests are often suggested as the causes of such slow down in productivity (Ladha et al., 2003). Climate change, which is widely agreed to be a reality (IPCC, 2007), will have its adverse impacts on productivity of this important cropping system posing a real threat to food security in Asia (Aggarwal and Mall, 2002; Pathak et al., 2003). The objective of this paper is to assess the potential of resource-conserving technologies (RCTs) on mitigation of GHG in rice-wheat system.

Vulnerability of Rice-Wheat System due to Climate Change

Increased temperature will be the most important driver of future yields as it plays a crucial role in determining growing season and yields of rice and wheat. The rate of many development processes is a positive linear function of temperature between a base temperature (at and below which the rate of a particular process is zero) and an optimum temperature, and a negative linear function of temperature between this optimum and a ceiling temperature. Generally, growth rate of rice increases linearly in the temperature range of 22-31°C and temperature beyond this affects growth and productivity. During flowering and grain filling, high temperature reduces yield by causing spikelet sterility and shortening the duration of grain filling phase. An increase in leaf-surface temperature would have significant effects on crop metabolism and yields, and it may make crops more sensitive to moisture stress (Wassmann et al., 2009).

Predicted effects of climate change on wheat production include reduced grain yield over most of India, with the greatest impacts in the lower potential areas such as eastern IGP. Physiological traits that are associated with wheat yield in heat-prone environments are canopy temperature depression, membrane thermo-stability, leaf chlorophyll content during grain filling, leaf conductance and photosynthesis, senescence. Grain growth is shorter with heat stress, thereby influencing grain filling and resulting in lower yield (Ortiz et al., 2008; Wassmann et al., 2009).

Yield of rice-wheat system of the IGP may decrease as per the global warming forecast. This may be aggravated by water scarcity, drought, flood and decline in soil organic C content. With increase in temperature, drought could be a major concern in the rice-wheat belt of South Asia. It is estimated that a 1°C increase in air temperature will lead to 37 mm more potential evapo-transpiration south of 40° N. Frequent droughts not only reduce supplies but also increase the amount of water needed for plant transpiration. Where they occur, drier soil condition will suppress root growth and decomposition of organic matter, and will increase vulnerability to wind erosion. On the other hand, less rainy days and increased intensity of rainfall events will reduce the amount of water available for crop growth with increased runoff and drainage.

Mitigation of Climate Change with RCTs

Resource-conserving technologies encompass practices that enhance resource- or input-use efficiency and provide immediate, identifiable and demonstrable economic benefits such as reductions in production costs, savings in water, fuel and labor requirements and timely establishment of crops resulting in improved yields. Yields of rice

and wheat in heat and water-stressed environments can be raised significantly by adopting RCTs, which minimize unfavorable environmental impacts, especially in small and medium-scale farms (Kataki, 2001; Pathak and Wassmann, 2007). Resource conserving practices like zero-tillage (ZT) can allow rice-wheat farmers to sow wheat sooner after rice harvest, so the crop heads and fills the grain before the onset of pre-monsoon hot weather. As average temperatures in the region rise, early sowing will become even more important for wheat. Field results showed that the RCTs are increasingly being adopted by farmers in the rice-wheat belt of the IGP because of several advantages of labour saving, water saving, and early planting of wheat (Gupta and Sayre, 2007). Currently, approximately 4.0 M ha was under RCTs and 0.5 million farmers are using these technologies (Erenstein et al. 2007). The RCTs in rice-wheat system also have pronounced effects on mitigation of greenhouse gas emission (Table 1). Govaerts et al. (2006) observed that under ZT combined with residue retention on soil surface, C sequestered in the uppermost layer was higher than for conventional tillage (CT). Metay et al. (2007) reported reduced emission of methane under ZT system and increased or similar emission in continuous ZT direct seeding compared to puddled transplanting rice field. Similarly the impact of ZT on N₂O emission have indicated contrasting results, with lower (Drurey et al., 2006), equal (Lemke et al., 1999) and higher (Roquette et al., 2008) depending upon the soil type (Jantalia et al., 2008). The RCTs also bring many environmental benefits. For example, using zero-tillage for wheat on 1 ha of land in the rice-wheat-cropping systems of the IGP can save 1 million L of irrigation water and 98 L of diesel as well as reducing carbon dioxide emissions by 0.25 Mg (Reeves et al., 2001).

The RCTs in rice-wheat system has pronounced effects on mitigation of GHG emission and adaptation to climate change (Table 1). It has been showed that global warming potential (GWP) varied between 2290 kg CO₂ equi. ha⁻¹ in direct drill-seeded rice and wheat on beds and 3680 kg CO₂ equi. ha⁻¹ in conventional puddled transplanted rice and tilled wheat. Compared to the conventional practice all the RCTs reduced the GWP by 13 to 38% (Fig. 1). Yields of rice and wheat in heat and water-stressed environments can also be raised significantly by adopting RCTs, which minimize unfavorable environmental impacts, especially in small and medium-scale farms. Specific impacts of various RCTs on GHG mitigation and climate change adaptation are briefly discussed below.

Table 1. Potential benefits of the key resource conserving technologies (RCTs) in terms of climate change adaptation relative to conventional practices

RCTs	Potential benefits relative to conventional practices
Zero tillage	Reduced water use, C sequestration, increases yield and income, reduced fuel consumption, reduced GHG emission, more tolerant to heat stress
Laser-aided land leveling	Reduced water use, reduced fuel consumption, reduced GHG emission, increased area for cultivation
Direct drill seeding of rice	Less requirement of water, time saving, better post-harvest condition of field, deeper root growth, more tolerance to water and heat stress, reduced methane emission
Diversification	Efficient use of water, increased income, increased nutritional security, conserve soil fertility, reduced risk
Raised bed planting	Less water use, improved drainage, better residue management, less lodging of crop, more tolerant to water stress
Leaf colour chart for N management	Reduces fertilizer N requirement, reduced N loss and environmental pollution, reduced nitrous oxide emission

Source: Wassmann et al. (2009)

Zero Tillage

Conventional land preparation practices for wheat after rice involve as many as 10-12 tractor passes. This enhances emission of carbon dioxide from soil. In zero tillage combined with residue retention on surface, C is sequestered in soil. Changing to a zero-till system on one hectare of land would save 98 L of diesel and approximately 1 million L of irrigation water; this represents about a quarter ton less emission of carbon dioxide, the principal contributor to global warming. However, impact of zero tillage on methane and N₂O emissions have showed contrasting results with lower, equal and higher compared to the conventional systems depending upon the soil type and water management. Zero-tillage allows rice-wheat farmers to sow wheat sooner after rice harvest, so the crop heads and fills the grain before the onset of pre-monsoon hot weather. As average temperatures in the region rise because of climate change, early sowing will become even more important for wheat (Aggarwal and Pathak, 2009).

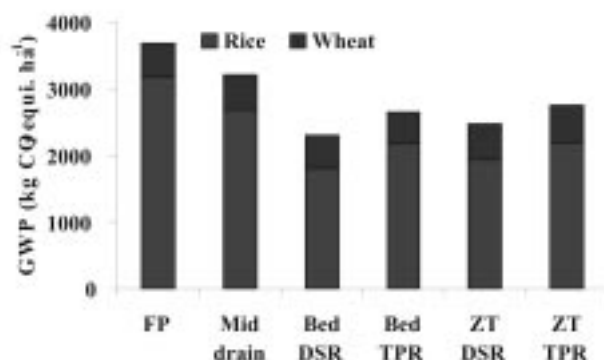


Figure 1. Global warming potential (GWP) of rice-wheat system under different resource conserving technologies. (FP, farmers' practice; mid-drain, midseason drainage; DSR, direct-seeded rice; TPR, puddled transplanted rice; ZT, zero tillage. (Source: Pathak et al. unpublished)

Laser-aided Land Leveling

Laser leveling of uneven field reduces water use allowing crop to grow in water-limited condition. It also reduces fuel consumption because of efficient use of tractor and reduces GHG emission, particularly carbon dioxide. Besides, several other benefits such as operational efficiency, weed control efficiency, water use efficiency, nutrient use efficiency, crop productivity and economic returns and environmental benefits are also has been reported due to laser-aided land leveling compared to conventional practice of land leveling.

Direct Drill Seeding of Rice

Direct drill seeding of rice (DSR) could be a potential option for reducing methane emission. Methane is emitted from soil when it is continuously submerged such as in case of conventional puddled transplanted rice. However, DSR crop does not require continuous soil submergence, thereby either reducing or totally eliminating methane emission when it is grown as an aerobic crop. Moreover, deeper root growth of DSR crop provides better tolerance to water and heat stress. Besides, the unpuddled soil in DSR does not crack with moisture stress whereas the puddled soil develops cracks, which reduces yield significantly even after providing irrigation (Aggarwal and Pathak, 2009).

Crop Diversification

Diversification i.e., growing a range of crops suited to different sowing and harvesting times, assists in achieving sustainable productivity by allowing farmers to employ biological cycles to minimize inputs, maximize yields, conserve the resource base, reduce risk due to both environmental and economic factors. The RCTs such as bed planting and zero tillage expand the windows of crop diversification. The farmers of the rice-wheat belt have taken the initiative to diversify their agriculture by including short duration crops such as potato, soybean, urd, mungbean, cowpea, pea, mustard, and maize into different combinations. Such diversification would not only improve income, employment and soil health but also reduce water use and GHG emission and more adaptability to heat and water stress.

Raised Bed Planting

In raised bed planting a part of soil surface always remains unsubmerged and aerobic. Thus it not only reduces water use and improves drainage but also reduces methane emission. Crops on beds with residue retained on surface is less prone to lodging and more tolerant to water stress, thereby making it more adaptable to unfavourable climate.

Leaf Colour Chart and Nitrification Inhibitors

The most efficient management practice to maximize plant N uptake and minimize N losses is to synchronize supply with plant demand. Implicit in this general concept of synchrony between supply and demand is the need to

maintain low levels of mineral N in soil when there is little or no plant growth and to provide sufficient N to meet plant requirements during periods of rapid development. The strategy to achieve this objective is site-specific nutrient management that includes site-specific quantitative knowledge of crop nutrient requirements, indigenous nutrient supply, and recovery efficiency of applied fertilizer N. A practical way of site-specific N management is leaf colour chart (LCC)-based N application. It provides a simple, quick and nondestructive method of N fertilizer application. With this N use efficiency is increased and less N fertilizer is required. As a consequence less accumulation of mineral forms of N (NH_4^+ and NO_3^-) within the crop root zone and hence less losses of N and nitrous oxide emission.

Use of urease inhibitors or nitrification inhibitors along with LCC would further reduce nitrous oxide emission. It was found that in the presence of nitrapyrin, AM, and DCD emission of nitrous oxide was reduced by 12, 24 and 63%, respectively, where as sodium thiosulphate, sulphur, thiourea and acetylene had no effect on emission of nitrous oxide (Pathak and Nedwell, 2001).

Conclusions

Climate change poses serious threats to productivity and sustainability of the rice-wheat cropping system, the backbone of food security of south Asia. Conservation agriculture involving continuous minimum mechanical soil disturbance, permanent organic soil cover and diversified crop rotations provides opportunities for mitigating greenhouse gas emission and climate change adaptation. Recent research efforts have attempted to develop RCTs, which are more resource efficient, use less inputs, improve production and income, and reduce greenhouse gas emission compared to the conventional practices. Some of these technologies are being adopted by the farmers of the Indo-Gangetic Plains (IGP) on large scale, which would help farmers in combating climate change to a considerable extent. However, there are uncertainties in assessing the impacts of RCTs on GHG mitigation and climate change adaptation under different agro-climatic and management conditions. These uncertainties need to be reduced by developing mechanistic simulation models using exhaustive data on soil, climate and crop management.

References

- Aggarwal PK, Pathak H 2009. Can conservation cultivation combat climate change? *Indian Farming* (in Press).
- Aggarwal PK, Mall RK 2002. Climate change and rice yields in diverse agro-environments in India II. Effect of uncertainties in scenarios and crop models on impact assessment. *Climatic Change* 52, 331-343.
- Drury CF, Reynolds WD, Tan CS, Welacky TW, Calder W, McLaughlin NB 2006. Emissions of nitrous oxide and carbon dioxide: Influence of tillage type and nitrogen placement depth. *Soil Sci Soc Am J* 70, 570-581.
- Erenstein O, Farooq U, Malik RK, Sharif M 2007. Adoption and Impacts of Zero Tillage as a Resource Conserving Technology in the Irrigated Plains of South Asia. *Comprehensive Assessment of Water Management in Agriculture - Research Report 19*. IWMI, Colombo, Sri Lanka.
- Govaerts B, Sayre KD, Deckers J 2006. Towards minimum data sets for soil quality assessment. The case of zero-tillage wheat/maize rotations in the highlands of Mexico. *Soil Tillage Res* 87, 163-174.
- Gupta R, Sayre K 2007. Conservation agriculture in South Asia. *J Agril Sci*, 145, 207-214.
- IPCC (Intergovernmental Panel on Climate Change) 2007. Fourth Assessment Report of the Intergovernmental Panel on Climate Change: The Impacts, adaptation and vulnerability (Working Group III). Cambridge University Press, United Kingdom and New York, NY, USA
- Jantalia CP, dos Santos HP, Urguiaga S, Boddey RM, Alves BJR 2008. Fluxes of nitrous oxide from soil under different crop rotations and tillage systems in the south of Brazil. *Nutr Cyl Agroecosyst* 82, 161-173.
- Kataki PK, Hobbs P, Adhikary B 2001. The rice-wheat cropping system of south Asia: Trends, constraints and productivity—A Prologue. *J Crop Prod* 3, 1-26.
- Ladha, JK, Hill JE, Duxbury JD, Gupta RK, Buresh RJ (Eds) 2003. Improving the productivity and sustainability of Rice-Wheat systems: issues and impact. *American Society of Agronomy Spec. Publ. 65*. ASA, CSSA, SSSA, Madison, WI. USA. 211 p.
- Lemke RL, Izaurralde RC, Nyborg M, Solberg ED 1999. Tillage and N source influence soil-emitted nitrous oxide in the Alberta Parkland region. *Can J Soil Sci* 79, 15-24.
- Metay A, Oliver R, Scopel E, Douzet JM, Moreira JAA, Maraux F, Fiegl BJ, Feller C 2007. N_2O and CH_4 emissions from soils under conventional and no-till management practices in Goiania (Cerrados, Brazil). *Geoderma* 141, 78-88.

- Ortiz R, Sayre KD, Govaerts B, Gupta RK, Subbarao GV, Ban T, Hodson D, Dixon JM, Ortiz-Monasterio JI, Reynolds M 2008. Climate change: Can wheat beat the heat? *Agric Ecosyst Environ* 126, 46-58.
- Pathak H, Ladha JK, Aggarwal PK, Peng S, Das S, Yadvinder Singh Bijay-Singh, Kamra SK, Mishra B, Sastri ASRAS, Aggarwal HP, Das DK, Gupta RK 2003. Climatic potential and on-farm yield trends of rice and wheat in the Indo- Gangetic plains. *Field Crops Res* 80(3), 223-234.
- Pathak H, Nedwell DB 2001. Strategies to reduce nitrous oxide emission from soil with fertiliser selection and nitrification inhibitor. *Water Air Soil Pollution* 129(1/4), 217-228.
- Pathak H, Wassmann R 2007. Introducing greenhouse gas mitigation as a development objective in rice-based agriculture: I. Generation of Technical Coefficients. *Agril Systems* 94, 807-825.
- Reeves T, Pingali PL, Rajaram S, Cassaday K 2001. Crop and natural resources management strategies to foster sustainable wheat production in developing countries. In: Bedo, Z., Lang, L. (Eds.), *Proceedings of the 6th International Wheat Conference, 5–9 June 2000, Budapest, Hungary*. Kluwer Academic Press, Dordrecht, pp. 22–36.
- Rochette P, Angers DA, Chantigny MH, Bertrand N 2008. Nitrous oxide emissions respond differently to no-till in a loam and a heavy clay soil. *Soil Sci Soc Am J* 72, 1363-1369.
- Wassmann R, Jagadish SVK, Sumfleth K, Pathak H, Howell G, Ismail A, Serraj R, Redona E, Singh RK, Heuer S (2009) Regional vulnerability of climate change impacts on Asian rice production and scope for adaptation. *Adv Agron* 101: (in press)

Session 3.2: Biodiversity

Diversifying Crop Rotations with N₂-fixing Legumes

Bruno J.R. Alves*, **Claudia P. Jantalia**, **Luis Henrique De B. Soares**, **Segundo Urquiaga**
and **Robert M. Boddey**

Embrapa-Agrobiologia, Km 7, BR 465, Caixa Postal 75.505, Seropédica, Rio de Janeiro, 23890-000, Brazil
(*Email: bruno@cnuno@embrapa.br)

In southern Brazil it is estimated that over 80 % of mechanised crop production is managed under the principles of Conservation Agriculture (CA). The crop rotations have been diversified as experience has been gained with CA, but few farmers include N₂-fixing legumes. However, there are many reports from studies in this region showing that legumes used as winter cover crops, or summer leys or intercrops, can make significant contributions of N to subsequent cereals, with greater efficiency than if the residues are incorporated into the soil under conventional tillage. We report recent results that show that if more N is fixed by the legume than is exported from the system as agricultural product, then a proportion of the remaining N can be immobilised in the soil as organic matter, sequestering carbon in the process. Legume N appears to be much more effective at soil C accumulation than N from industrial fertilizer. We also discuss briefly the difficulties in the adoption of CA by resource-poor farmers. One of the major constraints is that often all crop residues are utilised for animal feed (despite their often poor value as forage) leaving no mulch for CA. We suggest that such farmers should form "micro-treelots" of fast-growing legume trees on the most degraded areas of their land, and use the foliage as forage. These trees can grow vigorously on completely degraded areas (even sub-soils) if pre-inoculated with selected rhizobia and arbuscular mycorrhizal fungi, and provide not only forage but also firewood and fencing posts, and recuperate the degraded soils

Key words: Biological nitrogen fixation, Carbon sequestration, Crop rotations, Fast-growing legume trees, Legumes, N fertilizer substitution, Resource poor farmers.

According to the UN Food and Agriculture Organization (FAO, 2008), the three basic principles of conservation agriculture (CA) are:

- 1 continuous minimal mechanical soil disturbance,
- 2 permanent organic soil cover,
- 3 diversified crop rotations of annual crops and plant associations of perennial crops.

Experience in Brazil, the country which has the largest area of crops under CA, all of which is in tropical and subtropical regions, has shown that all three principles have great importance to conserve soil integrity, fertility and organic matter content. The direct planting into the undisturbed soil without tillage maintains soil aggregate integrity and leads to the conservation of soil organic matter and physical structure. While year-round (permanent) soil cover is not always possible, especially in dryer areas, the protection that it affords the soil surface from water loss and excessive temperatures as well as from rainfall impact means that serious efforts should be made to approach this ideal. The idea of encouraging crop diversity may seem to some as a luxury for resource-poor farmers, but well-planned diverse rotations can play an important role in reducing carry-over of crop pests and diseases from one year to the next, and also different growth patterns and rooting habits can be important in optimizing nutrient use efficiency and nutrient conservation.

The principles of conservation agriculture are equally appropriate to medium to large-scale mechanised farming or for resource-poor farmers of the Third World. In these times of global warming much attention has been focussed on the potential of CA to mitigate greenhouse gas emissions via the "sequestration" of atmospheric CO₂ and its transformation into soil organic matter. This may seem a goal of little relevance to the resource-poor smallholder struggling to produce sufficient food for his/her family; or a small surplus for health care or schooling for their children, but the build up of SOM that CA can promote in favourable conditions, is of great interest to such farmers. Increased SOM content, especially with year-round soil cover, can protect the soil from erosion, decrease water loss, increase water holding capacity while permitting infiltration of excess water, and also increase nutrient stocks and buffering capacity (e.g. cation exchange capacity). Not all, or even most, of these benefits automatically accrue just by ceasing tillage and maintaining soil cover, but a discussion of all of the factors which influence SOM build up and the accompanying benefits to soil fertility and integrity are beyond the scope of this review. Here we discuss the influence of the introduction of legumes, especially as green manures or cover crops, in rotations managed under the principles of CA.

Most species of legumes, especially herbaceous and grain legumes, can form a root-nodule symbiosis with species of the rhizobium group of bacteria that are able to obtain agronomically-significant inputs of nitrogen from biological nitrogen fixation (BNF). In the paper we discuss the role of legumes in providing sustainable inputs of N to crop rotations and particular advantageous features of their presence in conservation agriculture not only as a supply of N, but also in stimulation soil organic matter (SOM) accumulation.

Substituting N Fertilizer with BNF

Nitrogen (N_2) as a gaseous component of the atmosphere is effectively an unlimited resource, but it is frequently the nutrient that most limits crop productivity. Today the largest single input of N for crop nutrition is synthetic fertilizer, mainly manufactured using the Haber Bosch process from natural gas. Smil (2001) showed that N fertilizer production has greatly improved in energetic efficiency over the past 50 years from $>80 \text{ GJ Mg}^{-1} \text{ NH}_3$ before 1955 to $27 \text{ GJ Mg}^{-1} \text{ NH}_3$ in the most efficient plants operating in the late 1990s. The mean value given by Laegreid et al. (1999, p. 204) is 54 MJ kg N^{-1} for urea production in plants operating in 1999 and is probably close to the actual value today (West and Marland, 2002). This has been translated into greenhouse gas (GG) emissions by several authors and estimates are generally close to 4.4 kg CO_2 per kg urea N manufactured when processing, transport and application are included (Kongshaug, 1998; Schlesinger, 2000, West and Marland, 2002).

Obviously if a large proportion of our N fertilizer could be substituted by biological N_2 fixation considerable mitigation of global CO_2 emissions could be realized. The main practical handicap would appear to be that there is not usually time in the agricultural season to plant a N_2 -fixing legume before the cereal crop that requires the nitrogen. In temperate climates the growing season is often limited by low temperatures and in the arid and semi-arid regions of the tropics and sub-tropics by the prolonged dry season.

In temperate regions this time limitation may not be so serious as generally believed. At the Rodale Institute in Pennsylvania (latitude approximately 40°N), Drinkwater et al. (2000) reported that hairy vetch (*Vicia villosa*) planted in late August after winter wheat (*Triticum aestivum*) was able to accumulate between 140 and 220 kg N ha^{-1} in the period until early May the next year when maize (*Zea mays*) was planted. Christopher and Lal (2007) have given many examples from the United States in States such as Kentucky, Alabama, Georgia, North Carolina, of very considerable N inputs from species of vetch, clover (*Trifolium* spp.), pea (*Pisum* spp.) and white lupin (*Lupinus albus*) ranging from 36 to 266 kg N ha^{-1} . However, it was not clear how many of these cover crops were planted through the winter season. These authors also gave many examples of the effectiveness of the utilisation of such legumes in terms of fertilizer equivalents for maize sorghum and other crops, and these ranged from 15 to 200 kg N ha^{-1} . These data show that in the more southerly regions of the United States the replacement of considerable quantities of fertilizer N by legume N is feasible.

In North America and Europe such practices to substitute N fertilizer are popular with organic farmers, as certified organic producers are not permitted to use industrially produced N fertilizer. However, at the same time, they are also not permitted to use herbicides, so weed control mainly depends on tillage. This quandary was well illustrated by the results of Drinkwater et al. (2000). In the organic production studied at the Rodale Institute systems weeds were controlled with tillage and where hairy vetch preceded maize, high maize yields (approximately 8 Mg ha^{-1}) were achieved, equivalent to the addition of 145 kg N ha^{-1} of fertilizer added in the plots under conventional (non-organic) management. However, the level of soil nitrate resulting from the mineralization of the vetch residues and SOM rose soon after tillage so that within 5 to 6 weeks mineral N had reached over $120 \text{ mg N kg soil}^{-1}$ to 5 cm depth and over $50 \text{ mg N kg soil}^{-1}$ in the 5-20 cm depth interval. At this time the maize plants were still too small for this mineral N (equivalent to approximately 170 kg ha^{-1}) to be utilized, which suggests that there would have been large N leaching losses detrimental to water quality of local aquifers as well as responsible for off-site N_2O emissions of unknown magnitude. Considerable loss of N as leached nitrate has also been observed by several authors when cover crops have been tilled into the soil (Sarrantonio and Scott, 1988; McCracken et al., 1994, Brandi-Dohrn et al., 1997). These data show that integrating legumes into crop rotations under conventional tillage can have negative environmental impacts.

In the no-till treatment in the Rodale Institute study (Drinkwater et al., 2000) under organic management maize yield was only 1.3 Mg ha^{-1} owing to severe weed competition ($6 \text{ Mg dry matter ha}^{-1}$) but soil mineral N levels did not exceed 40 mg N kg^{-1} in the surface 5 cm of soil, or 15 mg N kg^{-1} in the 5-20 cm depth interval at any time during the crop. These results suggest that if herbicide had been used instead of tillage the slower release of N from residues

would have avoided excessive NO_3^- leaching loss, but unfortunately the in the only no-till treatment in the experiment, no legume was planted.

While there is reluctance by most conventional farmers in the Northern Hemisphere to integrate cover crops with no direct financial return into their cropping systems, this is not the case in southern Brazil. The southern region (the States of Rio Grande do Sul, Santa Catarina and Paraná) is responsible for the production of 34 % of Brazil's soybean (*Glycine max* - 18 M tonnes), 44 % of its maize (19 M tonnes), 89 % of its wheat (2.2 M tonnes) and 70 % of its rice (*Oryza sativa* - 8 M tonnes) (IBGE, 2007). Apart from rice, which is almost all grown under wetland conditions in this region, most of the other three major crops are grown in rotations, with soybean and maize as summer crops and wheat in winter. Today more than 80 % of the soybean-based crop rotations are managed under zero tillage (ZT) (Boddey et al., 2006, FEBRAPDP, 2008). Oats (*Avena sativa* and *Avena strigosa*) and oil radish (*Raphanus sativus* var. *oleifera*) are also commonly grown as winter crops and used solely to provide residues (no harvested material removed from the field) for the following maize or soybean crops. Many research institutes recommend the use of the legumes hairy vetch or lupins as winter green manure crops although to date only a few farmers have adopted these crops.

The standard practice is to maintain year-round soil cover, and ZT in Brazil is generally referred to as 'direct drilling into the trash' ("plantio direto na palha") and the three principles of CA are followed. As soybean residues are of high N content (low C:N ratio) and decompose very quickly, desiccant herbicides such as glyphosate are almost universally used for weed control prior to the winter crop. However, in many cases maize stover or oats or oil radish can be cut down using a knife roller and the residues maintain complete soil cover until planting of the next crop and this dispenses the need for herbicides (Derpsch, 2002).

As soybean in Brazil can fix all of the N it needs for maximum yield (Alves et al., 2003, Hungria et al., 2006), the use of a winter legume to precede this crop is unnecessary or even undesirable. However, several studies in southern Brazil have shown that the integration of winter leguminous green-manures into the zero till rotations as the crop prior to maize can substitute considerable quantities of N fertilizer. In a study at Eldorado do Sul, near Porto Alegre (RS), Giacomini et al. (2004) found that under ZT management maize preceded by vetch (*Vicia sativa*) yielded over three consecutive seasons (years) a mean of 6.0 Mg grain ha^{-1} , compared to 4.3 Mg ha^{-1} when preceded by oats or 3.7 Mg ha^{-1} when preceded by a natural fallow (spontaneous vegetation). The yield increase was equivalent to 70 % of that experienced with the application of 180 kg N ha^{-1} as urea. Another study performed under ZT management in the same state at Santa Maria, showed that when N was applied to maize on an oat/maize sequence at an average rate of 139 kg ha^{-1} , biomass production increased by 92% over the treatment without N (Lovato et al., 2004). However, in a vetch/maize system biomass production increased only 38% with the same level of N fertilization, clearly indicating that the legume winter cover crop may supply most of the N required by the maize.

No studies seem to have been published in Brazil which show the pattern of release of N from green manures is matched to the N requirement of the following crop. However, there is considerable indirect evidence that under ZT most residue N is immobilized in the soil (along with organic C) and thus leaching losses are considerably lower than under conventional tillage. This aspect is discussed in the following section on carbon sequestration.

While substitution of N fertilizer by N_2 fixation will reduce the greenhouse gas emissions derived from the manufacture of the fertilizer, N_2O emissions may not be lower. The International Panel on Climate Change standard practice for calculating N_2O emissions is considered as 1 % of either effectively applied N fertilizer (N fertilizer minus NH_3 volatilization losses), or of the N contained in the residues (or manures) returned to the soil, or any other N source (IPCC, 2006). This other N source may be the N mineralized from "native" SOM when the soil is tilled. It may be that less N fertilizer is required than is present in legume residues to produce the same crop yield, so it is possible that N_2O emissions could be higher when using BNF than N fertilizer. As yet few studies have been made on N_2O emission from crop rotations managed under ZT or CT in Brazil, even though this country has the largest area in the world of cropping under CA systems (~24 M ha, FEBRAPDP, 2008). Preliminary results suggest that while N_2O emissions from rotations managed under ZT are somewhat (~50 %) higher than the same crops managed under CT, emissions in the free-draining Oxisols which cover most of the cropping area of southern and central Brazil, are considerably lower than those calculated using IPCC guidelines (Jantalia et al., 2006; 2008). The calculation of the total greenhouse emission or mitigation must take this into account as well as any changes in soil C stocks incurred by the inclusion of the legume in the rotation.

Soil Carbon Sequestration

Mechanized Agriculture

In recent years a consensus, held especially in the United States, has evolved that a change from conventional tillage (CT) to reduced or zero tillage will lead to the accumulation of soil carbon. In a review of 143 comparisons at 45 different US sites of reduced, or zero, tillage with CT, West and Post (2002) found that on average stocks of carbon (C) in the soil were increased by $57 \text{ g m}^{-2} \text{ yr}^{-1}$ (570 kg C ha^{-1}) under reduced tillage/ZT compared to CT. However, recently this consensus has been challenged by Baker et al. (2007) who pointed out that in none of the trials were the soils sampled to a depth greater than 30 cm and in 68 % of the comparisons, to 20 cm or less. These authors presented evidence that in studies, particularly in Canada (VandenBygaart et al., 2003), where soils had been sampled to greater depths, more C was found at depth under CT suggesting that the apparent soil C accumulation under ZT was an artifact of the sampling depth. Two studies performed in the Cerrado (central savanna) region of Brazil where soils were sampled to 80 to 100cm depth, also registered the same phenomenon (Centurion et al., 1985; Corazza et al., 1999).

Most of the earlier studies performed in southern Brazil also sampled the soil to less than 30 cm depth and in many cases soil C concentration or stocks were considerably higher under ZT than under CT after 5 to 9 years of the different crops rotations (Sidiras and Pavan, 1985; Bayer and Mielniczuk, 1997; Bayer and Bertol, 1999; Bayer et al., 2000; Amado et al., 2001). In all of these studies, a winter green-manure legume, or a summer forage legume was included in the rotations. However, studies on long-term experiments by Machado and Silva (2001), Freixo et al. (2002) and Sisti et al. (2004) working at sites at the soybean centre of Embrapa in Londrina (PR) and the Embrapa wheat centre in Passo Fundo (RS), showed that even after 13 years of continuous wheat-soybean, there were no significant differences in stocks of soil organic carbon (SOC) to depth of 40 or 100 cm between ZT and CT management.

The study of Sisti et al. (2004), however, appears to provide an explanation of this disparity between the results of the different studies. In this study and those of Machado and Silva (2001) and Freixo et al. (2002), no legume was included in the rotation, or the only legume was soybean. Results obtained using the ^{15}N natural abundance (Shearer and Kohl, 1986; Boddey et al., 2000) and the ureide abundance technique (Herridge, 1982) have shown that while soybean is able to obtain 70 – 80 % of its N requirement from biological N_2 fixation (BNF), the proportion of N exported from the field as grain is usually equal to, or slightly greater than this, such that soybean makes no overall contribution to the soil N reserves (Alves et al., 2003, 2006). SOM generally has a C:N ratio of between 11 and 13, so that to “sequester” 1 Mg of C (3.67 Mg of CO_2) it is necessary to have an input of approximately 80 kg N. In the studies where green manure legumes were incorporated into the rotation, the crop and its residues were not removed from the field so that there was a considerable overall N gain from BNF. Sisti et al. (2004) compared three crop rotations managed under either ZT or CT, and found that there was no significant difference between SOC stocks under the different tillage systems in a continuous sequence of wheat/soybean (R1), but in the other two rotations (R2 and R3) where vetch as a winter crop was included before maize, either one year in two or one year in three, SOC stocks were approximately 17 Mg ha^{-1} higher to a depth of 100 cm after 13 years of cropping under ZT than under CT (Table 1).

The results of the study by Diekow et al. (2005) led to similar conclusions. They showed that after 14 years of CT from 1969 to 1983 the soil C stocks (0-17.5 cm) originally under a native pasture declined from 39.0 to $30.4 \text{ Mg C ha}^{-1}$. Subsequently, when the soil was left fallow without vegetation (weeds controlled with herbicide) for a further 17 years (1983 to 2000) SOC stocks further decreased to $24.9 \text{ Mg C ha}^{-1}$. The effects of three different crop sequences managed under ZT on the recovery of SOC stocks were examined: a continuous oats-maize sequence, an inter-crop of lablab (*Lablab purpureum*) with maize or an inter-crop of pigeon pea (*Cajanus cajan*) with maize. All were managed under ZT with or without N fertilizer – 120 kg N ha^{-1} from 1983 until 1994 and 180 kg N ha^{-1} thereafter. The continuous oats-maize under ZT even with N fertilizer increased SOC stocks to only $29.2 \text{ Mg C ha}^{-1}$, which indicated no recovery of SOC stocks since the previous 14 years of CT (Fig. 1). However, where the legumes were present in the inter-crops, even without N fertilizer SOC stocks to 17.5 cm depth reached 38.3 to $38.8 \text{ Mg C ha}^{-1}$ almost equal (difference not significant at $P < 0.05$) to those under the native grassland 31 years earlier (39 Mg C ha^{-1}).

Both of these studies of Diekow et al. (2005) and Sisti et al. (2004) demonstrate the very significant impact of N_2 -fixing legumes on the accumulation of SOC under ZT, and the data of Sisti et al. (2004) showed that this did not occur under CT, nor when soybean was the only legume present. This was presumably owing to the zero or

Table 1. C and N stocks in different depth intervals beneath three crop rotations managed under Zero Tillage (ZT) or Conventional Tillage (CT). Values of individual treatments (rotation x tillage) are means of three replicates

Rotation	Soil C stock (Mg.ha ⁻¹)			Soil N stock (Mg.ha ⁻¹)		
	Tillage treatment			Tillage treatment		
	ZT	CT	Mean	ZT	CT	Mean
Depth Interval 0-30 cm						
R1	60.9a ¹	62.2a	61.6A ²	5.0a	4.8a	4.9C
R2	64.7a	59.3b	62.0A	5.3a	4.9a	5.1B
R3	69.6a	60.5b	65.0A	6.2a	4.8b	5.5A
Mean	65.0a	60.7b		5.5a	4.9b	
Coef.variation (%)	4.3	2.4				
Depth Interval 0-100 cm						
R1	168.0a	167.5a	167.7A	13.8a	13.5a	13.6B
R2	178.2a	161.3b	169.7A	14.8a	13.6b	14.2A
R3	179.4a	162.7b	171.0A	15.2a	13.2b	14.2A
Mean	175.2a	163.8b		14.6a	13.4b	
Coef.variation (%)	4.1	1.1				
Depth Interval 30-70 cm						
R1	67.9a	67.8a	67.9A	5.5a	5.4a	5.4B
R2	71.9a	64.7b	68.3A	5.9a	5.4b	5.7A
R3	70.0a	64.8b	67.4A	5.8a	5.2b	5.5B
Mean	69.9a	65.8b		5.7a	5.3b	
Coef.variation (%)	4.6	1.7				

¹Means in the same row followed by the same lower case letter are not significantly different at P<0.05.

²Means in the same column followed by the same upper case letter are not significantly different at P<0.05.

Reprinted with permission of the authors.

negative N balance of soybean caused by the export of very large quantities of N from the field in the grain (high N harvest index). A further most important discovery common to these two studies was that under ZT where green-manure legumes were present, the accumulation of soil C stocks under ZT were much greater than those under CT when the soil was sampled to below 30 cm depth. Diekow et al. (2005) sampled the soil to 107.5 cm and found that up to 24 % of the overall SOC losses from the fallow and oat-maize sequence and up to 63 % of gains in the maize/legume inter-crops fertilized with N, occurred at depths below 17.5 cm. Similarly, Sisti et al. (2004) found that between 46 and 68 % of the difference in SOC stocks between ZT and CT in the rotations which included vetch, occurred at 30 to 70 cm depth (Table 1).

There are two possible explanations for these results: The root biomass and turnover are greater at depth in the soil under ZT leading to more C deposition from root residues, or soil C is lost at depth under CT. As crop yields in both experiments were not significantly affected by the tillage system it would seem unlikely that root biomass or turnover would be greater at depth under ZT. However, the N (NO₃⁻) resulting from mineralization following tillage under CT treatment may be leached to below the plough layer and stimulate SOM mineralisation and hence C loss from deeper in the profile as was suggested by Khan et al. (2007).

While these results suggest that loss of SOM from depth under C is responsible for part of the difference in N and C stocks between the ZT and CT treatments, the data from the studies of Sisti et al. (2004) and Diekow et al. (2005) still demonstrate that there was an accumulation of soil C and N under ZT where a green manure legume was present. In the case of Sisti et al. (2004) this is suggested by the fact that the C and N stocks under the continuous wheat/soybean sequence (R1), were not affected differentially by tillage treatment, where presumably the lack of an overall positive N balance permitted neither C sequestration under ZT nor the stimulation of mineralization at depth under CT. The soil C and N stocks beneath R1 were higher than under R2 and R3 managed with CT, but lower than when managed with ZT. The results of Diekow et al. (2005) are even clearer as the stocks of soil C and N before the introduction of the 17-year experiment were recorded.

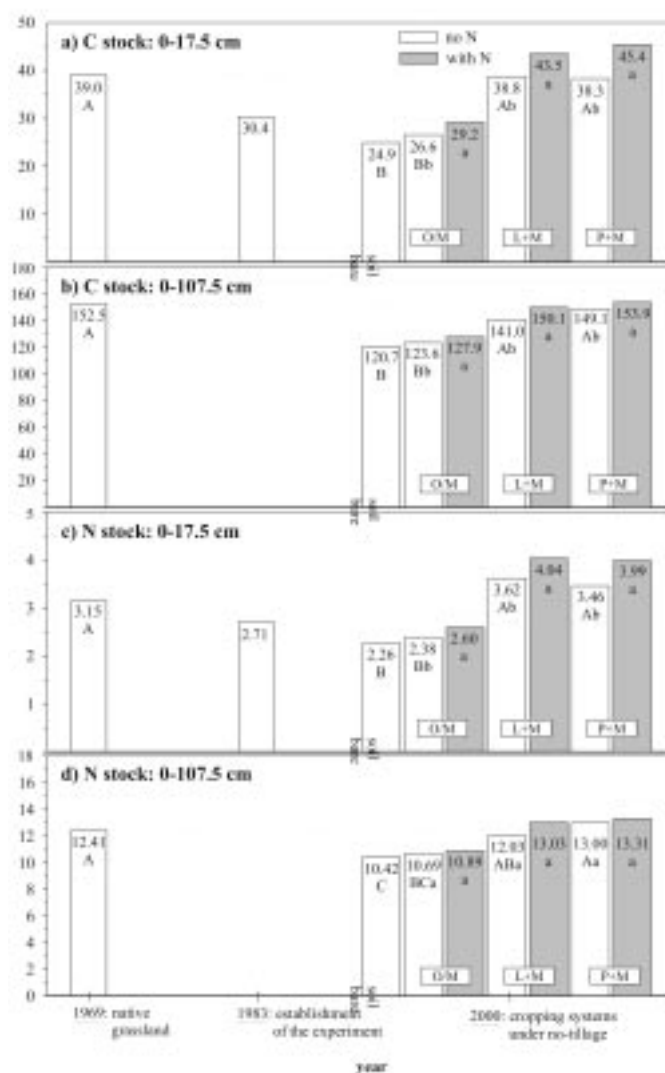


Figure 1. Stocks of soil organic C and total N in the 0-17.5 and 0-107.5 cm layers, as affected by long-term no-till cropping systems and nitrogen fertilization. O = oat, M = maize, L = lablab, P = pigeon pea. Capital letters compare the effect of cropping systems, without N fertilization, and lower case letters compare the effect of N fertilization, within each cropping system, at $P < 0.05$ of Tukey test. To compare the N fertilization effects on the soil N stock of the 0-17.5 cm and 0-107.5 cm, the significance level was $P < 0.10$. After Diekow et al. (2005). Reprinted with the permission of the authors.

In this study of Diekow et al. (2005) the effect of the addition of legume (pigeon pea and lablab) or oat residues preceding maize on soil C accumulation under ZT, the authors included for all three rotations, treatments with or without N fertilizer for the maize (120 kg ha^{-1} from 1983 to 1994, and 180 kg N ha until the end of the study in 2000). Maize following oats accumulated just 1.5 Mg C ha^{-1} of soil C to a depth of 17.5 cm (and 2.9 Mg C ha^{-1} to 107.5 cm depth) over the 17 year period (Fig. 1). The values for maize following lablab and pigeon pea were respectively 13.9 and $13.4 \text{ Mg C ha}^{-1}$ to 17.5 cm depth and 20.3 and $28.4 \text{ Mg C ha}^{-1}$ to 107.5 cm depth. When N fertilizer was applied (a total of $2400 \text{ kg N ha}^{-1}$ over 17 years) a further 2.6 , 4.7 and 7.1 Mg C ha^{-1} were accumulated to a depth of 17.5 cm, or 4.3 , 9.1 and 4.8 Mg C ha^{-1} , to a depth of 107.5 cm, respectively, for the oats, lablab and pigeon pea treatments. These increases for such large N fertilizer inputs can only be described as modest. When the soil N stocks to 107.5 cm are considered, only 200 kg more N (equivalent to 8.3% of the applied N) were recovered in the soil when maize followed oats, although this values was slightly higher in the pigeon pea treatment (13%) and considerably higher (42%) in the lablab treatment. These results indicate that the use of N fertilizer to accumulate soil C is inefficient and considering the fossil C cost involved in fertilizer manufacture, rarely is the balance positive, even

without counting the resulting N₂O emissions. This was the conclusion made by Zannata et al. (2007) on a study made on another experiment conducted at the same site, where in the absence of a legume before the maize the addition of N fertilizer gave only marginal C mitigation benefit (~100 kg C ha⁻¹ year) even under ZT, and was prejudicial to C mitigation under conventional tillage.

The same point has been made much more forcibly by Khan et al. (2007). These authors studied the changes in carbon stocks after 50 years of fertilizer N addition to maize in the Morrow plots of the University of Illinois (USA). These plots have always been managed under conventional tillage and since the start of N fertilizer addition in 1955, N was added at 164 to 224 kg N ha⁻¹ of urea for each maize crop, and since 1967 a maize/soybean rotation was established with 336 kg N ha⁻¹ of urea addition to each maize crop. To a depth of 15 cm the change in soil C stocks in the N fertilized plots ranged from +2.2 to -3.4 Mg C ha⁻¹ over the 50-year period. When sampling depth was increased to 46 cm the C stocks in all N-fertilized plots were lower after 50 years and the higher the N addition the greater the soil C loss. It is apparent that with tillage, addition of N fertilizer stimulates SOM mineralization. The authors calculated that N fertilizer addition exceeded N exported from the plots in grain by 60 to 160 %, suggesting that most of this excess N is leached out as nitrate. These authors reviewed many other studies in the literature, mainly conducted in the USA, but also some in Canada and Europe, which also showed that under conventional tillage N fertilizer promotes soil C loss not gain. C accumulation apparently did occur at some sites that were managed under reduced or zero tillage. However, Khan et al. (2007) echo the aforementioned study of Baker et al. (2007) that nearly all available studies were restricted in sampling depth to less than 30 cm, and where sampling was made to greater depth, C accumulation under reduced tillage was no longer apparent.

It is clear that recent findings in studies conducted in the southern region of Brazil contradict these conclusions. There are two main reasons for this:

1. Firstly all the Brazilian studies which show positive soil C accumulation were managed under ZT. Conservation tillage in the USA is defined as any tillage system that retains more than 30 % of crop residues on the soil surface and cannot be considered as true conservation agricultural practice. Some of these systems can still result in considerable tillage and disruption of soil macroaggregates which are thought to enhance the formation of highly stable microaggregates (within macroaggregates) in which C is stabilized and sequestered in the long term (Six et al., 1999; 2000). This model to explain the mechanism of C accumulation in undisturbed soils was first developed for the high activity clay (HAC) soils commonly found in most of the agriculturally productive area of the USA. However, recent studies in Brazil suggest that essentially the same mechanism operates in the low activity clay (LAC) soils (principally Oxisols) common to most of Brazil's cropped land both in the southern and the Cerrado (central savanna) regions (Madari et al., 2005; Zotarelli et al., 2007).
2. C accumulation under ZT appears only to occur when there is a legume in the system which fixes more N than is removed in the crop products or lost for the system. The most common rotations used by farmers in Brazil are wheat/soybean – oats or oil radish/maize. While no studies seem to have been performed with oil radish in the rotation, the evidence suggests that as soybean makes no net N contribution to the cropping system, under these rotations there will be little or no soil C sequestration. If farmers would increase their adoption of winter green manure legumes in southern Brazil all the evidence cited above suggests that considerable gains in soil C stocks could be achieved and as most of the soils are free-draining Oxisols, C stocks below 30 cm would not be prejudiced.

Resource-poor Farmers

Those resource-farmers who have little or no access to fertilizers or other agrochemicals are those who are suffering most from the loss of soil organic matter and so-called “nutrient mining” (Stoorvogel and Smaling, 1998). In the southern region of Brazil as well as neighbouring regions of Paraguay there has been considerable acceptance of CA techniques and many farmers have found that they can produce higher yields with lower labour inputs than when tillage is abandoned and CA is adopted (Bolliger et al, 2006). In this region there has been considerable development of cheap and simple manual or animal powered machinery to help with spraying and planting as well as knife rollers which reduce the dependency on herbicides (de Freitas, 2000). However, adoption of CA by poor farmers in the drier regions of north-eastern Brazil has been almost zero. In other regions of the world adoption has been sparse and even when successfully introduced with subsidised or facilitated inputs and strong extension backup (Ito et al., 2007), only some few of these projects have been found to be sustainable after external support has been withdrawn (Bolliger et al., 2008).

Several authors list many reasons why CA adoption by resource-poor farmers is difficult and often not sustained (e.g. Erenstein, 2003; Knowles and Bradshaw, 2007), but often years of tradition have led farmers to think that ploughing or hoeing is an essential part of crop husbandry. In many parts of the world especially semi-arid regions, prior to planting it is traditional to slash down weeds and burn them before tillage and planting. It is a large paradigm leap to thinking of these weed to crop residues as being valuable as a mulch, especially if the farmers are not familiar with, or have no access to herbicides.

An important point that must be made is that CA cannot be introduced to resource poor farmers without inputs of industrial fertilizers, and herbicides. Simple nutrient balances show that in most tropical and subtropical regions of subsistence farmers are removing more nutrients from the soil than they are adding (Vlek et al., 1997; Stoorvogel and Smaling, 1998). The adoption of CA will not provide extra inputs of nutrients, but can help reduce greatly their loss from the system. The successes in the adoption of CA reported by Ito et al. (2007) of the Sasakawa Africa Association in Ethiopia, Malawi, Mozambique and Mali, may as yet be limited in scale, but CA was introduced as a package which included improved seeds, fertilizers, back-pack sprayers and intensive monitoring and training of farmers.

One of the greatest constraints to the introduction of CA is that even if farmers have access to fertilizers and other agrochemicals, they usually have various uses for the crop residues and are reluctant to leave them in the field as mulch. Sometimes residues are used as fuel or bedding but the most common use is for animal fodder. Few small-holders have access to pastures for feeding animals separate from their food and fibre producing crops. It is here that carefully selected legumes can make a difference. If the farmer needs fuel or fencing, or even rough timber to build a chicken house, then he has a demand for trees. If such trees are fast-growing, able to thrive on degraded soil, and have high leaf protein, then he has access to fuel, timber and fodder.

On virtually all properties, it is usual to find at least some areas which are essentially devoid of vegetation, and they are so severely nutrient deficient (or even eroded) that they are useless for normal crop or fodder production. On these areas it is possible plant fast-growing legume trees using the technology developed over the last 20 years by researchers at Embrapa Agrobiologia (Franco and de Faria, 1997). The process of how the tree seedlings/ plantlets are prepared was recently described by Macedo et al. (2008). The trees are established from cuttings or seedlings and initially grown in shade houses in plastic growth pockets typically containing 150 cm³ of a mixture of 10% phosphate rock, 30% cow manure, 30% sand and 30% clay (1:1). The innovative and original aspect of this technology is the inoculation of all seedlings with carefully selected rhizobium strains (Franco and de Faria, 1997) and with an arbuscular mycorrhizal fungi inoculant.

The rhizobium inoculant consists of a sterilised mixture of peat, CaCO₂ and live rhizobia bacteria grown on a culture medium. The arbuscular mycorrhizal fungi inoculant is composed of a mixture of two different fungi species, *Glomus clarum* and *Gigaspora margarita*, both of which are produced by Embrapa Agrobiologia. This inoculant consists of colonised roots of *Brachiaria decumbens*, spores and soil from culture pots. Small holes (~3 mm diameter) were made in the plastic bags and portions of 1 g of each inoculant were introduced through the holes into the substrate prior to planting the seeds. The seedlings were transferred to the field after they had reached a height of approximately 30 cm and planted in holes (20 x 20 x 20 cm) at a spacing of 2 x 2 m between the plants. One litre of chicken manure was applied to each hole.

The study of Macedo et al. (2008) was to assess the impact of this technology on the recuperation of a hill-side where the top soil had been completely removed to form the foundations of shopping centre (!!). In this high rainfall area *Acacia mangium*, *A. auriculiformis*, *Enterolobium contortisiliquum*, *Gliricidia sepium*, *Leucaena leucocephala*, *Mimosa caesalpiniiifolia*, and *Paraserianthes falcataria* were used. However, the team have selected tree species appropriate for many different edaphoclimatic conditions ranging from the lowland humid tropics to arid tropical regions and for the recovery of soils which are acid or alkaline or even saline soils (de Faria and Campello, 2000). Most important of all rhizobium strains have been selected for almost all of these species.

In the tropics and sub-tropics these selected trees inoculated with both rhizobium and arbuscular mycorrhizae grown at extremely fast rates, and have been used to recuperate severely degraded soil damaged by engineering works (road cuttings etc) as well on areas damaged by mineral extraction or on mine waste tips or slag heaps.

The introduction of “micro-treelots” on small-holder properties to act as an alternative to residues for forage or even fuel, could help immensely in facilitating the preservation of mulch in CA systems, especially as most of these

legume trees have leaves of high protein content, of far higher nutritive value for livestock than residues of maize, other cereals or even legumes and other dicots.

Conclusions

Until the recent large increases in fertilizer prices the use of legumes to supply N for cereal crops in the developed countries and developed regions of Third World countries has been largely ignored and research funding has been derisory. However, with the rise of fertilizer prices and the increasing awareness of the high fossil energy cost of N fertilizer, interest is returning to this field. In this article we show that legume N has a valuable role to play in crop rotations managed under CA. Firstly, if legume residues are left on the soil surface and there is no tillage then N release is gradual and often may benefit a succeeding non-legume crop more efficiently, and with lower NO_3^- leaching losses, than if introduced into a rotation under conventional tillage. Data from Brazilian studies indicate that true carbon sequestration, as opposed to surface accumulation of soil C, can be realised if legumes are introduced into rotations under CA if the N exported in grain from the field is lower than the N derived from biological nitrogen fixation by the legume.

The adoption of CA by resource poor farmers in many regions of the world has been restricted owing to the lack of a complete package of technology including industrial fertilizer and other agrochemicals as well as improved seeds apart from improvements in infrastructure and markets. Just introducing the CA principles to a farmer with no fertilizer inputs on a soil which has already been mined for many decades, is not going to improve his yields or wellbeing. While industrial fertilizers used wisely in integrated nutrient management under conventional tillage can make considerable positive impacts in such situations, in the long-term tillage will lead to loss of SOM, erosion and decreasing soil fertility and crop productivity.

One of the great hindrances for the adoption of CA by in many regions of the Third World, is that farmers need the crop residues for animal feed or other uses. We propose that the establishment of "micro-treelots" on degraded areas of small farms, will provide animal forage, fuelwood and even fencing posts as well as eventually recuperate the degraded soil. This technology, like CA itself, comes as a package. It is essential to plant seedlings which have been pre-inoculated with both carefully-selected rhizobium strains and appropriate arbuscular mycorrhizal fungi.

The sustainable adoption of CA by resource-poor farmers is going to be extremely difficult and large investments in fertilizer, other agrochemicals and seeds will be necessary. It is not an alternative to integrated nutrient management or integrated natural resource management strategies, but a complement which will enhance their viability and increase their sustainability. Legume as cover crops, and intercrops, can play an important role in substituting industrial fertilizer and building up soil organic matter.

Acknowledgements

The authors would like express their appreciation to the International Atomic Energy Agency (IAEA/FAO process No. BRA-12978), Embrapa, FINEP, the National Research Council (CNPq) and the Rio de Janeiro State research Foundation (FAPERJ) for generous funding of their research on legume BNF and greenhouse gas emissions in recent years. RMB, BJR and SU gratefully acknowledge research fellowships from CNPq.

References

- Alves, B.J.R., Boddey, R.M. and Urquiaga, S. 2003. The success of BNF in soybean in Brazil. *Plant Soil* **252**, 1-9.
- Alves, B.J.R., Zotarelli, L., Fernandes, F.M., Heckler, J.C., de Macedo, R.A.T., Boddey, R.M., Jantalia, C.P. and Urquiaga, S. 2006. Fixação biológica de nitrogênio e fertilizantes nitrogenados no balanço de N em soja, milho e algodão. (In Portuguese, with English abstract). *Pesquisa Agropecuária Brasileira* **41**, 449-456.
- Amado, T.J.C., Bayer, C., Eltz, F.L.F. and Brum, A.C. 2001. Potencial de culturas de cobertura em acumular carbono e nitrogênio no solo no plantio direto e a melhoria da qualidade ambiental. (In Portuguese, with English abstract) *Revista Brasileira de Ciência do Solo* **25**, 189-197.
- Baker, J.M., Ochsner, T.E., Venterea, R.T. and Griffis, T.J. 2007. Tillage and carbon sequestration - What do we really know? *Agriculture, Ecosystems and Environment* **118**, 1-5.
- Bayer, C. and Bertol, I. 1999. Características químicas de um Cambissolo húmico afetadas por sistemas de preparo, com ênfase à matéria orgânica. (In Portuguese, with English abstract) *Revista Brasileira de Ciência do Solo* **23**, 687-694.
- Bayer, C. and Mielniczuk, J. 1997. Nitrogênio total de um solo submetido a diferentes métodos de preparo e sistemas de culturas. (In Portuguese, with English abstract) *Revista Brasileira de Ciência do Solo* **21**, 235-239.

- Bayer, C., Mielniczuk, J., Amado, T.J.C., Martin-Neto, L. and Fernandes, S.V. 2000. Organic matter storage in a sandy clay loam Acrisol affected by tillage and cropping systems in southern Brazil. *Soil and Tillage Research* **54**, 101-109.
- Boddey, R.M., Peoples M.B., Palmer B., and Dart, P.J. 2000. Use of the ¹⁵N natural abundance technique to quantify biological nitrogen fixation by woody perennials. *Nutrient Cycling in Agroecosystems* **57**, 235-270.
- Boddey, R.M., Jantalia, C.P., Macedo, M.O., Oliveira, O.C. de, Resende, A.S., Alves, B.J.R. and Urquiaga S. 2006. Potential of carbon sequestration in soils of the Atlantic Forest region of Brazil. In: *Carbon Sequestration in Soils of Latin America*. (R. Lal et al., Eds.), pp 305-347. Howarth Press, New York.
- Bolliger, A., Magid J., Amado, T.J.C., Skóra Neto, F., Ribeiro, M. de F. de S., Calegari, A, Ralisch, R., Neergaard, A. de (2006) Taking stock of the Brazilian "Zero-till revolution": A review of landmark research and farmers' practice. *Advances in Agronomy* **91**, 47-110.
- Bolliger, A., Magid, J. and Neergaard, A. de. 2008. Why South African smallholders are not embracing zero-till: exogenous and endogenous constraints to smallholder zero-till adoption in KwaZulu-Natal. Submitted.
- Brandi-Dohrn, F.M., Dick, R.P., Hess, M., Kauffman, S.M., Hemphill, D.D. Jr, and Selker, J.S. 1997. Nitrate leaching under a cereal rye cover crop. *Journal of Environmental Quality* **26**, 181-188.
- Centurion, J.F, Demattê, J.L.I. and Fernandes, F.M. 1985. Efeitos de sistemas de preparo nas propriedades químicas de um solo sob cerrado cultivado com soja. (In Portuguese, with English abstract) *Revista Brasileira de Ciência do Solo* **9**, 267-270.
- Christopher, S.F. and Lal, R. 2007. Nitrogen management affects carbon sequestration in North American cropland soils. *Critical Review in Plant Science* **26**, 45-64.
- Corazza, E.J., Silva, J.E. da, Resck, D.V.S., and Gomes. A.C. 1999. Comportamento de diferentes sistemas de manejo como fonte ou depósito de carbono em relação à vegetação de Cerrado. (In Portuguese, with English abstract) *Revista Brasileira de Ciência do Solo* **23**, 425-432.
- Faria, S.M. de and Campello, E.F.C. 2000. Algumas espécies de leguminosas fixadoras de nitrogênio recomendadas para revegetação de áreas degradadas. *Recomendação Técnica*, **7**. Embrapa Agrobiologia, Seropédica, RJ.
- Freitas, V. H. de. 2000. Soil management and conservation on small farms. Strategies and methods of introduction, technologies and equipment. *FAO Soils Bulletin* **77**. FAO Rome.
- Derpsch, R. 2002. Sustainable agriculture. In: *The Environment and Zero-Tillage*. (H.M. Saturnino and J.N. Landers, Eds.), pp 31-51. Associação de Plantio Direto no Cerrado (APDC), Brasília.
- Diekow, J., Mielniczuk, J., Knicker, H., Bayer, C., Dick, D.P., and Kogel-Knabner, I. 2005. Soil C and N stocks as affected by cropping systems and nitrogen fertilisation in a southern Brazil Acrisol managed under no-tillage for 17 years. *Soil Tillage Research* **81**, no. **1**, 87-95.
- Drinkwater, L.E., Janke, R.R., and Rossoni-Longnecker, L. 2000. Effects of tillage intensity on nitrogen dynamics and productivity in legume-based grain systems. *Plant Soil* **227**, 99-113.
- Erenstein, O., 2003. Smallholder conservation farming in the tropics and sub-tropics: a guide to the development and dissemination of mulching with crop residues and cover crops. *Agriculture Ecosystems and Environment* **100**, 17-37.
- FAO (2008) <ftp://ftp.fao.org/docrep/fao/010/ai552e/ai552e00.pdf>
- FEBRAPDP, 2008 Federação Brasileira de Plantio Direto na Palha. www.febbrapdp.org.br/port/index.html. (accessed 12 Nov. 2008)
- Franco, A.A. and Faria, S.M.de. 1997. The contribution of N₂-fixing tree legumes to land reclamation and sustainability in the tropics. *Soil Biology and Biochemistry* **29**, 897-903.
- Freixo, A.A., Machado, P.L.O. de A., Santos, H.P. dos, Silva, C.A., and Fadigas, F. de S. 2002. Soil organic carbon and fractions of a Rhodic Ferrasol under the influence of tillage and crop rotation systems in southern Brazil. *Soil and Tillage Research* **64**, 221-230.
- Giacomini, S.J., Aita, C., Chiapinotto, I.C., Hübner, A.P., Marques, M.G., and Cadore, F. 2004. Concorciação de plantas de cobertura antecendo o milho em plantio direto. II-Nitrogênio acumulado pelo milho e produtividade de grãos. (In Portuguese, with English abstract) *Revista Brasileira de Ciência do Solo* **28**, 751-762.
- Herridge, D.F. 1982. Use of the ureide technique to describe the nitrogen economy of field-grown soybeans. *Plant Physiology* **70**, 7-11.
- Hungria, M., Franchini, J.C., Campo, R.J., Crispino, C.C., Moraes, F.L., Sibaldelli, R.N.R., Mendes, I.C. and Arihara J. 2006. Nitrogen nutrition of soybean in Brazil: contributions of biological N₂ fixation and of N fertilizer to grain yield. *Canadian Journal of Plant Science*. **86**, 927-939.
- IBGE 2008. Instituto Brasileiro de Geografia e Estatística. Available at www.sidra.ibge.gov.br/bda/default.asp?t=5&z=t&o=1&u1=1&u2=1&u3=1&u4=1&u5=1&u6=1&u7=1&u8=1&u9=3&u10=1&u11=26674&u12=1&u13=1&u14=1. (accessed 12 Oct. 2008, verified 12 Dec. 2008)
- IPCC 2006. International Panel for Climate Change. Guidelines for National Greenhouse Gas Inventories. Available at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm>. (accessed 12 Nov. 2007, verified 12 Feb. 2008)
- Ito, M., Matsumoto, T. and Quinones, M.A. 2007. Conservation tillage practice in sub-Saharan Africa: The experience of Sasakawa Global 2000. *Crop Protection* **26**, 417-423.
- Jantalia, C.P., Zotarelli, L., Santos, H.P. dos, Torres, E., Urquiaga, S., Boddey, R.M., Alves, B.J.R. 2006. Em busca da mitigação da produção de óxido nitroso em sistemas agrícolas: Avaliação de práticas usadas na produção de grãos no sul do país. In: *Manejo de Sistemas*

- Agrícolas: Impacto no Seqüestro de C e nas Emissões de Gases de Efeito Estufa* (B.J.R Alves et al., Eds.) (In Portuguese, with English abstract), p. 81-107. Genesis, Porto Alegre, RS, Brazil.
- Jantalia, C.P., Santos, H.P. dos, Urquiaga, S., Boddey, R.M., and Alves, B.J.R. 2008. Fluxes of nitrous oxide from soil under different rotations and tillage systems in the South of Brazil. *Nutrient Cycling in Agroecosystems* **82**, 161-173.
- Khan, S.A., Mulvaney, R.L., Ellsworth, T.R., and Boast, C.W. 2007. The myth of nitrogen fertilization for soil carbon sequestration. *Journal of Environmental Quality* **36**, 1821-1832.
- Knowles, D. and Bradshaw, B. 2007. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food Policy* **32**, 25-48.
- Kongshaug, G. 1998. Energy Consumption and Greenhouse Gas Emissions in Fertilizer Production. In: *IFA Technical Conference*, Marrakech, Morocco, 28 September-1 October, 1998, 18p.
- Lægread, M., Bøckman, O.C., and Kaarstad, O. 1999. *Agriculture, Fertilizers and the Environment*. CABI, Wallingford, UK.
- Lovato, T., Mielniczuk, J., Bayer, C., and Vezzani, F. 2004. Adição de carbono e nitrogênio e sua relação com os estoques no solo e com o rendimento do milho em sistemas de manejo. (In Portuguese, with English abstract) *Revista Brasileira de Ciência do Solo* **28**, 175-187.
- Macedo, M.O., Resende, A.S., Garcia, P.C., Boddey, R.M., Jantalia, C.P., Urquiaga, S., Campello, E.F.C., Franco, A.A. (2008) Changes in soil C and N stocks and nutrient dynamics 13 years after recovery of degraded land using leguminous nitrogen-fixing trees. *Forest Ecology and Management* **255**, 1516-1524.
- Machado, P.L.O. de A. and Silva C.A. 2001. Soil management under no-tillage systems in the tropics with special reference to Brazil. *Nutrient Cycling in Agroecosystems* **61**, 119-130.
- Madari, B., Machado, P.L.O.A., Torres, E., Andrade A.G.de, and Valencia, L.I.O. 2005. No tillage and crop rotation effects on soil aggregation and organic carbon in a Rhodic Ferralsol from southern Brazil. *Soil and Tillage Research* **80**, 185-200.
- McCracken, D.V., Smith, M.S., Grove, J.H., MacKown, C.T., and Blevins, R.L. 1994. Nitrate leaching as influenced by cover cropping and nitrogen source. *Soil Science Society of America Journal* **58**, 1476-1483.
- Sarrantonio, M. and Scott, T. 1988. Tillage effects on availability of nitrogen to corn following a winter green manure crop. *Soil Science Society of America Journal* **52**, 1661-1668.
- Schlesinger, W.H. 2000. Carbon sequestration in soils: some cautions amidst optimism. *Agriculture, Ecosystem and Environment*. **82**, 121-127.
- Shearer, G.B., and Kohl, D.H. 1986. N₂-fixation in field settings: estimations based on natural ¹⁵N abundance. *Australian Journal of Plant Physiology* **13**, 699-756.
- Sidiras, N. and Pavan, M.A. 1985. Influência do sistema de manejo do solo no seu nível de fertilidade. (In Portuguese, with English abstract) *Revista Brasileira de Ciência do Solo* **9**, 249-254.
- Sisti, C P J, Santos, H P dos, Kochhann, R A, Alves, B J R, Urquiaga, S., and Boddey, R M. 2004. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. *Soil and Tillage Research* **76**, 39-58.
- Six, J., Elliott, E.T., and Paustian, K. 1999. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Science Society of America Journal* **63**, 1350-1358.
- Six, J., Elliott, E.T., and Paustian, K. 2000. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. *Soil Biology and Biochemistry* **32**, 2099-2103.
- Smil, V. 2001. *Enriching the Earth*. MIT Press, Cambridge, Massachusetts.
- Stoorvogel, J.J., Smaling, E.M.A. 1998. Research on soil fertility decline in tropical environments: integration of spatial scales. *Nutrient Cycling in Agroecosystems* **50**, 151-158.
- VandenBygaart, A.J., Gregorich, E.G., and Angers, D.A.. 2003. Influence of agricultural management on soil organic carbon: a compendium and assessment of Canadian studies. *Canadian Journal of Soil Science* **83**, 363-380.
- Vlek, P.L.G., Kuhne, R.F., and Denich, M. 1997. Nutrient resources for crop production in the tropics. *Philosophical transactions of the Royal Society of London* **352**, 975-985.
- West, T.O., and Marland, M. 2002. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. *Agriculture Ecosystems and Environments* **91**, 217-232.
- West, T.O. and Post W.M. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. *Soil Science Society of America Journal* **66**, 1930-1946.
- Zanatta, J.A., Bayer, C., Dieckow, J., Vieira, F C B, and Mielniczuk, J. 2007. Soil organic carbon accumulation and carbon costs related to tillage, cropping systems and nitrogen fertilization in a subtropical Acrisol. *Soil and Tillage Research* **94**, 510-519.
- Zotarelli, L., Alves, B J R., Urquiaga, S., Boddey, R M., and Six, J.. 2007. Impact of tillage and crop rotation on light fraction and intra-aggregate soil organic matter in two Oxisols. *Soil and Tillage Research* **95**, 196-206.

The Importance of Biodiversity in Crop Rotations under Direct Drill in Controlling Weeds, Plant Diseases and Crop Pests

Renato Serena Fontaneli*, Henrique Pereira Dos Santos, Leandro Vargas, João L. Nunes Maciel, Jose Roberto Salvadori

Wheat National Research Center – Embrapa – Caixa Postal 451, 99.001-970 - Passo Fundo, RS Brazil
(*Email: renatof@cnpt.embrapa.br)

Weeds in combination with insects and crop diseases, destroy an estimated one-third of the worldwide crop production potential. It has been estimated in North America that over 80,000 diseases affect crops caused from parasitism by approximately 8,000 fungal species, 200 bacterial species, 500 viral species, and 500 nematode species. An individual crop may have 100 or more known diseases affecting plant population; dying of plant tissue and destruction of leaf area resulting in decreased photosynthesis; reduction of absorbing water and nutrients because of root rot; destruction or plugging of the translocation system; causing lodging, wilting, and blight; production of harmful toxins to the crop plant, to people or animals, resulting lower quality crop products.

Crop production systems in Brazil are very diversified, especially in the south region (Paraná, Santa Catarina, and Rio Grande do Sul states). In general, include crops such as soybean, corn, and rice in the summer season and wheat, barley, oat, triticale, rye, canola or annual pasture (oat and or ryegrass) during the winter. Most of annual pasture are used in very small grazing pasture which can be considered as winter cover crop or green manure. Rice is cultivated in low land areas of the middle south of Rio Grande do Sul state under irrigation. In the hill areas (500 to 1.200m a.s.l.), the soil is very well drained, crops are grown under no till system using annual grass straw, mostly oat and annual ryegrass. Besides exclusively crop systems, there is variation including animal forest production that constitutes integrated livestock-crop-forest production systems.

Average monthly rainfall in south Brazil ranges from about 120 mm (march) to 210 mm (September), and the total annual rainfall ranges from about 1.200 to 2.000 mm. Average mean temperature ranges from 12°C (June-July) to 22°C (January). Passo Fundo county, in the Rio Grande do Sul state, headquarter of National Wheat Research Center of Embrapa's national research development systems and Londrina county in the Paraná state, headquarter of National Soybean Research Center both located on the south region of Brazil are leaders on no till system and pursuit new crops and arrangements to keep sustainability of brazilian agriculture.

Brazil's soy fields, totaling almost 22.0 million hectares, representing about 45% of all grain planted in the country, whose total area is estimated to reach 48 million hectares, close to 40% of this area are located in the south region. Favorable climatic conditions is contributing greatly for Brazil to consolidate its position as worldwide leader in soy exports, beef, poultry and pork meats, sugarcane, coffee, cocoa etc. This paper will cover the importance of biodiversity in crop rotations under direct drill in controlling weeds, plant diseases and crop pests centered in the south Brazil crop systems.

A. Biodiversity in Crop Rotations under Direct Drill in Controlling Weeds

Weed Selection by Repeated Glyphosate Spraying

Soybean transgenic technology allows sprays glyphosate in post-emergency without injury. It was responsible by lower weed control cost, whose in some case lowered by 70%. Weed control problems such as roundleaf spurge (*Euphorbia heterophylla*) and common beggarticks (*Bidens pilosa*) disappear. However, farms and scientists became surprised due to the short time the weeds got resistance to repeated glyphosate applications. This situation was a surprise because new technology was adopted by farms before official government authorization. There was dissociation between adoption and research studies.

In spite of that, glyphosate is considered a low risk to weed selection resistance in a global point of view, there are at the moment 12 resistant weed species, with eight species identified in the last four years. The first case was registered in Australia in 1996, ryegrass (*Lolium rigidum*), following silver crabgrass (*Eleusine indica*), amaranth

(*Amaranthus palmeri* and *Amaranthus rudis*), common ragweed (*Ambrosia artemisiifolia*), horseweed (*Conyza canadensis* and *Conyza bonariensis*), annual ryegrass (*Lolium multiflorum*), johnsongrass (*Sorghum halepense*) and buckhorn plantain (*Plantago lanceolata*). Among such species resistant to glyphosate, horseweed (*Conyza canadensis*) is very important world wide, such as in the corn belt region of USA, and in Brazil.

Glyphosate has been used by farms in Brazil in the last 30 years, especially to make mulching to no till crop systems and apple and citrus orchards. Soy technology resistant to glyphosate becomes easy weed control. Nowadays, two or three glyphosate spray by season are enough to appropriated control (the first before seeding, and after emergency one or two more). The elimination of others herbicides, increased selection of weed resistant biotypes.

Resistant plant biotypes are not new in the south Brazil agriculture history. Tolerant plants such as *Euphorbia heterophylla* was selected by metribuzin (Sencor® and Lexone ®) in the 1990's in the Rio Grande do Sul state. This weed problem was solved by a new herbicide released, imazaquin (Scepter®). Imazaquin was used massively during some years and again allows the selection of new weed biotype of *Euphorbia heterophylla* and *Bidens pilosa* resistants. In addition, allows tolerance *Cardiospermum halicacabrum*. These herbicides were not used anymore in some farms. Metribuzin and imazaquin resistance/tolerance characteristics are similar to what is happening nowadays with glyphosate, again the weed population dynamic was not considered.

Scientists know that herbicides promote change proportion of some biotype which results in dominance. Some herbicide molecule do not controls in the same way for different species, so some of them are benefited resulting in increased frequency. In some places this situation happens and there is appearance of new weed problems. Thus, it is necessary to manage different herbicides to avoid weed tolerance/resistance. The time of this incidence varies from two years with herbicides inhibitors of ALS to 20 years on glyphosate case. The number of weed plants resistant to glyphosate is increasing rapidly in soy transgenic in countries such as USA, Brazil and Argentine. In the Brazil, were identified two resistant species of horseweed (*Conyza canadensis*) and annual ryegrass (*Lolium multiflorum*), and four tolerant species of roundleaf spurge (*Euphorbia heterophylla*), vine (*Ipomoea* spp.), spreading dayflower (*Commelina benghalensis*), and Brazil pusley (*Richardia brasiliensis*). Fastness of new cases identification will be correlated with glyphosate uses on weed plant management.

Rio Grande do Sul (RS) State Case of Resistance Weeds

Transgenic soy is seeded in almost the totality area of the Rio Grande do Sul state. Glyphosate is used a unique herbicide and management method, resulting in ample selection pressure to tolerant/resistant weed species. We can note seeing evolution of some tolerant weed species such as vine (*Ipomoea* sp.), roundleaf spurge (*Euphorbia heterophylla*), Brazil pusley (*Richardia brasiliensis*), and spreading dayflower (*Commelina* sp.), and resistant weed species such as annual ryegrass (*Lolium multiflorum*) and horseweed (*Conyza canadensis*). Annual ryegrass in 2003 and horseweed in 2005 were the first two weed resistant cases reported to science. After that it was reported horseweed resistant to glyphosate in Paraná and São Paulo states of Brazil.

A multi-institutional consortium composed of wheat research center of Embrapa's research systems, Fundacep (cooperatives research system), and Universidade de Passo Fundo are monitoring new resistance and tolerance in the RS state. During the 2006/2007 season, fifteen new events of annual ryegrass and five of horseweed resistants. Fortunately it was not found a new event of roundleaf spurge (*Euphorbia heterophylla*). Soy costs will increase with weed resistant to glyphosate because will need for a different type of herbicide that is more expensive, and in addition the efficiency of control is reduced. Thus, farms must eliminate weed resistant/tolerate using other weed control management.

What should be done?

If it is not reasonable continue use glyphosate what should be done? The main motivation not to do not acquire weed resistant/tolerant is that the actual herbicide available technology are more expensive, less efficient, and more dangerous environmentally.

The decision is under the farmer's control, because assistant agronomist are not obligated to use a specific herbicide, so must be considered other weed management options. Farms should be encouraged to use prevention management to avoid resistant weeds, because the costs will, at least be higher, as the problem increases.

Some main management recommendations:

- Do not use in the same area more than two times herbicides with the same mechanisms of control. If was identified weed resistant/tolerant, must be adopted herbicide rotation with similar efficiency to stop the problem.
- Do monitoring and eliminate plant suspicious. After the herbicide application plant survive must be mechanically eliminated before seed production.
- Do crop rotation. Crop rotation plans allow more alternative management to be adopted.

B. Biodiversity in Crop Rotations under Direct Drill in Controlling Diseases

Wheat Diseases Control

Climatic conditions are suitable to plant diseases originated by fungi, bacteria, viruses and nematodes. By definition crop diseases have an impact on crop rotation. On table 1 it is summarized some important wheat diseases with typical traits used to control or to reduce its pathogenicity. These organisms are important to us and our environment in the areas, such as, biological control of pathogenic organisms; improvement to soil tilth and productivity; organic matter decomposition and nutrient recycling; symbiotic relationships improving nutrient uptake by roots and legume nitrogen fixation.

Table 1. Main control management for wheat diseases control in Brazil.

Disease	Agent	Main control methods
FOOTROOT	<i>Gaeumannomyces graminis</i> var. <i>tritici</i>	Crop rotation
FUSARIUM HEADBLIGHT	<i>Fusarium graminearum</i> <i>Bipolaris sorokiniana</i>	Crop rotation Healthful seeds Fungicide seed treatment
POWDERED MILDEW	<i>Blumeria graminis</i> f.sp. <i>tritici</i>	Seed treatment with systemic fungicide
LEAF RUST	<i>Puccinia triticina</i>	Resistant variety Spray fungicide
TAN SPOT	<i>Drechslera tritici-repentis</i>	Crop rotation Healthful seeds Fungicide seed treatment
SPOT BLOTCH	<i>Bipolaris sorokiniana</i>	Adequate plant date Crop rotation Healthful seeds Fungicide seed treatment
GLUME BLOTCH	<i>Stagonospora nodorum</i>	Adequate plant date Crop rotation Healthful seeds Fungicide seed treatment
GIBBERELLA EAR ROT/SCAB	<i>Gibberella zeae</i>	Spray fungicide Resistant variety Use of different seeding dates
WHEAT BLAST	<i>Pyricularia grisea</i>	Spray fungicide on spikes Resistant variety Adequate seeding date
LOOSE SMUT	<i>Ustilago tritici</i>	Spray fungicide on spikes Resistant variety
BACTERIOSES	<i>Xanthomonas campestris</i> pv. <i>undulosa</i>	Fungicide seed treatment Crop rotation Healthful seeds
SOIL-BORNE WHEAT MOSAIC VIRUS - SBWMV	Soil-borne wheat mosaic virus – SBWMV	Resistant variety Avoid areas with traditional problem
BARLEY YELLOW DWARF VIRUS – BYDV	Barley yellow dwarf virus – BYDV	Resistant or tolerant variety Seed treatment to pest control

The main disease control rules constitutes that the diseases integrated management (DIM), including healthy seeds, rational fertilizations, fungicide seed treatment, crop rotations, adoption of resistant varieties, and fungicide spraying.

Crop rotation is a management to disease control which prevents survival of necrotrophic organisms due to food privation and absence of host plants. Wheat has a variety of leaf diseases (spot blotch, glume blotch, and fusarium head blight), root diseases, and foot root (*Gaeumannomyces graminis* var. *tritici*) where crop rotation is the most efficient recommendation. Crop the same specie year after year (monoculture), to let reintroduction of path organisms each six months. Scientist of south Brazil state that is necessary, at least, one year without wheat to permit straw decomposition in order to kill agent microorganisms of these complex diseases. Species such as oat, brassica, turnip, lupine, annual clover, vetch, etc are indicated to crop rotation systems.

Resistant varieties are the most important experience to wheat disease control. However, adoption of this recommendation is reduced by shortage of varieties with adequate resistance level. Thus it is important to know diseases reaction of each genotype available to projecting powerful crop rotation system. Another related limitation is less resistance according to new variety areas increased. This resistance detriment is well documented related with leaf rusts which appearance of new races is common and it abbreviates variety life. Fungal races that can cause a particular disease may differ in their pathogenicity under different conditions and thus, differ in the amount of disease they cause.

Considering that fungicide spraying is the most important management strategy to control wheat leaf diseases such as powdered mildew, leaf rust, tan spot, spot blotch, glume blotch, gibberella ear rot or scab, and brusone can be considered the most important wheat diseases in Brazil. Thus it is necessary to know some specific characteristics of each disease agent to evaluate the real importance to wheat crop.

POWDERED MILDEW - appear in all plant parts, but is common in leaves. In dry years, can be a predominant disease.

LEAF RUST – practically happens every years in each area worldwide. In Brazil, *Puccinia triticina* agent survives in voluntary plants.

TAN SPOT/ SPOT BLOTCH/GLUME BLOTCH – group of diseases. In brazilian conditions at least three of them are important. Seeds and crop residues are important to the survival of microorganisms in the absence small grain crops.

GIBBERELLA EAR ROT or SCAB – it is very common in south Brazil region, especially in Rio Grande do Sul state. It is a floral fungal infection. Some crops as corn, sorghum, triticale, rye, etc are not resistant.

BRUSONE – is a disease observed in Paraná and Mato Grosso do Sul states as well as other Cerrado region states (Mato Grosso, Goiás, Federal District ,part of Minas Gerais, São Paulo, and Bahia). It has light spores with easy scattering by wind.

Soybean Diseases Threat

Asian rust is now the most serious problem for soy farms. More than forty other diseases have already been identified in Brazil. Asian rust economic implications vary year to year from 15% to 100% in losses, depending on weather conditions favoring the disease.

End-of-cycle diseases are common in all the country, especially under hot and warm conditions. This complex includes brown spot (*Septoria glycines* and *Cercospora kikuchii*), target spot (*Corynespora cassicola*), antracnosis (*Colletotrichum truncatum*), oidium (*Erysiphe diffusa*) and blight (*Rhizoctonia solani*). The fungi survive overwinter in the crop residues. Antracnosis is a main problem in the Cerrado region due to high temperatures and precipitation. Bligh is more common in Mato Grosso, Maranhão, Tocantins, and Pará states. The end-of-cycle diseases can be controlled by fungicides used in Asian rust, but preventive management practices like crop rotation, balanced fertilization, healthy and treated seeds must be adopted by the farmers.

Virus diseases such as stem necrosis and common soy mosaic only can be controlled using resistant cultivars.

C. Biodiversity in Crop Rotations under Direct Drill in Controlling Crop Pests

Crop production systems in Brazil are very diversified, especially in the south region. In general, include crops such as soy, corn or rice during the summer season and wheat, barley, oat, triticale, rye, canola or annual pasture

(oat and or ryegrass) in the winter. From each five hectares cropped in the summer, just one is cropped with small grain cereals. Most of annual pasture primarily are used as green manure. In the middle south of Rio Grande do Sul state, low land areas are cultivated rice as flood irrigation. In the upland areas (500 to 1.200 m a.s.l.) no till system is used predominantly, mostly oat and annual ryegrass straw in the winter, and soy/crop rotation in the summer season. In the Cerrado region, biggest main soy crop region of Brazil, after harvest it, pearl millet is seeded in the end of rain season, during the last rains as cover crop. Crop rotation and succession are responsible to agriculture sustainability in South-America environments.

Invertebrate herbivorous animals, such as insects, acarus, diplods, and mollusks, associated with these crop systems are diversified in species, habits, biological characteristics and damage abilities. Green or crop residue managements and soil preparation affects dynamic population, depending on biotics and abiotics factors, such as time of management actions, habitat and biological cycle duration, mobility, predators etc, in addition to soil type and climatic conditions. Replacement of native vegetation, discontinued and diversified, by homogeneous coverage in extensive areas, carry out a strong pressure in the qualitative and quantitative phytophagous fauna resulting in suppression of the natural source of food, allowing the development of few species adapted to simple environment, becoming a plague, on the aerial architecture and subterranean plant parts.

Soil management is long been recognized as the main responsible for dynamic population of organisms, especially those related with the soil. In this particular, no till system come determining intensive changes in the spectrum of organism plagues spectrum in the dominant crop production systems.

No till systems favors growth of species population with subterranean habits, residents in the area, with low mobility and long life cycle considering short life of most crops. Production and preservation of crop residues on soil surface soil, demand to success of no till systems, changes substantially the microclima, resulting also in changes of noxious and beneficial fauna. Crop residues on soil surface can affects positive or negative effects on potential plagues.

Others processes very common in no till system, with crop rotations and herbicide uses to kill green vegetation before seeding, also can affects the soil fauna. In general, second harvest in the some season tend to increase plague problems. Dry up herbicides such as glyphosate suppress suddenly and totally the food to insects and others small animals presents in the area. Depending on the host specificity degree of them, the results can be disastrous in the following crop, mainly, if the plant density is low.

Examples of some organisms effects on crop production:

- a) Soybean-tamandua, *Sternechus subsignatus* (Coleoptera: *Curculionidae*), to feed with soy and others legumes plants. It has strong soil relationship, because in south Brazil stays six months during the winter season as adult larvae. Its geographic expansion and evolution as a plague, probably follows the soybean way on no till system. In the other hand, corn rotation or another no host crop such as sorghum or sunflower, is a successful strategy to control.
- b) White Grubs Complex (Coleoptera: *Scarabaeidae*), especially the pasture grub (*Diloboderus abderus*) and the wheat grub (*Phyllophaga triticophaga*), due to one to two years biological life cycle can be related with the winter crops and the initial cycle of summer crops.

Grubs are insects that typically damage plant roots adapted to new crops and following a meadow or sod crop. In no till system has been increased grub population. However, in soybean and corn crops it can be controlled managing the seeding date, establishing a new crop when larvae stop feeding, going to the pupa metamorphosis phase.

- c) Tin-Tack (*Dichelops furcatus* e *D. melacanthus*) are insects of secondary importance as soy vegetative plague. However, live under crop residues and are found sucking corn and wheat seedlings. Elevated population of these plagues can be related with second crop during the summer and no till system. Second crop make available feed releasing insects to look for food in the native plants. Crop residues on no till system constitutes an important environmental resource to protection during winter time.
- d) Crickets (Orthoptera: *Gryllidae*) are omnivorous insects with large geographic distribution, considered insect plague in small crops, such as ornamental and horticultural plants. In corn and soybean, just recently has been

reported as an occasional soil surface plague. The most common specie is the brown-cricket (*Anurogryllus muticus*) which lives in soil galleries. It has nocturnal habit damaging seedling on soil surface, delaying plant development. Damages are increased on drought and high temperature periods during emergency on no till system. Again, probably the no till associated with herbicide sprayed pre-seeding that reduce opportunity to look for others feed source.

- e) Besides the above insects plagues others animal species have been reported as erratic plagues such as diplopods, milipods, and gastropods (snails and spiral shell). Diplopods, normally, feed of crop residues and has been found in the farms with so much straw and no till system. Snails and spiral shell are mollusks herbivorous, which live in humid environment and with intermediate temperatures, being considered important plagues in orchards, gardens and greenhouses. In large areas growing soy, corn, bean, and wheat, several species have been recently reported in no till system, with excess much crop residues, especially in areas cultivated with brassica.

Final Considerations

In recent years, there has been increasing awareness of the importance of preserving out natural resources and the environment. As a result, it has become more important to asses the environmental impacts of agricultural production. No-till systems makes numerous positive contributions, but still also some concerns about crop rotation combinations, social and economic sustainability.

Soil improvement characteristics in no-till systems have long been recognized, but often are forgotten or ignored on many farms. After land has been devoted to no-till system for several years, the trend is for subsequent crops to produce better than otherwise have been the case.

Crop rotation can interrupt weed, disease, insect, and nematode cycles, while the deep root penetration of many species into compacted soil layers can leave channels that improve water and air movement and enhance root penetration of subsequent crops, resulting in follow crops more productive and healthy.

Crop rotation is a basic, desirable agronomic practice that enhances long-term soil productivity. Because of numerous potential benefits that can be realized, many arable crops should be grown in rotation with forage grasses and grass/legume mixtures.

Agricultural production is essential, but it must also be protective of the environment. When properly planned and managed, no-till crop production systems are environmentally friendly type of agricultural production. In fact, it can be argued that agriculture and nature are rarely in better harmony than crop rotations under direct drill.

What could be more noble and satisfying than spending a lifetime living on, and caring for, the land? A good farmer is a true conservationist.

References

- BALL, D.M.; HOVELAND, C.S.; LACEFIELD, G.D. Southern forages 4th ed. Norcross, GA: International Plant Nutrition Institute (IPNI), 2007. 322p.
- GASSEN, D. N. O manejo de pragas no sistema plantio direto. In: EMBRAPA. Centro Nacional de Pesquisa de Trigo. Plantio direto no Brasil. Passo Fundo: Embrapa-CNPT / Fundacep Fecotrigo / Fundação ABC / Aldeia Norte, 1993. p. 129-139.
- MILANEZ, J. M.; CHIARADIA, L. A. Lesma: praga emergente no oeste catarinense. Agropecuária Catarinense, v. 12, n. 1, p. 15-16, mar. 1999.
- MULLEN, R.E. Crop Science: Principles and Practice. Iowa State University: Ames, 1996. 354p.
- REIS, E.M.; ABRÃO, J.J.R. Effect of tillage and wheat residue management on the vertical distribution and inoculum of *Cochliobolus sativus* in soil. Plant Disease, Saint Paul, v.67, n.10, p. 1088-1089, 1993.
- REIS, E.M.; KOHLI, M.M. Wheat diseases in South America and strategies for their control. In: REGIONAL WHEAT WORKSHOP FOR EASTERN, CENTRALAND SOUTHERNAFRICA, 8., 1993, Kampala, Uganda. Developing sustainable wheat production systems: proceeding. Addis Ababa, Ethiopia: CIMMYT, 1994. p.153-163.
- REUNIÃO DA COMISSÃO BRASILEIRA DE PESQUISA DE TRIGO E TRITICALE (1.:2007: Londrina, PR). Indicações técnicas para a safra 2008: trigo e triticale. Londrina: Embrapa Soja, 2008. 147p.

- REUNIÃO DE PESQUISA DE SOJA DA REGIÃO SUL (34: 2006: Pelotas, RS). Indicações técnicas para a cultura da soja no Rio Grande do Sul e em Santa Catarina 2006/2007. Pelotas: Embrapa Clima Temperado, 2006. 240p.
- RIGON et al. (eds.) Anuário brasileiro da soja 2007. Santa Cruz do Sul: Editora Gazeta Santa Cruz, 2007. 136p.
- SALVADORI, J. R.; PEREIRA, P. R. V. S. Manejo integrado de corós em trigo e culturas associadas. Passo Fundo: Embrapa Trigo, 2006. 9 p. html. (Embrapa Trigo. Comunicado Técnico Online, 203). Disponível em: http://www.cnpt.embrapa.br/biblio/co/p_co203.htm
- SALVADORI, J.R.; ÁVILA, C. J.; SILVA, M. T.B. da. Ed. Pragas de solo no Brasil. Passo Fundo: Embrapa Trigo; Dourados: Embrapa Agropecuária Oeste; Cruz Alta: Fundacep Fecotrigo, 2004. 544p.
- SALVADORI, J. R.; PEREIRA, P. R. V. da S.; CORRÊA-FERREIRA, B. S. Pragas ocasionais em lavouras de soja no Rio Grande do Sul. Passo Fundo: Embrapa Trigo, 2007. 34 p. html. (Embrapa Trigo. Documentos Online, 91). Disponível em: http://www.cnpt.embrapa.br/biblio/do/p_do91.htm
- SANTOS, H.P. dos; REIS, E.M. Rotação de culturas em plantio direto. Passo Fundo: Embrapa Trigo, 2003. 212p.
- SANTOS, H.P. dos; LHAMBY, J.C.B.; PRESTES, A.M.; REIS, E.M. Características agronômicas e controle de doenças radiculares de trigo, em rotação com outras culturas de inverno. Pesquisa Agropecuária Brasileira, Brasília, v.33, n.3, p.277-288, 1998.

Enhanced Opportunities for Use of Plant Genetic Resources in Conservation Agriculture Initiatives: A Critical Appraisal

P.L. Gautam^{1*}, S.K. Sharma² and I.S. Bisht²

¹Indian Council of Agricultural Research, Krishi Bhawan, New Delhi-110114, India

²National Bureau of Plant Genetic Resources, Pusa Campus, New Delhi-110 012, India

*Corresponding author; ddgcs.icar@nic.in

Conservation agriculture (CA) which has its roots in universal principles of providing permanent soil cover, minimum soil disturbance and crop rotations is now considered the principal road to sustainable agriculture world over. This is a way to achieve goals of higher productivity while protecting natural resources and environment. Globally, CA is currently practiced on more than 100 million ha in more than 50 countries and the area is expanding rapidly. The new technologies, on the one hand, are encouraging the farmers to take up new ways of managing their resources more productively and, on the other hand throwing new challenges to the scientific community to solve emerging problems associated with new technologies. Zero- or reduced-tillage having crop residues is different than conventional tillage in several ways. Important differences being soil structure shift in host-weed competition, availability of different moisture regime if sown deep or under stubbles, emergence of new pathogen population that survive on crop residues and shift in crop-pest scenario. There could be requirement for a different plant type suiting to a specific mechanization, agronomical initiatives such as allelopathy and specific issues related to the problem soils. Further, there could be greater scope of crop diversification and need for adopting a different breeding approach targeting a specific location or environment. A critical appraisal of various germplasm enhancement opportunities for CA initiatives has been deliberated in this paper, which may be considered for appropriate design and application. The areas where enough opportunities exist for crop genetic enhancement under CA initiatives include: varietal development programmes targeted to tillage requirement; selecting genotypes suiting to soil factors under reduced tillage; genotype suiting to water stress; strengthening pre-breeding activities for pest resistance; selecting genotypes for quicker residue decomposition; varieties adapted to specific ecological/ environmental/ problem soils/ agronomic/ crop diversification/ mechanization requirements, etc. Due to multitude of environments occurring at farmers' fields, participatory approaches such as Participatory Varietal Selection (PVS) may be immensely beneficial in CA. Further, new scientific approaches of molecular tools could be applied for allele mining and developing improved varieties and crops for enhanced yields with low production costs.

Key words: Conservation agriculture, plant genetic resources (PGR), genetic enhancement

Over the past three decades or so, internationally, rapid strides have been made to evolve and spread resource conservation technologies (RCTs) like zero- and reduced-tillage systems, better management of crop residues, planting systems which enhance water and nutrient conservation, system of rice intensification (SRI), etc. Conservation Agriculture (CA) which has its roots in universal principles of providing permanent soil cover (through crop residues, cover crops, agroforestry, etc.), minimum soil disturbance and crop rotations is now considered a principal road to sustainable agriculture (Hobbs, 2007). Its principles are already widely adopted (FAO, 2002). The basic elements of CA include, very little or no soil disturbance, no burning, direct seeding into previously untilled soil, crop rotation and permanent soil cover. The use of the term conservation agriculture instead of no-tillage, conservation tillage, direct-seeding and several other related terms has helped greatly to improve the understanding of a more sustainable way of farming in national and international organizations worldwide (Derpsch, 2005).

Globally, CA is currently practiced on about 100 million ha in more than 50 countries and the technology is showing increasing interest by farmers (Derpsch, 2005). The countries with the biggest area under no-tillage are the USA, followed by Brazil, Argentina, Canada, Australia and Paraguay. Adoption rates are increasing much faster in South America than in other parts of the world and also the quality of no-tillage is better in terms of permanently not tilling the soil and permanent soil cover. Adoption rates continue to be very low in Europe, Africa and most parts of Asia. In India, significant efforts to develop and spread these technologies are underway through the combined efforts of several institutions/agencies and CA is being practiced in about 1.9 million ha area in Indo-Gangetic Plains (Hobbs and Gupta, 2004; Hobbs et al., 2006). In 2007, IRRI researchers developed crop residue and weed management options for minimum-till and direct-seeded rice (DSR) farming systems following principles of CA (IRRI, 2007). Weed and residue management practices for dry-seeded rice after conventional and zero-tillage, and wet-seeded rice after puddling, were developed and widely assessed in rice-rice and rice-wheat systems of the Indo-Gangetic Plains. Besides, there are several other options being tried to improve water use efficiency in rice production including the SRI in India and many other countries ((Viraktamath, 2008). No-till systems for wheat,

developed and introduced in the past, have opened the way for no-till rice cropping in India and Australia (ACIAR, 2008). While at the beginning it was thought that no-tillage would only work under certain climates and soils, it has become clear that the technology can be practiced successfully in a wide range of climatic, soil and geographic conditions. Through the years no-tillage has been shown to work in all kind of environments. Conditions where the technology does not work are rare and often limiting conditions can be overcome by using appropriate technologies. It has been shown to be easier to adapt the no-tillage technology to physical conditions than to human conditions. The new technologies, on the one hand, are encouraging the farmers to take up new ways of managing their resources more productively and, on the other hand throwing new challenges to the scientific community to solve emerging associated problems.

The concepts supporting the formulation of direct-seeded cropping systems with permanent soil cover (DSPSC), could become a basis for the global development of ecosystem-friendly, sustainable agriculture managed according to a “biology driven” farming model. In all large tropical, subtropical and temperate ecoregions, irrespective of the type of agriculture practiced, DSPSC systems provide complete erosion control and are much more profitable than conventional cropping systems with tillage, due to the large cost savings in labour, farm machinery, and fuel with DSPSC systems (Seguy et al., 2006).

Studies have demonstrated that both above and below-ground biodiversity can benefit from conservation tillage. Enhanced use of plant genetic resources for genetic enhancement is, however, crucial for the three main practices of CA as component of sustainable agriculture. Because tillage is reduced in CA, farmers have to rely more on the action of crop roots and soil organisms to improve the soil and keep their crops healthy. To make sure that soil organisms have a chance to grow and thrive, farmers practising CA reduce their use of chemical pesticides and establish an effective system of crop rotation. Crop rotations and combinations have several benefits viz. better nutrient uptake in the soil; more soil organisms; fewer weeds, pests and diseases; integration of livestock by providing forage and manure, and food security and diversification of income sources. Reduced tillage is a way back to early evolutionary processes where different crops have originated and survived for long in their niche environments under no-till situations. Joshi *et al.* (2005) have differentiated the reduced-tillage having crop residues from the conventional tillage and emphasized for need of germplasm enhancement and an altogether different breeding approach such as participatory research to develop varieties suiting to specific location or environment. We, therefore, foresee enough opportunities for enhanced use of plant genetic resources in addressing various challenges of CA practices. A critical appraisal of these opportunities has been deliberated in this article based on the three principles of CA, i.e. permanent soil cover, minimal soil disturbance and crop rotations which must be considered together for appropriate design and application. Further, one important activity to be supported in CA has been to promote agroforestry for fiber, fruit and medicinal purposes. Agroforestry (trees on farms) provides many opportunities for value added production, particularly in tropical regions, but these technologies are also used as living contour hedges for erosion control, to conserve and enhance biodiversity, and to promote soil carbon sequestration (Dumanski et al., 2006).

Enhanced PGR Use in CA Practices

Maintenance of Permanent Soil Cover

The design of crop rotations and the choice and management of cover crops must ensure that the biomass production is sufficient to satisfy the different needs (food and other crops, livestock feed and residue cover on the soil) and that soil, water and nutrient resources are adequate for the crop. This implies that cover crops have multiple purposes. Keeping the soil covered is a fundamental principle of CA. The soil cover has several functions (Table 1). Crop residues are left on the soil surface, but cover crops may be needed if the gap is too long between harvesting of one crop and establishing the next. Cover crops improve the stability of the CA system, not only on the improvement of soil properties but for their capacity to promote biodiversity in the agroecosystem. While commercial crops have market value, cover crops are mainly grown for their effect on soil fertility or as livestock fodder. In regions where small amounts of biomass are produced, such as semi-arid regions or areas of eroded and degraded soils, cover crops are beneficial as they- protect the soil during fallow period; mobilize and recycle nutrients; improve the soil structure and break compacted layers and hard pans; permit a rotation in a monoculture, and can be used to control weeds and pests. Cover crops are grown during fallow periods, between harvest and planting of commercial crops, utilizing the residual soil moisture. Their growth is interrupted either before the next crop is sown, or after sowing the next crop, but before competition between the two crops starts. Cover crops energize crop production, but they also present many challenges.

Table 1. Functions of soil cover

Nature	Action
Physical	<ul style="list-style-type: none"> • Protection against impact of rain drops- less surface sealing and crusting • Less run-off • Increased water infiltration • Reduced evaporation • Protection against soil erosion by water and wind • Prevention of overheating of soil surface • Reduced diurnal variation of temperature • Smothering of weeds • Source of soil organic matter build-up
Biological	<ul style="list-style-type: none"> • Habitat for predators; prevention of pest out-breaks • Stimulation of soil life (fauna and flora)
Global	<ul style="list-style-type: none"> • Carbon sequestration • Preservation of biodiversity (below ground biodiversity; arthropods; small vertebrates; birds)

Source: Steiner, K., 2002

A broad range of species may serve as cover crops. In south eastern Africa, for example, where small holdings dominate, only a few leguminous species have been adopted. These are sun hemp (*Crotalaria juncea*), more a shrub than a cover crop, velvet bean or mucuna (*Mucuna pruriens*) and to some extent lablab (*Lablab purpureus* syn. *Dolichos lablab*), a species providing edible seeds. Generally these green manures/cover crops are relay cropped under maize or sorghum. As farmers are reluctant to plant non-food crops, many extension services and development programmes favour the promotion of cropping systems that provide a dense ground cover at least during the growing season i.e. intercropping of legumes (cowpea, beans, soybeans, groundnuts). As different cover crops produce different amount of biomass, the density of the residues varies with the crops and thus the ability to increase water infiltration. A dense cover crop (e.g. hairy vetch- *Vicia pilosa*) will provide good soil cover. Crops and genotypes with dense cover, therefore, is one of the important criteria to be considered in cover crop selection.

The choice of cover crops depends on the climatic zone, the prevalent soils (low pH and water logging is often a limitation), the farming system, the production goals of the farmer and of the available seeds. A range of cover crops can be used as vegetative cover, e.g. grains, legumes, root/oil crops. All have the potential to provide great benefit to the soil. However, some cover crops have certain attributes, which need to be kept in mind when planning a rotation scheme. It is important to start the first years of CA with cover crops that leave a lot of residue on the soil surface, which decompose slowly (because of high C/N ratio). Grasses and cereals are most appropriate for this stage, also because of their aggressive and abundant rooting system, which takes less time to improve the soil. In the following years, when the soil shows a healthier appearance, legume cover crops can be incorporated in the rotation. Leguminous crops enrich the soil with nitrogen and decompose rapidly because of low C/N ratio. Later, when the system is stabilized it is possible to include cover crops with an economic function, like livestock fodder.

The selection of cover crops should depend on many management considerations including the presence of high levels of lignin and phenolic acids, which give the residues a higher resistance to decomposition and thus results in soil protection for a longer period (Fig 1). Plant constituents such as lignin and other polyphenols retard decomposition. Palm and Sanchez (1990) reported that both the decomposition rate and the N-release patterns of tropical legumes (*Inga edulis*, *Cajanus cajan*, and *Erythrina* spp.) were related to the amount of polyphenol compounds such as lignin in the leaf. *Erythrina* leaves had the lowest concentrations of polyphenols and the fastest decomposition rates of the three species studied. The grain species (oats and wheat) show more resistance than common vetch (legume) to decomposition. The latter has a lower C:N ratio and a lower lignin content and is thus subject to a rapid decomposition (Fig 2).

Agroecological adaptations of most commonly used cover crops are presented in Table 2.

Planting through the Soil Cover

This can be done through direct seeding, direct planting or broadcasting into the soil cover, depending on the specific conditions (soil, climate, seed and cover properties). Suitable machinery and implements are available for manual, animal drawn or mechanized agriculture. Uphoff et al. (2006) elaborated in detail about understanding the functioning and management of soil systems.

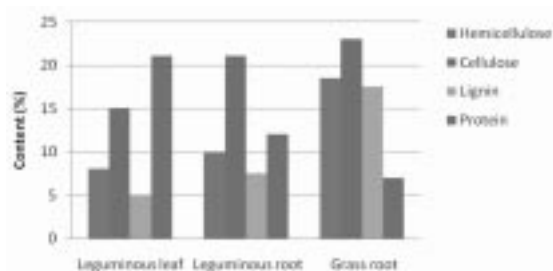


Figure 1. Composition of leaves and roots of leguminous and grass species (Source: Primavesi, 1984)

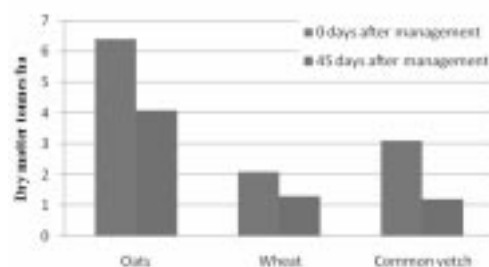


Figure 2. Reduction of dry matter of different cover crops (Source: Ruedell, 1995)

Table 2. Agroecological adaptations of most commonly used cover crops

Adaptations	Cover crops
Legumes adapted to humid lowlands	<i>Centrosema pubescens, Vigna mungo, Pueraria phaseoloides</i>
Legumes adapted to fire	<i>Centrosema pubescens, Desmodium adscendens, Glycine wightii, Macroptilium atropurpureum</i>
Legumes adapted to cold conditions	<i>Clitoria ternatea, Desmodium intortum, Desmodium incinatum, Glycine wightii, Lotononis bainesii, Medicago sativa, Phaseolus lathyroides, Trifolium spp.</i>
Legumes adapted to frequently flooded or inundated areas	<i>Lotononis bainesii, Phaseolus lathyroides, Pueraria phaseoloides, Vigna luteola, Vigna umbellata</i>
Legumes that tolerate drought	<i>Cajanus cajan, Canavalia brasiliensis, Canavalia ensiformis, Clitoria ternatea, Desmanthus virgatus, Desmodium uncinatum, Dolichos lablab, Galactia striata, Glycine wightii, Indigofera endecaphylla, Leucaena endecaphylla, Macrotyloma axillare, Stylosanthes guyanensis, Stylosanthes hamata, Stylosanthes humilis, Stylozobium spp., Vigna unguiculata</i>
Legumes adapted to shade	<i>Arachis pintoi, Calopogonium mucunoides, Canavalia ensiformis, Indigofera spp., Leucaena leucocephala, Pueraria phaseoloides, Trifolium repens</i>
Legumes adapted to fertile soils	<i>Glycine wightii, Medicago sativa, Stilozobium deeringianum (= Mucuna pruriens), Trifolium spp., Vicia sativa, Vicia villosa</i>
Legumes adapted to medium fertile soils	<i>Centrosema pubescens, Galactia striata, Macroptilium atropurpureum, Lupinus albus, Lupinus angustifolius, Lathyrus sativus, Crotalaria juncea</i>
Legumes and other species tolerant to low soil fertility	<i>Cajanus cajan, Calopogonium mucunoides, Canavalia brasiliensis, Canavalia ensiformis, Centrosema spp., Desmodium spp., Galactia striata, Indigofera spp., Leucaena leucocephala, Lotus corniculatus, Lupinus luteus, Macroptilium atropurpureum, Stylosanthes spp., Stylozobium aterrimum, Teramnus uncinatus, Vicia villosa, Vigna unguiculata, Zornia diphlla, Lolium multiflorum, Ornithopus sativus, Secale cereale, Spergula arvensis.</i>

Source: FAO, 2008. Conservation Agriculture Website : <http://www.fao.org/ag/ca>

RCTs effect on wheat productivity under puddle and non-puddled situations recorded higher yield in direct seeded conditions when earlier crop of rice was dry seeded (Fig 3). Conservation tillage requires varieties suiting to a particular resource conservation practice. Genotypes required for zero-tillage and surface seeding would be having different characteristics than those required for the raised bed. Because of the time needed to till the soil, late seeding occurs often in conventional tillage. Late planting of wheat after first fortnight of November reduces wheat yields by an average of 35 kg/day/ha, and when planting is delayed beyond the 20th of November yield losses of 50-65 kg/day/ha may occur. These losses are avoided by using the no-tillage system in Indo-Gangetic Plains. In raised bed cultivation, it has been demonstrated that all varieties of wheat do not perform well and there is genotype x tillage interaction (Sayre, 1998). Therefore, varietal development programme should be targeted to the tillage requirements.

Suitable rice genotypes for direct seeding are being identified under the project on zero-tillage rice establishment in India and Australia (ACIAR, 2008). Breeding lines sourced from IRRI and Indian national programmes performed well under DSR. The performance of basmati genotypes under DSR at certain locations is noteworthy. More genotypes need screening and are being tried under the project. Further, through IRRI-CIMMYT alliance, IRRI research emphasized requirement of high-yielding early maturing rice varieties for direct-seeding and maize varieties

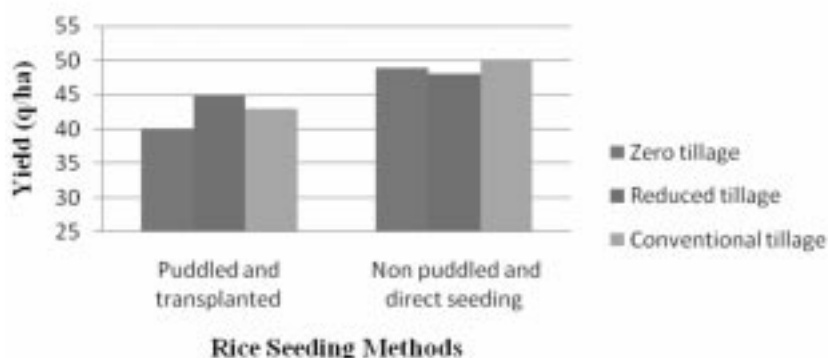


Figure 3. Performance of different tillage on wheat yield under puddled and non-puddled condition (mean of two years) (Source: Tripathi et al., 2005)

that can germinate and establish under conditions of excess moisture in rice-maize systems particularly in Bangladesh (IRRI, 2007).

A zero-till field has compact soil which is often unfavourable for root growth. Reduced root growth in high strength soils is responsible for patchy growth and losses in yield of wheat under direct drill with surface straw retained (Cornish and Lymberg, 1987). Although the root of the plant is the most important organ that nourishes the plant, but this trait has been often neglected by plant breeders (Manske et al., 2001). This aspect needs increased attention. In reduced tillage, soil is less disturbed, therefore, it has been suggested that the soil root contact would be better and favourable for the release of root exudates such as organic acids, carbohydrates, amino acids, enzymes, alkaloids, flavonoids, steroids and terpenoids. These root exudates promote the microflora of rhizosphere and promote competition among microbes and may be helpful in getting protection from pathogens. Therefore, there is need to screen varieties/crop germplasm for better release of root exudates.

Crops are often grown in environments where water is a limiting factor. In around 70% of irrigated wheat area of North-eastern Plain Zone (NEPZ) of India, for example, farmers are able to provide one or two irrigations and mostly the sowing is done on residual moisture. Hence taking advantage of available moisture and reducing evaporation from the soil is important. Any increase in early seedling vigour should reduce evaporative losses from the soil surface (Richards, 1992). If crop duration is short, greater vigour is likely to increase final biomass and yield. Furthermore, greater crop vigour may be an effective way to reduce weed growth and hence herbicide use in most environments. Among traits that contribute to increase seedling vigour, coleoptile length is most important (Fick and Qualset, 1976). Short coleoptiles result in poor emergence, which leads to poor crop establishment. Better emergence is achieved by sowing wheat with long coleoptiles. The presence of dwarfing genes in wheat is associated with a significant reduction in coleoptile length (Fick and Qualset, 1976) and poor emergence under deep sowing. It has been suggested that the accumulation of modifier genes that favour emergence could be important in breeding for better emerging semi-dwarf wheats (Allan, 1980). Phenology is a major determinant of drought independent harvest index (HI) as it can determine the amount of pre-anthesis and post-anthesis water use. If flowering occurs a few days earlier, it may mean an extra 5-10 mm of soil water for post-anthesis use and hence a higher HI. Therefore, for water limited areas, one needs to focus on early flowering genotypes (Richards et al., 2001).

Under increasing population pressure, many of the problem soils are being used for crop cultivation. Under RCTs in Indo-Gangetic Plains, zero-till wheat, for example, performs better in saline soils. However, in case of alkali soils, contact of seed with alkali crust may be harmful for seed germination. Therefore, development of tolerant varieties for saline conditions is an important requirement. For situations such as direct-seeded rice, we need cultivars that do not suffer from chlorosis, Zn and P deficiency and are able to germinate when seeds are placed deeper in moist zones. Inheritance of micronutrients traits has been reported in many crops including wheat and barley. Such information needs to be utilized for evaluation and introgression of favourable genes in different crops under RCTs.

The sowing depth of seeds might vary under reduced tillage. In surface seeding, seeds are dispersed on the soil surface, while a machine performing sowing under crop residue system may place the seed at lesser depth than recommended in tilled sowing. Hence, varieties displaying better germination and growth under shallow or

surface seeding would be more desirable. The presence of mulch on the upper part of the soil keeps it wetter and in most situations, this is desirable because it is beneficial to germination and plant growth. In case of use of Star (Punch) Planter, planting in the presence of residue would be easier to crops like rice, pulses, maize, etc. However, wheat shows better performance under drill sown condition may not respond to this machine due to inadequate plant population. For making wheat adjust punch sowing, we need to either modify punch machine to deliver appropriate amount of seed or develop varieties having profuse tillering with many effective tillers. Variability of synthetic wheats may be utilized for developing such varieties. Further, enhanced use of mechanization is expected in most parts of the world adopting RCTs. Erect growth habit along with synchronized flowering and maturity, especially in pulses would be important for machine harvesting.

Crop Residue Management and Weed Control

Crop residue management stimulates soil structure formation by soil fauna, improves soil fertility and helps to control weeds with less dependence on herbicides. Weed control in CA is based on an integrated set of techniques:

- agronomic (mulch cover, crop rotation and appropriate sowing date)
- mechanical (hand weeding, slashing and use of knife rollers)
- chemical (use of desiccants or other rapidly decomposing herbicides only where needed, mainly during the transition of CA).

Crop residues are not waste but a tremendous natural resource. Disposal of crop residues is based on decomposition, which is primarily influenced by environment and management factors with secondary influences including the species and cultivar type. Several workers have reported differences in residue decomposition due to difference in N, C/N, lignin/N, and polyphenol/N ratios even for the same species (Kumar and Goh, 2000). Thus the selection of crop genotypes which could promote micro-climate more favourable for the growth and reproduction for the saprophyte would be better. Varietal differences in the decomposition of wheat and barley straw have been reported (Summerell and Burgees, 1989). This also suggests possibility for selection of such cultivars in cereals.

There could be less sunshine available to the early seedlings emerging out of soil in a reduced tillage field with plenty of crop residues compared to conventionally tilled field. The reduced tillage also affects soil temperature (Unger and McCalla, 1980). The reduced tillage may benefit early sowing (October or early November) of wheat in environments such as NEPZ of India, where optimal temperature is attained in the second fortnight of November. However, this may not be beneficial for summer blackgram, mungbean, vegetables and even for rice. Hence, for these crops, varieties that germinate well and produce vigorous seedlings under relatively lower temperature would be more desirable. The crop residue present under reduced tillage may create the problem of phytotoxicity for various crops (Cochrane et al., 1977; Lynch, 1978). Under anaerobic conditions phytotoxic compounds such as acetic acid and butyric acid may be formed which influence germination of seeds. The phytotoxicity is reported within as well as between crops. Therefore, the traits related to seedling resistance to organic acids may require increased attention while breeding for crops to be grown under crop residue and conservation tillage.

Weed control without tillage is more complicated and requires much more knowledge. Some crops grow more vigorously than others, cover the soil quickly and tend to smother the weeds. Including these crops (e.g. cowpeas) in the rotation together with the other weed control methods will reduce weed populations and make annual weed control easier. Some green manure cover crops are very vigorous and can effectively reduce weed populations when planted as intercrops or sole crops in rotation. Good weed control can be expected from velvet bean (*Mucuna pruriens*), lablab (*Lablab purpureus*) and sunhemp (*Crotalaria juncea*). Velvet beans and lablab, if sown as intercrops, need to be seeded at about three (lablab) to six weeks (velvet bean) after the maize crop so that they do not compete too much and reduce maize yield (CIMMYT, 2008).

Tillage is widely used to control weeds directly and by burying their seeds. Variation in the occurrence of weed, both at species and temporal level, may shift in the reduced-tillage. Varieties having faster early emergence or those displaying better competition would be more desirable. In view of the greater use of herbicides in CA, breeders also need to look for herbicide tolerant varieties. Further, the genotypes of crops which exhibit favourable allelopathy to suppress the weeds may be identified (Wetson, 1996). For example, the residue of rye and other small grains have been shown to inhibit weed emergence and growth (Shilling et al., 1986), probably due to phytotoxic effects (Kumar and Goh, 2000). Such traits need to be identified in case of all crops of the target zone.

Weeds have been shown to germinate less in CA in Rice-Wheat (RW) systems (50-60% less) because the soil is less disturbed and less grassy weeds (*Phalaris minor*) germinate than in tilled soils. There is also evidence of allelopathic properties of cereal residues in respect to inhibiting surface weed seed germination (Lodhi and Malik, 1987; Steinsiek et al., 1982; Jung et al., 2004). Researchers have noticed that some rice cultivars suppress the barnyard grass (*Echinochloa crus-galli*) and other annual weed species (Kim and Shin, 1998; Kuk et al., 2001). A number of allelochemicals have been identified in rice root exudates and in decomposing rice straw. These include phenolic and aromatic acids, benzene derivatives, fatty acids, sterols (Rimando and Duke, 2003). This particular set of allelopathic effects could be utilized positively to protect rice crops from deleterious weed impacts once more is known about how and under what conditions these biochemical compounds are produced.

Weeds will also be controlled through management of cover crops. Farming practices that maintain soil microorganisms and microbial activity can also lead to weed suppression by biological agents (Kennedy, 1999). Further, experiments evaluating the suitability of different crop species and their cultivars to wide-row (WR) cropping have been extremely useful in identifying cultivars with greater suitability to WR systems. Field experiment conducted to investigate weed behaviour and management under WR have shown that WR system significantly reduce the establishment of problematic weeds such as annual rye grass. More investigations on weed dynamics and management under WR cropping system are underway (ACIAR, 2008). IRRI-CIMMYT collaboration also highlighted the merit of integrating improved site specific nutrient management (SSNM) with residue management (IRRI, 2007). Further, the SRI-like practices as wider plant spacing, more root growth, due to reduced weed competition, and aeration of soil, giving roots more oxygen and N due to increased microbial activity in soil, enhanced soil organic matter are of potential importance in CA (Uphoff, 2005; Prasad, 2006; Viraktamath, 2008).

Insect Pest and Disease Control

Pest and disease controls are based on Integrated Pest Management (IPM) technologies. IPM is essential to CA because it helps build up soil biota and promote biological tillage. IPM techniques enable farmers to monitor and control pest levels in the fields without disturbing natural balances, and to resort to synthetic pesticides only when and where it is absolutely necessary. In CA, pest levels are also kept under control by crop rotation. Cover crops, intercropping and crop rotations can also help promote biodiversity both below the soil surface and above ground. This diversity is important to maintaining a well-functioning and stable ecological system. Where many different types of organisms co-exist, there are: fewer problems with diseases, insects and nematodes; more competition among species; and more possibility for many types of predators to thrive. In such a situation, no single pest organism is able to reach a population of sufficient size to affect crop yield seriously.

A list of the impacts of minimum tillage on specific crops and their associated pathogens can be found in Sturz et al. (1997). The effects of tillage on the development and severity of crop diseases are variable, depending on the disease, the specific type of tillage system used, and the effectiveness of the other disease management practices applied (Felton et al., 1987). A summary of the effect of crop residues on the growth and reproduction of pathogen is presented in Table 3. In reduced tillage system, there could be more favour to facultative parasites as well as saprophytes. Crop residue may promote such pathogens that survive and multiply on crop residues. Some of the diseases such as spot blotch of wheat caused by *Bipolaris sorokiniana* which is considered the most important disease of eastern India (Joshi et al., 2004), have shown a decline under zero-tillage in eastern Uttar Pradesh where planting is normally done under the late sown conditions. The breeding programmes must, therefore, target to strengthen pre-breeding as well as breeding populations using suitable resistant sources. In this direction, identification of simple morpho-physiological markers can simplify the efforts of breeders (Joshi and Chand, 2002; Joshi et al., 2004; Singh, 1992a,b). In addition to disease, conservation tillage may have variable effects on insects. Tolerant varieties could be one of the options in the integrated management of some insect pests.

Issues Related to Crop/Cropping System Diversification

Sustainable crop production through crop diversification is an important issue in rice-wheat cropping areas adopting RCTs. The common crop rotations involving pulse crops in such areas are rice-pea-wheat, rice-lentil and rice-gram. Due to unstable and poor yield of pulse crops, the area under diversification is not growing. Genotypes which can perform better under RCTs in lentil, gram, pea, mungbean etc. are expected to promote crop diversification and profitability of farmers. Similarly, there is ample scope to promote mungbean cultivation after the harvest of wheat. A mungbean genotype having maturity duration of 60-65 days and resistance to mungbean yellow mosaic virus is the demand of the farmers.

Table 3. Effect of crop residues on the growth and reproduction of pathogens of different crops grown in rice-wheat cropping system areas of India

Disease	Pathogen & its nature	Host range variability	Incidence	Spatial variability	Temporal variability	Effect of crop residue
1. Soil borne (Seedling diseases, collar rot, damping-off etc.)	Facultative parasites: <i>Phythium</i> , <i>Phytophthora</i> , <i>Rhizoctonia</i> , <i>Scelerotium</i> , <i>Macrophomina</i>	Broad+	Locally high	Very high depending on scale and habitat	Periodic cyclics of disease	May promote disease up to 15 November
2. Wilt	Facultative Saprophyte: <i>Fusarium udam</i> <i>F. oxysporum</i> fs. <i>ciceri</i> <i>F. oxysporum</i> fs. <i>pisi</i> <i>F. oxysporum</i> fs. <i>lini</i>	Pigeon pea Chick pea Pea Lentil	High	Depended on scale and habitat	Periodic cyclics of disease	Survive on own residue for 2 to 4 years. No chance of multiplication on other crops residue. If multiplies on other residue, will not be virulent
3. Necrotroph (Foliar diseases) Sheath blight of rice Bacterial blight of rice Spot blotch of wheat and barley	Facilitative saprophyte: <i>Rhizoctonia Solani</i> <i>Xanthmonas oryzae</i> pv. <i>Oryzae</i> . <i>Bipolaris sorokiniana</i>	Restricted except sheath blight pathogen	Very high	Very high. Depends on the scale and habitat	Periodic cyclics of disease	Survival not detected on the residue of wheat and paddy. All pathogens survive on residue for a limited period. Most pathogens are host-specific. Hence, can not shift to other hosts.

Source: Joshi *et al.*, 2005

In India, the high intensity cropping sequences in major ecologies have shown marked advantage over existing cropping systems (Sharma *et al.*, 2002; Gill and Brar, 2005). Suitable genotypes, therefore, need to be selected which can efficiently use the nutrients from soil and applied sources and convert them with desired output. Cropping systems should be selected such that the residual nutrients left by one crop are efficiently utilized by the succeeding crops. Studies at PAU, Ludhiana revealed that there are different cropping systems which not only gave more productivity than rice-wheat system but also helped to save substantial quantity of irrigation water.

Intercropping is one of the important ways to increase the productivity and provide income stability under limited soil moisture conditions. In India, some of the promising intercropping systems are maize + blackgram at Palampur, Ranchi and Banswara; maize + soybean in Ranchi; maize + cowpea at Karjat; sorghum + soybean at Sehore; sorghum + pigeonpea at Indore; pigeonpea + greengram at Bichpure and Hanumangarh; rice + soybean at Kalyani and Jabalpur, and wheat + rapeseed at Indore. Most of these intercropping systems were found to be highly remunerative over the sole cropping (Gill and Brar, 2005).

The crops perform well in different cropping systems if grown as per soil suitability. Selection of crops made on the basis of soil suitability revealed that chickpea and canola can be good option for wheat crop in Allowal Common Area of Punjab, India. It would save enough irrigation water if 10% wheat area is diverted to chickpea and canola each as compared to wheat grown on the same acreage (Gill *et al.*, 2003). Suitable location specific crops and genotypes, therefore, need to be identified under RCTs.

Inclusion of legumes in different cropping systems helps improve soil fertility. Besides N-fixation, legumes also help in solubilization of P, increase in soil microbial activity, organic matter restoration and improvement of physical health of soil (Wani *et al.*, 1995). Results from the AICRP-CS showed consistent better productivity from rice-pulse than rice-wheat systems (Hegde, 1992).

In North-eastern Plain Zone of India, there are enough opportunities and potential for boro rice in standing water/ water logged areas. Deepwater and floating rice are usually harvested using boats in such areas. Improvement in deepwater and floating rice and sugarcane landrace named “bansa” (which is able to withstand a meter of standing water for several months) could be an effective option for productivity enhancement and improving livelihoods of the farmers.

Conventional and Non-Conventional Breeding Approaches

Large-scale base-broadening is required through pre-breeding or germplasm enhancement. Such broadening is needed to supply new traits, to bring new levels of productivity and stability of performance, and to provide useful new qualities to food and feed products. Due to multitude of environments occurring at farmers fields, especially in country like India, participatory approach such as PVS (Witcomb and Virk, 2001) would be immensely beneficial. In PVS, varietal trials for selection are conducted on the farmers’ field. This exposes the lines to the real environment and gives a better scope for selection. Since farmers’ choice plays a key role in selection, it ensures desired trade-off traits of different crops. Farmers participatory selections has gained significant area under reduced/zero tillage world over.

Further, the new scientific approaches of molecular tools could also be applied for developing improved varieties and crops that enable producers to maximize yields and quality but minimize chemical input and production costs. The new methods will include more effective breeding strategies, and more comprehensive knowledge of microbial, insect, and crop genomic structures. More cost-effective markers must be developed, so as to improve the efficiency of gene identification and mapping. Molecular approaches have the potential for allele mining by discovering new alleles at important gene loci that can be used for crop improvement. Beneficial alleles can be identified for traits of interest; these alleles can then be transferred to elite breeding lines using marker-assisted selection.

Conclusions

It is being recognized that CA can make an important contribution to the agriculture sector through its multiple environmental and economic benefits. CA uses holistic production management systems that promote and enhance agroecosystem health, including aboveground and belowground biodiversity, biological cycles, and biological activity. These systems apply specific and precise standards of production based on no- or minimum-tillage techniques and selected cover crops and crop rotations. Their aim is to achieve optimal agro-ecosystems that are socially, ecologically and economically sustainable. Through effective harnessing of agro-ecological processes, CA provides an opportunity for reducing external input requirements and for converting low-input agricultural systems into more productive ones. A better understanding of linkages between soil life and ecosystem function and the impact of human interventions will enable the reduction of negative impacts and the more effective capture of the benefits of soil biological activity for sustainable and productive agriculture.

Zero or reduced tillage having crop residues is different than conventional tillage in several ways. Important differences being soil structure shift in host-weed competition, availability of different moisture regime if sown deep or under stubbles, emergence of new pathogen population that survive on crop residues and shift in crop-pest scenario. There could be requirement for a different plant type suiting to a specific mechanization, agronomical initiatives such as allelopathy and specific issues related to the problem soils. Further, there could be greater scope of crop diversification and need for adopting a different breeding approach targeting a specific location or environment. Hence in view of increasing coverage under RCTs, crop improvement programmes need to be reoriented according to the demand of the changing situation. There is a case for new breeding objectives, as in many environments under reduced tillage, suitable alternatives are scanty. Efficient genotypes having traits that could give added advantage to the growing plant can solve many of the problems and thereby enhance the chance of achieving greater profitability and sustainability. A clear understanding of the traits that need priority in breeding programme of different crops is required to harvest the advantages of upcoming resource conservation and non-conventional approaches of breeding can help us to meet this challenge.

Masanobu Fukuoka in his book “**The One-Straw Revolution**” claims “*With this kind of farming, which uses no machines, no prepared fertilizer and no chemicals, it is possible to attain a harvest equal to or greater than that of the average Japanese farm.*”

References

- ACIAR. 2008. Zero-tillage rice establishment and crop-weed dynamics in rice and wheat cropping systems in India and Australia. Project Overview and Progress Report (Project ID:LWR/ 2004/ 033; <http://www.aciar.gov.au/project/LWR/2004/033>).
- Allan, R.E. 1980. Influence of semi-dwarfism and genetic background on stand establishment of wheat. *Crop Science* **20**, 634-638.
- CIMMYT. 2008. Weed control in smallholder conservation agriculture. *CIMMYT Technical Bulletins on Conservation Agriculture* (Tech. Bull. 6; prepared by Christian Thierfelder and Patrick C. Wall as part of CIMMYT's BMZ and IFAD-Funded projects on Facilitating the Adoption of Conservation Agriculture in Eastern and Southern Africa).
- Cochrane, V.L., Elliot, L.F. and Papendick, R.I. 1997. The production of phytotoxin from surface crop residues. *Soil Science of America Proceedings* **41**, 903-908.
- Cornish, O.S. and Lymberg, J.R. 1987. Reduced early growth of direct drilled wheat in southern New South Wales: Causes and consequences. *Aust. J. Exp. Agric.* **27**, 869-880.
- Dumanski, J., Peiretti, R., Benetis, J., McGarry, D. and Pieri, C. 2006. The paradigm of conservation tillage. *Proc. World Assoc. Soil and Water Conserv.*, P1, 58-64.
- Derpsch, R. 2005. *The extent of conservation agriculture adoption: implications and impact*. Proceedings of the Third World Congress on Conservation Agriculture: Linking Production, Livelihoods and Conservation, Nairobi, Kenya, October, 3-7, 2005.
- FAO, 2002. *The Conservation Agriculture Working Group Activities 2000-2001*. Food and Agriculture Organisation of the United Nations, Rome, 25 p.
- FAO, 2008. Conservation Agriculture website: <http://www.fao.org/ag/ca/>
- Felton, W.L., Freeman, D.M., Fettel, N.A. and Thomas, J.B. 1978. Crop residue management tillage. In: *New Direction in Australian Agriculture* (P.S. Cornish and J.E. Pratley, Eds.) pp 14-221, Inkata Press, Melbourne, Australia.
- Fick, G.N. and Qualset, C.O. 1976. Seedling emergence, coleoptile length and plant height relationships in crosses of dwarf and standard height wheats. *Euphytica* **25**, 679-684.
- Fukuoka, M. 1978. *The One-Straw Revolution*. (Translated from the Japanese by Chris Pearce, Tsune Kurosawa and Larry Korn, originally published in Japan as *Shizen Noho Wora Ippon No Kakumei*), Other India Press, Mapusa 403 507, Goa, India.
- Gill, M.S. and Brar, L.S. 2005. Cropping system diversification opportunities and conservation agriculture. In: *Conservation Agriculture- Status and Prospects* (I.P. Abrol, R.K. Gupta and R.K. Malik, Eds.), pp 64-71. Centre for Advancement of Sustainable Agriculture, New Delhi.
- Hobbs, P.R. 2007. Conservation agriculture: what is it and why is it important for future sustainable food production? *Journal of Agricultural Science*, **145**, 127-137
- Hobbs, P.R. and Gupta, R.K. 2005. Problems and challenges of no-till farming for the rice-wheat systems of the Indo-Gangetic Plains in South Asia. In: *Sustainable Agriculture and the Rice-Wheat System* (R. Lal, P. Hobbs, N. Uphoff and D.O. Hansen, Eds.), pp 101-119. Columbus, Ohio, and New York, USA: Ohio State University and Marcel Dekker, Inc.
- Hobbs, P., Gupta, R. and Meisner, C. 2006. Conservation agriculture and its implications in South Asia. In: *Biological approaches to sustainable soil systems* (N. Uphoff, A.S. Ball, C. Palm, E. Fernandes, J. Pretty, H. Harren, P. Sanchez, O. Husson, N. Sanginga, M. Laing and J. Thies Eds.) pp. 357-372. CRC Press, Taylor & Francis Group.
- IRRI. 2007. Annual Report 2007. Research Programmes: Output 2. Management options and germplasm to address sustainability and scarce freshwater issues. International Rice Research Institute, Los Baños, Laguna, Philippines.
- Joshi, A.K., Arun, B., Chand, R., Chandola, V.K., Ram Krishna, K., Prasad, L.C., Srivastava, C.P., Raha, P. and Tripathi, R. 2005. Zero/reduced tillage/bed planting/surface managed crop residue systems-opportunities for crop genetic enhancement. In: *Conservation Agriculture- Status and Prospects* (I.P. Abrol, R.K. Gupta and R.K. Malik, Eds.) pp 114-123. Centre for Advancement of Sustainable Agriculture, New Delhi.
- Joshi, A.K. and Chand, R. 2002. Variation and inheritance of leaf angle and its relationship with resistance to spot blotch in wheat (*Triticum aestivum*). *Euphytica* **123**, 221-228.
- Joshi, A.K., Kumar, Sundeep, Ferrara, O. and Chand, R. 2004. Inheritance of resistance to spot blotch caused by *Bipolaris sorokiniana* in spring wheat. *Plant Breeding* **123**, 213-219.
- Jung, W.S., Kim, K.H., Ahn, J.K., Hahn, S.J. and Chung, I.M. 2004. Allelopathic potential of rice (*Oryza sativa* L.) residues against *Echinochloa crus-galli*. *Crop protection* **23**, 211-218.
- Kennedy, A.C. 1999. Soil microorganisms for weed management. *Journal of Crop Production* **2**, 123-138.
- Kim, K.U. and Shin, D.H. 1998. Rice allelopathy research in Korea. In: *Allelopathy in Rice: Proceedings of the Workshop on Allelopathy in Rice* (M. Olofsdotter Ed.) pp. 39-43. International Rice Research Institute, Manila, Philippines.
- Kuk, Y.I., Burgos, N.R. and Talbert, R.E. 2001. Evaluation of rice by-products for weed control. *Weed Science* **49**, 141-147.
- Kumar, K. and Goh, K.M. 2000. Crop residues and management practices: effects on soil quality, soil nitrogen dynamics, crop yield and nitrogen recovery. *Advances in Agronomy* **68**, 197-319.

- Lodhi, M.A.K. and Malik, K.A. 1987. Allelopathy in agroecosystems: wheat phytotoxicity and its possible role in crop rotation. *Journal of Chemical Ecology* **13**, 1881-1891.
- Lynch, J.M. 1978. Production and phytotoxicity of acetic acid in anaerobic soil containing plant residue. *Soil Biology and Biochemistry* **10**, 131-135.
- Manske, G.G.B., Ortiz-Monasterio, J.I. and Vlek, P.L.G. 2001. Techniques for measuring genetic diversity in roots. In: *Application of Physiology in Wheat Breeding* (M.P. Reynolds, J.I. Ortiz-Monasterio and A. McNab, Eds.), pp 88-100. CIMMYT, Mexico, D.F.
- Palm, C.A. and Sanchez, P.A. 1990. Decomposition and nutrient release patterns of the leaves of three tropical legumes. *Biotropica*, **22**, 330-338.
- Prasad, C. Shambu. 2006. System of Rice Intensification in India: Innovation History and Institutional Challenges. WWF International - ICRISAT Dialogue Project, ICRISAT, Patancheru - 500 324, Andhra Pradesh, India.
- Primavesi, A. 1984. *Manejo ecologico del suelo. La agricultura en regions tropicales*. 5^{ta} Edicion. El Ateneo. Rio de Janeiro, Brazil, 499 pp.
- Rebetzke, G.J., Richards, R.A., Fischer, V.M. and Mickelson, B.J. 1999. Breeding long coleoptile, reduced height wheats. *Euphytica* **106**, 158-168
- Richards, R.A. 1992. The effect of dwarfing genes in spring wheat in dry environment. II. Growth, water use and water use efficiency. *Aust. J. Agric. Res.* **43**, 529-539.
- Richards, R.A. 1996. Increasing the yield potential of wheat: Manipulating sources and sinks. In: *Increasing Yield Potential in wheat: Breaking the Barriers* (M.P. Reynolds, S. Rajaram, and A. McNab, Eds.), pp 134-149. CIMMYT, Mexico, D.F.
- Richards, R.A., Condon, A.G. and Rebetzke, G.J. 2001. Traits to improve yield in dry environments. In: *Application of Physiology in Wheat Breeding* (M.P. Reynolds, S. Rajaram, and A. McNab, Eds.), pp 88-100, CIMMYT, Mexico, D.F.
- Rimando, A.M. and Duke, S.O. 2003. Studies on rice allelochemicals. In: *Origin, History and Technology and Production* (C.W. Smith Ed.) pp. 221-244. Wiley, Hoboken, NJ.
- Ruedell, J. 1995. *Plantio direto na regiao de Cruz Alta*. FUNDACEP. 134 pp.
- Sayre, K.D. 1998. *Ensuring the Use of Sustainable Crop Management Strategies by Small Wheat Farmers in the 21st Century*. Wheat Special Report No. **48**. CIMMYT, Mexico, D.F.
- Seguy, L., Bouzinac, S. and Husson, O. 2006. Direct-seeded tropical soil systems with permanent soil cover: Learning from Brazilian Experience. In: *Biological approaches to sustainable soil systems* (N. Uphoff, A.S. Ball, C. Palm, E. Fernandes, J. Pretty, H. Harren, P. Sanchez, O. Husson, N. Sanginga, M. Laing and J. Thies Eds.) pp. 323-342. CRC Press, Taylor & Francis Group.
- Sharma, S.K., Dwivedi, B.S. and Singh, V.K. 2002. Diversification and globalization of agriculture. *Indian Farming* **52**, 51-57.
- Shilling, D.G., Jones, L.A., Worsham, A.D., Parker, C.E. and Wilson, R.G. 1986. Isolation and identification of some phytotoxic compounds from aqueous extracts of rye. *J. Agric. Food Chem.* **34**, 633-638.
- Singh, R.P. 1992a. Association between gene Lr34 for leaf rust resistance and leaf tip necrosis in wheat. *Crop Science* **32**, 874-878.
- Singh, R.P. 1992b. Genetic association of leaf rust resistance gene Lr34 with adult plant resistance to strip rust in bread wheat. *Phytopathology* **82**, 835-838.
- Steiner, K. 2002. Conservation tillage-Gateway to food security and sustainable rural development: Crop residue management and cover crops. *African Conservation Tillage (ACT) Network, Information Series No. 3*. Harare/Zimbabwe. (<http://www.fao.org/act-network>).
- Steinsiek, J.W., Oliver, L.R. and Collins, F. 1982. Allelopathic potential of wheat (*Triticum aestivum*) straw on selected weed species. *Weed Science* **30**, 495-497.
- Sturz, A.V., Carter, M.R. and Johnston, H.W. 1997. A review of plant disease, pathogen interactions and microbial antagonism under conservation tillage in temperate humid agriculture. *Soil and Tillage Research* **41**, 169-189.
- Summerell, B.A. and Burgess, L.W. 1989. Decomposition and chemical composition of cereal straw. *Soil Biol. Biochem.* **21**, 551-559.
- Tripathi, S.C., Mongia, A.D. and Jag Shoran. 2005. Resource conservation technologies and cropping system diversification opportunities. In: *Conservation Agriculture- Status and Prospects* (I.P. Abrol, R.K. Gupta and R.K. Malik, Eds.), pp 72-78. Centre for Advancement of Sustainable Agriculture, New Delhi.
- Unger, P.W. and McCalla, T.M. 1980. Conservation tillage systems. *Advances in Agronomy* **33**, 2-53.
- Uphoff, N. 2005. Features of the system of rice intensification (SRI) apart from increases in yield. CIFAD, Cornell University, Ithaca, NY, USA.
- Uphoff, N., Ball, A.S., Palm, C., Fernandes, E., Pretty, J., Harren, H., Sanchez, P., Husson, O., Sanginga, N., Laing, M. and Thies, J. 2006. *Biological approaches to sustainable soil systems*. CRC Press, Taylor & Francis Group, 764 p.
- Viraktamath, B.C. 2008. Research on system of rice intensification in India and priorities for the future. Paper presented in National Symposium on SRI at Tamil Nadu Agricultural University, Coimbatore, 1-3 December.
- Weston, L.A. 1996. Utilization of allelopathy for weed management in agroecosystems. *Agron. J.* **88**, 860-866.
- Witcombe, J.R. and Virk, D.S. 2001. Number of crosses and population size for participatory and classical plant breeding. *Euphytica* **122**, 451-462.

Session 3.3: Environmental Services

Environmental Service Provided by Conservation Agriculture in Tropical Rural Catchments: Water and Soil Credits?!”

J. Miguel Reichert¹, Jean Paolo Minela², Gustavo Henrique Merten², Nadia Bernardi Bonumá¹, and Dalvan Jose Reinert¹

¹Universidade Federal de Santa Maria, Soils Department, Av. Roraima 1000, Santa Maria-RS, 97105-900, Brazil

²Universidade Federal do Rio Grande do Sul, Hydraulics and Hydrology Research Institute (IPH), Porto Alegre-RS, Brazil

(*Email: reichert@smail.ufsm.br.)

This paper presents some recent research performed on surface hydrology and erosion and sedimentation in rural catchments in the process of adopting conservation agriculture practices, and on soil physical quality related to ecological properties and environment. The results are part of hydrosedimentological studies performed in two rural catchments in southern Brazil in which significant changes in soil conservation practices occurred, leading to sediment yield changes, and also a review of work on soil physics in Brazil and elsewhere. The experimental catchments were part of an environmental monitoring project that evaluated, using hydrosedimentometric and environmental variables, the impact of government (RS-Rural Program) soil and water conservation programs implemented for rural poverty reduction. The monitoring assessed the impact of these measures on environmental improvement, especially on the reduction of soil erosion and sediment yield. Several strategies are presented and discussed and implication for assessing environmental services are suggested.

Agriculture produces more than just crops (Dale and Polasky, 2007), since agricultural practices have environmental impacts that affect a wide range of ecosystem services, including water quality, pollination, nutrient cycling, soil retention, carbon sequestration, and biodiversity conservation. In turn, ecosystem services affect agricultural productivity. They point out that understanding the contribution of various agricultural practices to the range of ecosystem services would help inform choices about the most beneficial agricultural practices.

Agriculture is responsible for over 20% of anthropic greenhouse gas emissions globally. This includes about a quarter of all anthropic carbon dioxide fluxes, mainly from deforestation and fossil fuel use; about over half of total methane emissions, mainly from ruminant livestock, rice cultivation, biomass burning, and animal wastes; and about two-thirds of total nitrous oxide fluxes, mainly from cultivated soils, animal wastes, and biomass burning.

The expansion of agriculture frontier with forest clearing, over the last 140 years, has generated a net emission of 121 Gt of carbon to the atmosphere, characterizing our country as the single greatest emitter of greenhouse gases from land use change (Machado, 2005). In Brazil, over 50 million hectares are currently used for grain production. In contrast, about half the area under grain production is currently under no-tillage, which may contribute to several ecological benefits. However, there are many areas under conventional tillage, mainly in land with steeper slopes.

No-till is one of few agricultural practices that can deliver services that benefit farmers, society, and the environment, including benefits such as reduced erosion, C sequestration, energy conservation, and decreased N loss. No-till management increases soil aggregation, reduce erosion and sedimentation, and increase soil organic matter across a range of soil types, cropping systems, and climates. In southern Brazil many fields have been under continuous no-till since farmers see agronomic and environmental benefits, particularly since long-term yields equal or exceed those in tilled soils. In some systems, even if yields were to occasionally decline, no-till can still be economical because of reduced production costs. Soil fertility and soil structure increases over time under continuous no-till, whereas cultivating no-till systems can decrease soil aggregation and accelerate C and N losses.

No-tillage was developed in the southern part of Brazil to counteract soil erosion problems and declining levels of land productivity under “conventionally” tilled systems. The no-tillage strategy was based on not tilling and keeping soil covered at all times, to reduce surface sealing and crusting, sustain a soil with a stable and open structure, and reduce soil erosion and surface runoff (Bernoux et al., 2006). These authors organized information on C accumulation in tropical (west) and subtropical (south) Brazil, for no-tillage mulch based agriculture. In the Cerrado region, carbon accumulation rates vary from 0.4 to 1.7 t C ha⁻¹ yr⁻¹ for the 0–40 cm layer, which is similar to the range found in the southern region (–0.5 to 0.9 t C ha⁻¹ yr⁻¹). These values aggregate different soil and crop

types and the variability is high. However, some studies performed in Brazil reported that organic carbon (OC) contents under no-tillage and conventional systems can be very similar. Similarly, the organized data for gas emissions which showed low NO and N₂O emissions, low nitrification rates and the majority of inorganic N to be in the form of NH₄⁺, all indicative of a conservative N cycle in the Cerrado. Also, tillage regimes will result in lower CO₂ emissions than degraded pastures, but higher N₂O and NO emissions in Amazonia and that the addition of N fertiliser stimulates N₂O and NO emissions. Lindstrom et al. (1998) reported that globally, conservation or reduced tillage can store 0.1–1.3 t C ha⁻¹ yr⁻¹ and could feasibly be adopted on up to 60 percent of arable lands.

Among the challenges to continuous no-till is the increase are the increase of exchangeable aluminum with depth and the presence of a compacted soil layer (“no-till pan”), which affects water infiltration and root growth, and have induced farmers to till again the soil, with negative impact on the environment.

Direct payments programs to encourage no-till due its benefits to society are still incipient in Brazil, but many extension programs funded by national and international organization promote the adoption of no-till as a low-cost technology to improve sustainability in agriculture.

Pressure on natural resources, especially in developing countries, has been very intense due to the considerable economic dependence on primary activity and to the chaotic urban growth. In addition to reducing the productive capacity of the soil, soil erosion causes an increase in sediment yield and the consequent silting of rivers and reservoirs. Soil erosion also contributes to the degradation of the aquatic environment due to the presence of nutrients and contaminants associated to sediments.

Sediment yield and surface flow measurements become very important for water resources management, and may serve as an indicator of catchment land use and management. However, many problems arise when studies are carried out on a basin level. In an experimental parcel, for instance, the control of interfering variables is easier since isolation and control of the variables of interest is possible. In addition, it is possible to measure the parameters of the system in question with great precision. On the other hand, erosion studies carried out on a catchment scale are more representative of natural processes; however, they are more difficult to execute due to the spatial-temporal variation of the sediment yield sources as well as to the complex interaction between the contributing catchment, the deposition areas and the alluvial channel.

Soil and water conservation programs being implemented in Brazil, supported primarily by international financial organizations, also require information on basin level sediment yield (Freitas & Ker, 1996). One of the concerns of the financing organizations is the implementation of programs to monitor the environmental and economic impact of the projects.

In general, the results of these studies are almost always very limited and inconclusive due to methodological, management and political variables. In the case of Brazil, monitoring studies on a catchment level have tried to focus mainly on sediment yield as a parameter for assessing changes in the erosive process due to the implementation of soil conservation practices.

The relation between erosion and sediment yield is not linear. This behavior can be explained by the complex interaction among the variables related to erosion, particularly the dynamics of sediment yield source contribution, the conditions involved in the transfer of these sediments to the fluvial channel, and the adjustments that occur in this channel due to hydraulic modifications and changes in sediment contribution (Minella et al., 2008).

The Brazilian Agency for Water Resources (ANA, 2008) proposed the Program for Water Quality and Quantity Improvement in Rural Catchments. It provides financial compensation for farmers, known as Water Producer Program, that ‘buys’ the benefits (products) generated by the participant (concept of ‘provider-recipient’) where the payments are proportional to erosion abatement. The parameter for erosion abatement performance consists in the ratio of soil loss in the present condition to the worse case condition (bare soil).

According to D’Agostini (1999), the objective the efforts to control erosion is to know and allow conditions which result in reduced efficiency in converting potentially erosive energy into erosive work, as a combined effect of the set of factors that may be managed. This is an instrument that allows evaluation and comparison of the degree of adequacy of soil use and management, independently of topography, soil type and rainfall regime. To contribute towards the above general concept, D’Agostini (2008) introduces the \hat{a} index of environmental performance and the SCE coefficient of sediment control effectiveness.

Critical limits of soil bulk density, considering ecological properties, such as porosity and hydraulic conductivity, or crop growth and yield, have been pursued. Nevertheless, optimal and critical limits of soil bulk density depend upon soil texture, mineralogy, particle shape, and organic matter, which affect soil structure and, thus, water, air and mechanical resistance of the soil. Soil porosity and hydraulic conductivity are ecological properties due to their narrow relation with the environment, particularly with gas exchange with the atmosphere (Horn et al., 1995) and surface run off and erosion (Hamza & Anderson, 2005).

The knowledge of the critical values would help decisions about soil management and, consequently, improvements in soil quality for crop growth and yield. An increase in the bulk density is not necessarily detrimental to crop growth, because at certain limits this increase may contribute to soil water storage and load support ability when trafficked with machines or animal trampling. However, what are the limits of soil bulk density acceptable for adequate crop growth and yield while avoiding or minimizing soil and environmental degradation? This is one of the questions addressed in this paper.

While all kind of research is recognized as important, the most promising scientific breakthroughs for managing agricultural ecosystems in concert with ecological or environmental services derive from a systems approach to agricultural research (Robertson et al. 2004). The limitations of conventional problem-response research become readily apparent when a solution developed to solve one problem creates another problem elsewhere, as pointed out by Swinton et al. (2006). In contrast, they say that a systems approach, by exploring how ecosystem components interact, tends to better exploit synergies and predict the effects of a specific management intervention on other parts of the system. In this paper, we shall focus on work conducted mainly in rural catchment, trying to identify and credit the actors responsible for environmental services.

Objectives

The main objectives are (i) to discuss some recent research performed on surface hydrology and erosion and sedimentation in hilly rural catchment in the process of adopting conservation agriculture practices and (ii) to discuss the effect of soil pore quality and stability in relation to ecological functions and environmental services.

Methodology

1. Water and soil saving in catchments

Catchments characteristics

Data from two small rural catchments (Arvorezinha and Agudo) from southern Brazil (Figure 1) are presented in this paper. Most information has been or is being published (Merten & Minella, 2005; Minella et al., 2007, Bonumá et al., 2008; Minella et al., 2008a,b, 2009). One catchment is located in the municipality of Arvorezinha, which is in the Central-North region of the state of Rio Grande do Sul (28° 52' S and 52° 05' W). The drainage area spans 1.19 km² and is composed by small rural properties involved with tobacco production. Annual rainfall varies from 1250 to 2000 mm; with September and October being the months of greatest rainfall erosivity. In its upper parts, the topography is gently rolling, with an average slope of 7%. In the middle and lower parts of the catchment, the topography is deeply dissected, with shorter steeper slopes, steep sided valleys, high declivity and shallow soils. Local geology is characterized by continental flood basalts; and soils are shallow.



Figure 1. Location of Agudo and Arvorezinha catchments

The other catchment is located in Agudo, which is in the Central region of the state of Rio Grande do Sul (29° 38' S and 53 ° 21' W), with a drainage area that spans 3.32 km². Average annual rainfall is 1500 mm, landscape is hilly, with average slope of 12% and altitude varying from 120 to 480 m, and shallow soils. Small rural properties produce mainly tobacco.

In both catchments, natural resources from the region suffered considerable pressure from agricultural practices. The region also presented intense diffuse pollution (nutrients, agrochemicals and sediments) and soil degradation due to water erosion. Land management, which was initially based on a complete soil revolving technique, was altered to an approach that favored conservation agriculture. The objective was to improve the productive capacity of the soil and to reduce erosion and sediment yield. Monitoring of hydrosedimentometric variables was used to demonstrate the effects of changes in land use and management over a period of time.

Hydrosedimentologic Monitoring Approach

The monitoring of events included the assessment of precipitation, discharge, and suspended sediment concentration. Also, chemical analyses were performed on collected samples of suspended sediments (Minella et al., 2007, 2008b). Peak flow, surface runoff volume, and maximum and mean suspended sediment concentrations were determined for each event based on the hydrographs and sedimentographs. Sediment discharge was estimated by multiplying instantaneous flow monitored during the rain events and the suspended sediment concentration measured on the collected samples. The estimate of the sediment yield for each event was calculated by integration of the sediment discharge curve in the period of the event (Bonumá et al., 2008, Minella et al., 2008b). The precipitation variables assessed for each event were: (i) total rainfall volume, P_{total} (mm) and (ii) a rainfall index that accounted for the effect of precipitation during the two previous days (Minella et al., 2008b).

For the Arvorezinha catchment, the monitoring period was divided into two distinct sub-periods based on land management practices (traditional management and improved management), in order to obtain a statistical analysis capable of evaluating the hydrosedimentometric differences due to changes in land use and management. The analysis consisted of the comparison of the set of events that occurred in the period of conventional management (without soil conservation practices) with the set of events after the implementation of improved land management (Minella et al., 2008b).

Traditional management is characterized by soil revolving using plow and harrow in the whole cultivation area, with little crop residue remaining on the soil surface. Improved management is characterized by minimum till cultivation presenting crop residue on the surface and plowing only on the cultivation line. The monitoring period lasted from April 2002 to March 2006, which corresponds to four cycles of tobacco production. During this period, 50 storm events of intermediate and high magnitude were monitored. Due to the short period of the study, which was determined by the government program for evaluating land management techniques, the methodology was based on a comparison of the characteristics of the storm events in each period.

Three periods were considered (Minella et al., 2009): (i) Pre-treatment: storm events that occurred between April 2002 and October 2003 (19 events) comprised the period of traditional cultivation without improved land management practices. (ii) Post-treatment period: characterized by improved cultivation, consisted of storm events that occurred during and after October 2003 (31 events). (iii) Transition period: six events that happened between October 2003 and February 2004.

Fingerprinting Approach

In both catchments, the contribution of the main sediment sources to the samples collected during the events was determined. Procedures for sample collection, chemical and statistical analyses followed the sediment source tracing methodology known as *fingerprinting approach* (Walling, 2005). Statistical analyses consisted of two steps: (i) discrimination of potential sources using the Kruskal-Wallis test and the Wilks' Lambda minimization, and (ii) classification of the suspended sediment samples using a multivariate mixing model (Walling & Collins, 2000).

For each event, the relative (%) and absolute contributions (t) from the three main sediment sources, namely crop fields, unpaved roads and stream channels, were calculated (Minella et al., 2007, 2008b).

Energy Approach

In the Agudo catchment, ten significant rainfall-runoff events with different soil use and management, during 2004 and 2005, were chosen (Bonumá et al., 2008). In order to evaluate and compare the effectiveness of soil

management and, thus, performance of the actors (farmers) in controlling soil erosion, the methodology proposed by D'Agostini (1999) was used in which the rate of erosion is equal to the product of energy conversion to erosive work times the rate of energy change:

$$\frac{dWs}{dt} = \beta \frac{dE}{dt} .$$

where Ws = erosive work; β = coefficient of efficiency in converting energy potentially erosive into erosive work; E = energy.

In order to evaluate the environmental performance in controlling sediment production, D'Agostini (2008) proposed a coefficient of sediment control effectiveness (SCE):

$$SCE = (1 - \beta^{1/v})^v .$$

The lower the value of \hat{a} the more efficient is the set of management procedures in controlling soil erosion. A SCE equal to 1 represents maximum effectiveness in sediment control.

2. Critical Compaction Affecting Ecological Properties and Crop Development

Data from the literature and a database belonging to the authors were used to establish statistical relationships between critical and reference bulk density with clay or clay plus silt content, and between degree of compactness and macroporosity, hydraulic conductivity and yield of crops under predominantly no-tillage in subtropical Brazil, mainly in the southernmost state Rio Grande do Sul.

The degree of compactness (DC) relates the bulk density in the field (BD) to the BD reached through a soil compaction test in the laboratory (BD_{ref}). The BD was estimated by three strategies. One of them was to define the BD from the least limiting water range ($LLWR$) concept (Silva et al., 1994). Data of critical bulk density that restricts root growth or reduces crop yield are herein called BDC_{Rest} . The BDC_{Rest} was defined by a reduction in root growth or in crop yield (data from five authors). For root growth, several parameters have been used such as root density (root mass/volume of soil) (data from two authors), root dry mass and root surface (data from one authors), restriction to tap root growth (data from three authors). All these studies were conducted under field conditions, whereas preserved soil samples were used to determine soil bulk density values, and are cited in Reichert et al. (2008). Equations developed by Jones (1983) were also included, where he defined soil bulk density as critical when roots had their growth reduced by 20% compared to maximum growth at field capacity, for soils with a wide range in percentage clay and silt. The critical bulk density which restricts root growth (BDC_{Jones}) can be estimated by the following equations: $BDC=1.77-0.00063(\text{clay})$ and $BDC=1.83-0.00043(\text{clay} + \text{silt})$. These equations, although developed for temperate soils and controlled conditions, were included as a reference because no such quantitative relations was yet available for tropical soils under field conditions, until the work of Reichert et al. (2008).

Results and discussion

1. Water and Soil Saving in Catchments

Hidrosedimentologic Monitoring Approach: Intensity-duration of Events

The evolution of land use and management in the monitoring period is shown in Table 1. During the first monitoring year, which was the wettest one, land management was essentially traditional – in other words, without soil conservation. The second monitoring period saw the start of the implementation of improved practices by the RS-Rural program. From 2003 to 2005, the proportion of crop field areas with soil conservation fluctuated around 20% of the total catchment area; subsequently, in the last period this value doubled to 43.2%. Thus, the effect of the implementation of improved practices was partial. Although there was a gradual increase of the catchment areas with soil conservation, the total area of crop fields in the catchment also increased during the study period.

The results of the analysis of the hydrosedimentological variables under traditional management were compared to the results of improved land management, taking into consideration representative events of both periods (Minella

Table 1. Percentage of different land use and management practices in relation to total catchment area of Arvorezinha, from April 2002 to March 2006 (Minella et al., 2009)

Periods (April-March)	Forest, pasture and fallow (%)	Crop fields without soil conservation (%)	Crop fields with soil conservation (%)
2002-2003	55,9	44,1	0
2003-2004	49,3	29,7	21,0
2004-2005	38,6	42,3	19,1
2005-2006	36,0	20,8	43,2

et al., 2009). The analysis determined the relation between discharge and precipitation and between the responses of both in relation to the sediments before the implementation of improved land management, and also assessed the changes in these relations after the implementation of improved land management. The analyses focused on a group of: (i) 19 events monitored before October 2003 that are representative of the period before the implementation of management (pre-treatment), and (ii) 31 events associated with the period following the implantation of improved management (post-treatment). Six of the latter events (October 2003 and February 2004) were in the transition phase of the implementation of minimum-till cultivation.

An analysis by Minella et al. (2008b) of the same events for the two periods of management demonstrates that the surface runoff volume of rainfall events of low and intermediate magnitudes decreased approximately 60%, while higher magnitude events decreased approximately 20% after the implementation of minimum-till cultivation (Figure 2A). Considering only peak flow, the influence of improved management was significant only for rain events of low and intermediate magnitudes, with a reduction of 50% and 30%, respectively (Figure 2B). Sedimentological analysis verified that the sediment yield decreased for events of low and intermediate magnitudes (80% and 40%, respectively), and that there was no statistically significant difference for events of high magnitude between the two periods (Figure 2C). The horizontal bar indicates the range of the precipitation index for the periods in which differences were significant (>95%).

The effect of improved land management is less pronounced for high magnitude rain events due to the absence of mechanical practices for surface runoff control. The soil conservation program was limited to the implementation of minimum-till cultivation, without the promotion of other important practices such as terraces, vegetative cover and contour strip cropping, among others. This result confirms the fact that a water and soil conservation program must include specific measures which address not only soil protection, but also surface runoff control. Clearly, minimum-till cultivation increases soil protection from the impact of the falling raindrop in addition to promoting a gradual improvement of the physical structure of the soil, but it is not an effective means for reducing surface runoff during rain events of high volume and intensity.

Changes in land management did not alter the pattern of maximum sediment concentration (Figure 2D), indicating that sediment yield reduction is more dependent on the decrease in runoff volume more on the reduction of the suspended sediment concentration.

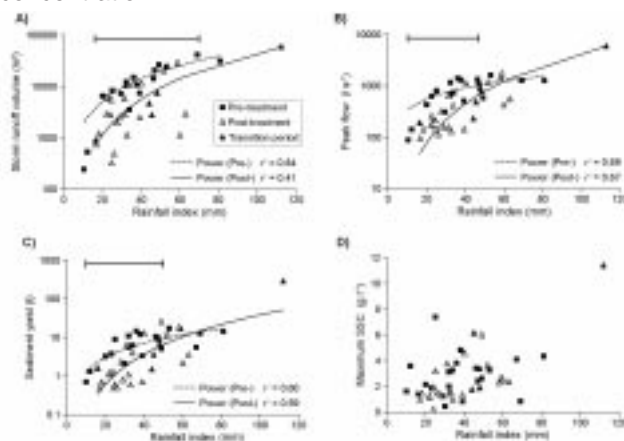


Figure 2. Comparison of peak flow, surface runoff volume, suspended sediment yield and maximum suspended sediment concentration in relation to the precipitation index for pre and post-treatment periods, in Arvorezinha (modified from Minella et al., 2008).

Fingerprinting Approach: Changes of Contribution from the Sediment Sources

Identification of the relative contributions from the main sediment sources (crop fields, unpaved roads and stream channels) in the monitoring period was performed by Minella et al. (2007, 2008b). For events between June 2003 a July de 2004 in both catchments (Minella et al., 2007), the contribution from the sediment sources was similar, with crop fields being the predominant source, followed by unpaved roads and stream channels (Table 2). However, the magnitude of each source and variability among periods were different. Agudo had more sediment from crop fields, possibly due higher slopes and, thus, greater ability to sediment transfer to channels and absence of riparian vegetation. For Arvorezinha, improper road allocation and their length favor unpaved roads as main sediment source. There was also a seasonal effect.

Table 2. Contribution of the three sediment sources to the sediment yield from the Arvorezinha and Agudo catchments, from June 2003 to July 2004 (Minella et al., 2007)

Period	Agudo			Arvorezinha		
	Crop fields %	Unpaved roads %	Stream channels	Crop fields	Unpaved roads	Stream channels
Jun-Oct	68	29	3	57	31	12
Nov-Feb	60	36	4	52	40	8
Mar-Jun	78	19	3	58	41	1
Average	68	28	4	55	38	7

The improvement of land management practices in the Arvorezinha catchment resulted in a significant change of the relative importance of the three sediment sources (Table 3). A comparison of the load-weighted means of the pre- and post-treatment periods (excluding the extreme event of October 25, 2003) indicates that the contribution of crop fields and unpaved roads reduced from 62% and 36% to 54% and 24%, respectively, while the contribution of the channels increased from 2% to 22%. The greatest difference between pre and post-treatment periods was found in the contribution of the stream channel sources.

Table 3. Contribution of the three sediment sources to the sediment yield from the Arvorezinha catchment, from April 2002 to March 2006 (Minella et al., 2008b)

Sediment source	Relative Contribution (%) ^a		
	Pre-treatment	Post-treatment	Post-treatment ^b
Crop fields	62	72	54
Unpaved roads	36	13	24
Stream channels	2	15	22

^a Load-weighted mean (Walling & Collins, 2000)

^b Load-weighted mean excluding the extreme event that occurred on October 25, 2003.

Some sources of uncertainty in the analysis of the catchment response are related to the effects of the October 25, 2003 event. Heavy rain and runoff volume, associated to recently plowed soil with little vegetation cover, resulted in significant erosion of the crop fields, which in turn led to an elevated sediment yield. The relative contribution of sources for this event, based on sediment source tracing, was 12% from stream channels, 8% from unpaved roads and 80% from crop fields.

Energy Approach: Recognition to Actors in Erosion Control

The coefficient of efficiency in converting energy potentially erosive into erosive work (β) varied from 0.002 to 1.533, whereas the coefficient of sediment control effectiveness (*SCE*) varied from 0.022 to 0.998 (Bonumá et al., 2008). For 2004, the mean accumulate β_m was 0.051, and 0.421 for 2005, due to differences in soil use and management. There was an increase in crop field and reduction in native vegetation, along with an increase in soil mobilization, from 16% to 31% of crop fields.

When comparing two sub-catchments of similar size in the Agudo catchment, the value was 0.01 and 0.002 whereas *SCE* was 0.990 and 0.998, respectively for sub-catchments A and B. Thus, the soil use and management

in sub-catchment B was more effective in controlling soil erosion. Also, the potential energy to produz erosion is higher in sub-catchment A, with steeper slopes, thus indicating that erosion control is more difficult.

Integrated Approach: The Impact of Changes in Land Management on Sediment Mobilization

Sediment mobilization from stream channels during the events increased substantially after the introduction of improved management practices and after mobilization from crop fields decreased (Minella et al., 2009).

Even though the peak flow decreased in the period with soil conservation, an increase in sediment mobilization from channel sources is clearly higher during the post-treatment period. The increase in sediment mobilized from the “stream channel” source in the soil conservation period suggests that, along with the reduction of erosion in crop fields, less sediment transfer to the stream channels occurs. Thus, the reduction in the supply of sediment to the channel, due to soil conservation practices, liberates the runoff energy for channel degradation processes (Merten et al., 2001). The deepening of the channel associated with incision may result in increased instability of the channel banks and, consequently, increased bank erosion. This could explain the increased sediment mobilization in the post-treatment period during high magnitude events, when the channel incision and bank collapse tend to be more effective.

The sediment load originating from unpaved roads also decreased. The implementation of minimum-till cultivation reduced the quantity of surface runoff coming from crop fields onto the roads, except for high magnitude events.

The introduction of minimum-till cultivation practices resulted in the reduction of sediment yield for low and intermediate magnitude events. For high magnitude events, sediment yield reduction was limited, possibly due to the absence of mechanical methods for surface runoff control (terraces, infiltration basin, crop strips, etc), which are essential in an erosion control program (decreasing the velocity and increasing surface runoff retention) in catchments (Morgan, 2005). The inclusion of suspended sediment source tracing techniques (Minella et al., 2007, 2008b) provided additional information about the changes in response of the sediment emission process “inside” the catchment, demonstrating that the “net difference” of the reduction documented by traditional monitoring encompasses a more complex series of changes.

Implications for Catchment Planning

A catchment is a complex structure, being an open system composed of interdependent processes and connected subsystems (Owens, 2005). The decrease in sediment mobilization from the crop field sources promoted an increase of sediment mobilization from stream channels and a reduction of sediment mobilization from roads. The physical mechanism possibly responsible for this process was the reduction of the sediment load contributed by crop fields to the stream channels, determining that the channel runoff leads to more erosion. Surface runoff reduction in crop fields led to a decrease in sediment transfer from the source basin to drainage. Likewise, the surface runoff reduction of roads diminished sediment mobilization and transport from roads to channels. In fact, during the field visits and surveying of monitoring sections, bank erosion and a deepening of the channels in the middle and inferior parts of the drainage network were observed (Minella et al., 2009).

This characteristic in the catchment response change emphasizes that any effort to reduce erosion and sediment yield which are due to improved land management in other catchments needs to consider the potential increase of sediment mobilization in the channels. In this context, the conservation of riparian vegetation is highly effective for water quality improvement, reducing of bank erosion, and increasing retention of sediment and pollutants from the springs (Johnson, 2003). Implementation of measures for the conservation of soil and riparian areas is simple and causes no damages to agricultural productivity. Hence, the concept of “integrated catchment management” needs to be in effect incorporated by soil and water conservation programs to allow for a reduction of negative impacts on water resources (Minella et al., 2009).

2. Critical Compaction Affecting Ecological Properties and Crop Development

The critical bulk density (Figure 3), when considering the least limiting water range, is actually lower than the critical values which restrict crop growth. Restrictions to root growth do not necessarily translate into reduced crop growth or yield, and root system of crops may have varying tolerance to soil compaction. Roots with reduced length may still provide proper supply of water and nutrients. Silva et al. (2004) demonstrated experimentally that values of air-filled porosity and of mechanical penetration resistance regarded to be critical did not stop corn growth; the crop

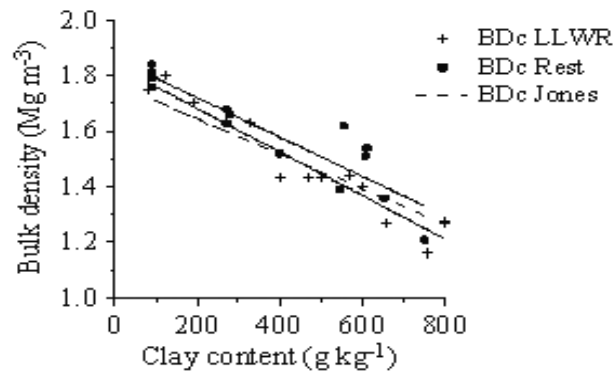


Figure 3. Critical bulk density considering the least limiting water range (BDc LLWR), restriction to root elongation or yield decrease (BDc Rest) and considering the equation of Jones (1983) (BDc Jones), as functions of clay (a) and clay plus silt content (b) (from Reichert et al., 2008).

continued to grow but at a lower rate. Therefore, the limits must be adjusted to slightly higher values for no-tillage soil.

If the pore diameter reduced by compaction, water and gas fluxes are decreased (Horn, 2003). Under saturated conditions the water flow mainly occurs in the macropores. Changes in soil hydraulic and aeration properties and in the configuration of the root system caused by soil compaction may reduce the nutrient uptake by the plants, and this may affect the environment. For example, N losses to the ground water and to the atmosphere may be greater in compacted than in uncompacted soil (Lipiec & Stepniewski, 1995). Destruction of inter- and intra-aggregate pores results in reduced aeration and water infiltration, increased soil strength of the compacted soil, worsening of pore functions and reduced root development. This may induce a more pronounced horizontal flux of water, which may cause soil erosion (Horn et al., 1995).

There are many complications when comparing the sensitivity of different crops to compaction, particularly when comparing crops with different growing seasons (Håkansson, 2005). Then the difference between crops may be caused by differences in climatic conditions between the seasons causing differences for instance in crop establishment or in risk of poor soil aeration rather than by differences in sensitivity to compaction as such. Soybean and black beans were grown here as summer crops and wheat as a winter crop.

The greatest crop yield is usually reached with a DC-value between 80 and 90% (Figure 4), as also demonstrated for temperate soils (Håkansson, 1990). However, the exact value depends on the method used to determine BD_{ref} . A low degree of compactness reduces the root-to-soil contact, whereas a high degree of compactness reduces soil aeration and increases penetration resistance with a negative effect on root growth and development. Thus, crop growth is negatively affected by soil compaction, but the highest yields are not obtained in a very loose soil.

The degree of compactness restricting macroporosity to $0.10 \text{ m}^3 \text{ m}^{-3}$ is usually lower than the degree of compactness restricting plant growth. While this topic needs further study, it is evident that under no-tillage a network of biopores and other continuous and stable macropores allows proper crop growth and yield, as demonstrated by the equations estimating critical bulk density as functions of least limiting water range and restrictions to root growth. No-tillage soil with high penetration resistance may still have greater corn yield than conventional tillage, when biopores are present in the former. As stated by Shaxson (2005), a different perspective should be considered in conservation of carbon, soil and water, considering the soil a life (rather than dead) porous system.

Our data show that ecological properties, such as aeration estimated from macroporosity or hydraulic conductivity, are primarily affected by soil compaction and these in turn affect plant development. This leads to conclude that when plant growth is affected, many ecological properties are also negatively affected.

The BDc values indicate conditions critical or restrictive to crop growth or development. The BD_{ref} -values, on the other hand, may be considered just as bulk density values seldom exceeded in the field soils, but they make it possible to establish critical DC-values both for crop growth and for soil quality, and these values are not necessarily the same. Most soil properties and processes are likely to be more closely related to the degree of compactness than to bulk density.

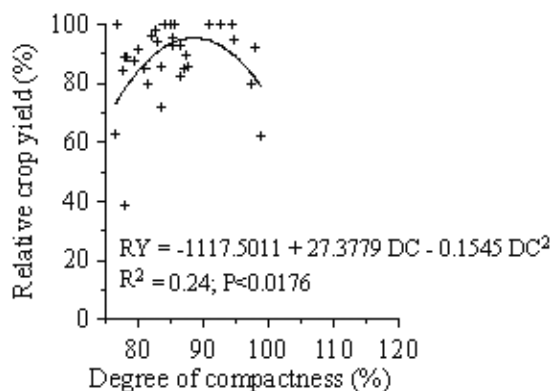


Figure 4. Relative yield (RY) of soybean as a function of degree of compactness (DC) calculated on the basis of BD_{ref} 1600 kPa undist (f), for soils from southern Brazil (from Reichert et al., 2008).

Although BDC and BD_{ref} are quantified independently, and the first considers the crop as indicator while the second the soil as indicator, these two values are interrelated. If a soil reaches BDC and this is adequately estimated, the corresponding DC -value should also be critical to plant growth. The advantage of using the degree of compactness is that different soils may be compared, while the use of BDC may make a comparison among soils erroneous.

Under long-term no-tillage, the whole previous ploughpan layer remains compacted, although the pore functioning is improved if the no-till is linked to low load input by confining the machinery traffic (Reichert et al., 2003). Typically, a layer from about 7 to 15-20 cm has high bulk density, low porosity, and high mechanical resistance, which could be referred to as a 'no-till pan'. The aforementioned layer underlies an upper layer (from 0 to about 7 cm) of reduced compaction due to rearrangement of soil particles and aggregates by various processes, such as biological processes, which are most intense near the surface mulch layer (Reichert et al., 2003), and action of coulters and shanks of no-till seeders and planters coulters.

Under no-tillage, a more stable and porous structure can be formed and newly formed pores and rearrangement of soil particles preserved if operations are carried out with light machines (machines with low ground pressure), preserving the newly formed pores and rearrangement of soil particles (Horn, 2004). Finer intraaggregate pores are formed as a result of shrinkage and rearrangement of particles, and biopores with greater strength against compression are formed by biological activity. Such pores are necessary to sustain proper pore functioning and soil mechanical properties in maintaining the long-term no-tillage.

Conclusions

Conservation agriculture practices contribute to reducing maximum flow, total runoff volume, total sediment yield, and, especially with respect to changes in relative sediment yield for each source as minimum cultivation increased. The soil conservation practices reached the goal of reducing erosion in crop fields. However, the implementation project only partially achieved the objective of reducing erosion in the catchment. The change in land management altered the hydrosedimentological regime of the catchment and created a new problem - the increase in sediment yield from the stream channels due to the lack of mechanical practices of soil conservation and preservation of riparian areas.

In the conservation of carbon, soil and water, a perspective of soil a life (rather than dead) porous system must be considered, to change from a strictly physical approach to a biological approach in catchment planning and use.

Soil ecological properties, like aeration estimated from macroporosity and hydraulic conductivity, are affected before deformation of soil structure restricts plant growth and yield. This shows the importance of a stable and open pore system to proper functioning of the catchment system.

References

ANA. Agência Nacional de Águas, 2008. O Programa do Produtor de Água. <<http://www.ana.gov.br/gestaoRecHidricos/ConservacaoAguaSolo/default2.asp>>. Access: 2 October 2008.

- Bernoux, M., Cerri, C.C., Cerri, C.E.P., Siqueira Neto, M., Metay, A., Perrin, A., Scopel, E., Raazfimbelo, T., Blavet, D., Piccolo, M. de C., Pavei, M., Milne, E. 2006. Cropping systems, carbon sequestration and erosion in Brazil, a review. *Agron. Sustain. Dev.* 26:1–8.
- Bonumá, N.B., Minella, J.P.G., Reichert, J.M., D'Agostini, L.R. 2008. Avaliação do manejo do solo no controle da erosão em uma bacia hidrográfica rural no sul do Brasil. In: *Anais VIII Encontro Nacional de Engenharia de Sedimentos (ENES)*, Campo Grande, Brazil.
- D'Agostini, L.R., 1999. Erosão: o problema mais que o processo. Ed. UFSC. Florianópolis.
- D'Agostini, L.R., 2008. Coeficiente controle da produção de sedimentos e o Programa 'Produtor de Água' (manuscript).
- Dale, V.H., Polasky, S. 2007. Measures of the effects of agricultural practices on ecosystem services. *Ecol. Econ.*: 64, 286–296.
- Freitas, P.I., Ker, J.C., 1996. Watershed research: actual situation, difficulties and perspectives to Brazil. In: Castro Filho, C., Muzzili, O. (Editors), *Integrated soil and water management in watersheds*, Brazilian Soil Society, Paraná, Brazil, pp. 43-57 (in Portuguese)
- Håkansson, I., 1990. A method for characterizing the state of compactness of the plough layer. *Soil Tillage Res.* 16, 105-120.
- Hamza, M.A., Anderson, W.K. 2005. Soil compaction in cropping systems. A review of the nature, causes and possible solutions. *Soil Tillage Res.*, 82, 121-145.
- Horn, R., 2003. Stress-strain effects in structured unsaturated soils on coupled mechanical and hydraulic processes. *Geoderma*, 116:77-88.
- Horn, R., 2004. Time dependence of soil mechanical properties and pore functions for arable soils. *Soil Sci. Soc. Am. J.* 68, 1131-1137.
- Horn, R., Domzal, H., Slowińska-Jurkiewicz, A., van Ouwerkerk, C., 1995. Soil compaction processes and their effects on the structure of arable soils and the environment. *Soil Tillage Res.*, 35:23-36.
- Horn, R., Vossbrink, J., Becker, S., 2004. Modern forestry vehicles and their impacts on soil physical properties. *Soil Till. Res.* 79, 207-219.
- Johnson, C., 2003. Low-cost methods for slowing stream bank erosion. *J. Soil Water Cons.*, 58(1): 12-21.
- Jones, C.A., 1983. Effect of soil texture on critical bulk densities for root growth. *Soil Sci. Soc. Am. J.* 47, 1208-1211.
- Machado, P.L.O. de A. 2005. Carbono do solo e a mitigação da mudança climática global. *Quim. Nova*, Vol. 28, No. 2, 329-334.
- Merten, G.H., Minella, J.P.G., 2005. Impact on sediment yield caused by intensification of tobacco production in a catchment in southern Brazil. In: Walling, D.E., Horowitz, A.J. (Editors), *Sediment Budgets 2*, IAHS Publ. 291, IAHS Press, Wallingford, UK, pp. 239-244.
- Merten, G.H., Nearing, M.A., Borges, A.L.O., 2001 Effect of sediment load on soil detachment and deposition in rills. *Soil Sci. Soc. Am. J.*, 65:861-868.
- Minella, J.G.M., Merten, G.H., Walling, D.E., Reichert, J.M., 2009. Changing sediment yield as an indicator of improved soil management practices in southern Brazil. *Catena* (accepted).
- Minella, J.P.G., Merten, G.H., Clarke, R.T. Reichert, J.M., 2008a. Estimating suspended sediment concentrations from turbidity measurements and the calibration problem. *Hydrol. Proc.*, 22: 1819-1930.
- Minella, J.P.G., Merten, G.H., Clarke, R.T., Reichert, J.M., Santos, D.R., 2007. Identificação e implicações para a conservação do solo das fontes de sedimentos em bacias hidrográficas. *R. Bras. Ci. Solo* 31: 1637-1646.
- Minella, J.P.G., Walling, D.E., Merten, G.H., 2008b. Combining traditional monitoring and sediment source tracing techniques to assess the impact of improved land management on catchment sediment yields. *J. Hydrol.* 348: 546 – 563.
- Morgan, R.P.C. 2005 *Soil erosion and conservation*. Blackwell Publishing, Oxford.
- Owens, P.N., 2005. Conceptual models and budgets for sediment management at the river scale. *J. Soils Sed.*, 5(4): 201-212.
- Reichert, J.M., Suzuki, L.E.A.S, Reinert, D.J., Horn, R., Håkansson, I. 2008. Reference bulk density and critical degree-of-compactness for no-till crop production in subtropical highly weathered soils. *Soil Tillage Res.* www.elsevier.com/locate/still.
- Reichert, J.M., Reinert, D.J., Braida, J.A., 2003. Soil quality and sustainability of agrossystems. *Ci. Ambiente* 27, 29-48. (in Portuguese with English abstract).
- Shaxson, T.F. 2006. Re-thinking the conservation of carbon, water and soil: a different perspective. *Agron. Sustain. Dev.*: 26:9–19.
- Silva, A.P., Imhoff, S., Kay, B.D., 2004. Plant response to mechanical resistance and air-filled porosity of soils under conventional and no-tillage system. *Sci. Agric.* 61, 451-456, 2004.
- Silva, A.P., Kay, B.D., Perfect, E., 1994. Characterization of the least limiting water range of soils. *Soil. Sci. Soc. Am. J.* 58, 1775-1781.
- Swinto, S.C., Lupi, F., Robertson, G.P., Landis, D.A. 2006. Ecosystem services from agriculture: Looking beyond the usual suspects. *Amer. J. Agr. Econ.* 88:1160–1166.
- Walling, D.E, Collins, A.L., 2000. *Integrated assessment of catchment sediment budgets: a technical manual*. University of Exeter, United Kingdom.
- Walling, D.E., 2005. Tracing suspended sediment sources in catchments and river systems. *Sci. Tot. Env.*, 344: 159-184.

Role of Carbon in Ecosystem Services from Conservation Agriculture

D.C. Reicosky*

*USDA-Agricultural Research Service, North Central Soil Conservation Research Lab,
803 Iowa Ave. Morris, MN 56267 USA (*E-mail: don.reicosky@ars.usda.gov)*

The world's farmers must broaden their perspective and shift conservation concepts and programs to get away from managing for only yield and erosion control and move to managing soil carbon (C) for crop production sustainability and maintaining environmental quality. This work reviews research on new technology, tillage-induced carbon losses and environmental benefits of soil carbon to highlight the role of the agronomist and the farmer who play a major role in optimizing the canopy conditions to maximize solar energy and carbon capture by photosynthesis and a major management role in nutrient cycling for optimum crop production and minimum environmental impact. With conservation tillage, crop residues are left more naturally on the surface to protect the soil and control the conversion of plant C to SOM (soil organic matter) and humus. Intensive tillage releases soil C to the atmosphere as CO₂ where it combines with other gases to contribute to the greenhouse effect. The combination of reducing the volume of soil disturbed by intensive tillage and using direct seeding techniques should enhance soil and air quality by increasing soil C content. Management emphasis on diverse rotations must be combined with maximum biomass and yield production and the use of cover crops to maximize the carbon input into the soil system. The smaller CO₂ loss following conservation tillage tools is significant and suggests progress in developing conservation tillage tools that can enhance soil C management. Conservation tillage reduces the extent, frequency and magnitude of mechanical disturbance caused by the moldboard plow and reduces the air-filled macropores and slows the rate of carbon oxidation. Any effort to decrease tillage intensity and maximize residue return should result in C sequestration for enhanced environmental quality. The soil is the fundamental foundation of our economy and our existence. While soil erosion continues to be a major problem, we must expand our thinking to address related soil quality issues, which translates to soil C. Carbon management to reduce our carbon footprint is required to address a complex list of issues including soil, water, air quality, biofuels, and climate change. Thus to maintain sustainability of the soil resource, we must think about soil C management and make efforts to maximize soil C input and minimize C loss. Today, we must place emphasis on conservation of all natural resources and additional emphasis on C as a key component in maintaining ecosystem stability and environmental quality.

Key words: soil organic matter, soil quality, environmental quality, conservation tillage, zero tillage, direct seeding, carbon sequestration

Conservation agriculture aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. Conservation agriculture contributes to global environmental conservation as well as to enhanced and sustained agricultural production and can play a central role in global agricultural policy. Food security and sustainability are important for all citizens. Agriculture, the major industry for food and fiber production, is known to cause emission and storage of greenhouse gases. Intensification of agricultural production has been an important factor influencing greenhouse gas emission. Agricultural activities contribute to carbon dioxide (CO₂) emissions to the atmosphere through the combustion of fossil fuel, soil organic matter (SOM) decomposition, and biomass burning. Improved conservation agricultural practices have great potential to increase soil carbon (C) sequestration and decrease net emissions of CO₂ and other greenhouse gases that contribute to global environmental security.

World soils are an important pool of active C and play a major role in the global C cycle and have contributed to changes in the concentration of greenhouse gases in the atmosphere. Agriculture is believed to cause some environmental problems, especially related to water contamination, soil erosion, and greenhouse effect (Houghton, Hackler & Lawrence, 1999; Schlesinger 1985; Davidson & Ackerman, 1993). The soil contains two to three times as much C as the atmosphere. In the last 120 years, intensive agriculture has caused a C loss between 30 and 50 %. By minimizing the increase in ambient CO₂ concentration through soil C management, we minimize the production of greenhouse gases and minimize potential for climate change. Recent results suggest scientific agriculture can also lessen environmental problems and mitigate the greenhouse effect. In fact, agricultural practices have the potential to store more C in the soil than farming emits through land use change and fossil fuel combustion (Lal et al., 1998).

Soil quality is the fundamental foundation of environmental quality. Soil quality is largely governed by SOM content, which is dynamic and responds effectively to changes in soil management, primarily tillage and C input. This review will primarily address soil C and its associated environmental benefits. Other recent reviews on the role of C sequestration in conservation agriculture were presented by Robert (2001), Uri (1999), Tebrugge & Guring (1999), Lal et al. (1998) and Lal (2000). Agriculture has an opportunity to offset some CO₂ emissions and will be a small, but significant player in sequestering C.

Key Role of Soil Organic Matter

Soil organic C represents a key indicator for soil quality, both for agricultural functions (production and economy) and for environmental functions (C sequestration and air quality). Soil organic matter is the main determinant of biological activity because it is the primary energy source. The amount, diversity and activity of soil fauna and microorganisms are directly related to SOM content and quality. Organic matter and the biological activity that it generates, have a major influence on the physical and chemical properties of the soils. Soil aggregation and stability of soil structure increases with increasing organic C. These factors in turn increase the infiltration rate and available water holding capacity of the soil as well as resistance against erosion by wind and water. Soil organic matter also improves the dynamics and bio-availability of main plant nutrient elements.

Soils contain relatively small amounts of C that could be considered analogous to a catalyst for biological activity where a small amount has a big impact. Farmers are the primary soil managers who each have a tremendous responsibility to maintain SOM for environmental benefit of the global population. Thus, farmers who use conservation agriculture or direct seeding techniques are providing ecosystem services and helping to maintain environmental quality for all of society. Quality food production and economic and environmentally-friendly management practices that are socially acceptable will lead to sustainable production and be mutually beneficial to farmers and all of society. It is important, therefore, that C loss from the soil system through historical land use of farming practices be restored to its natural potential using direct seeding and conservation tillage methods for sustainable production.

Sources and Sinks in Agricultural Systems

Agricultural systems contribute to C emissions through several mechanisms including direct use of fossil fuels in farm operations, indirect use of energy inputs for manufacturing chemicals (typically fertilizers), irrigation and grain drying and through intensive tillage of soils resulting in the loss of SOM. With conservation agriculture techniques, soils can accumulate C to offset other C losses. Thus, the soil can be converted from a “source” of C to a “sink” for C with improved soil and crop management.

Preliminary assessments indicate that soil C sequestration can be a tool to offset C emissions from burning fossil fuels. We in agriculture play a significant role because of the large amount of soil C in the C cycle within agricultural production systems. The limited use of crop rotations combined with intensive tillage decreases soil quality and soil organic matter. Any operation that removes or incorporates crop residue contributes to the decline of soil C through increased biological oxidation. The drive to maximize profit in food and fiber production has created environmental problems that have slowly crept up on conventional agriculture and now requires new knowledge, research and innovation to overcome these concerns.

A Case for Conservation Agriculture and Zero Tillage

Tillage or soil preparation has been an integral part of traditional agricultural production. Tillage is also a principle agent resulting in soil perturbation and subsequent modification of the soil structure with soil degradation. Intensive tillage loosens soil, enhances the release of soil nutrients for crop growth, kills the weeds that compete with crop plants for water and nutrients and modifies the circulation of water and air within the soil. Intensive tillage can adversely affect soil structure and cause excessive break down of aggregates leading to potential soil movement via erosion. Intensive tillage causes soil degradation through C loss and tillage-induced greenhouse gas emissions that impact productive capacity and environmental quality.

Recent studies involving a dynamic chamber, various tillage methods and associated incorporation of residue in the field indicated major C losses immediately following intensive tillage (Reicosky & Lindstrom, 1993, 1995). The moldboard plow had the roughest soil surface, the highest initial CO₂ flux and maintained the highest flux throughout the 19-day study. High initial CO₂ fluxes were more closely related to the depth of soil disturbance that resulted in a rougher surface and larger voids than to residue incorporation. Lower CO₂ fluxes were caused by tillage associated with low soil disturbance and small voids with no-till having the least amount of CO₂ loss during 19 days. The large gaseous losses of soil C following moldboard plowing compared to relatively small losses with direct seeding (no-till) have shown why crop production systems using moldboard plowing have decreased SOM and why no-till or direct seeding crop production systems are stopping or reversing that trend. The short-term cumulative CO₂ loss was related to the soil volume disturbed by the tillage tools. This concept was explored when Reicosky (1998) determined the impact of strip tillage methods on CO₂ loss after five different strip tillage tools and

no-till. The highest CO₂ fluxes were from the moldboard plow and subsoil shank tillage. Fluxes from both slowly declined as the soil dried. The least CO₂ flux was measured from the no-till treatment. The other forms of strip tillage were intermediate with only a small amount of CO₂ detected immediately after the tillage operation. These results suggested that the CO₂ fluxes appeared to be directly and linearly related to the volume of soil disturbed. Intensive tillage fractured a larger depth and volume of soil and increased aggregate surface area available for gas exchange that contributed to the vertical gas flux. The narrower and shallower soil disturbance caused less CO₂ loss suggests that the volume of soil disturbed must be minimized to reduce C loss and impact on soil and air quality. The results suggest environmental benefits and C storage of strip tillage over broad area tillage that needs to be considered in soil management decisions.

Reicosky (1997) reported that average short-term C loss from four conservation tillage tools was 31 % of the CO₂ from the moldboard plow. The moldboard plow lost 13.8 times more CO₂ as the soil not tilled while conservation tillage tools averaged about 4.3 times more CO₂ loss. The smaller CO₂ loss from conservation tillage tools was significant and suggests progress in equipment development for enhanced soil C management. Conservation tillage reduces the extent, frequency and magnitude of mechanical disturbance caused by the moldboard plow and reduces the large air-filled soil pores to slow the rate of gas exchange and C oxidation.

Carbon loss associated with intensive tillage is also associated with soil erosion and degradation that can lead to increased soil variability and yield decline. Tillage erosion or tillage-induced translocation, the net movement of soil down slope through the action of mechanical implements and gravity forces acting on the loosened soil has been observed for many years. Papendick, McCool, & Krauss (1983) reported original topsoil on most hilltops had been removed by tillage erosion in the Paulouse region of the Pacific Northwest of the US. The moldboard plow was identified as the primary cause, but all tillage implements will contribute to this problem (Grovers et al., 1994; Lobb & Kachanoski, 1999). Soil translocation from moldboard plow tillage can be greater than soil loss tolerance levels (Lindstrom, Nelson & Schumacher, 1992; Grovers et al., 1994; Lobb, Kachanoski & Miller, 1995; Poesen et al., 1997). Soil is not directly lost from the fields by tillage translocation, rather it is moved away from the convex slopes and deposited on concave slope positions. Lindstrom et al. (1992) showed that soil movement on a convex slope in southwestern Minnesota, USA could result in a sustained soil loss level of approximately 30 t ha⁻¹ yr⁻¹ from annual moldboard plowing. Lobb et al. (1995) estimated soil loss in southwestern Ontario, Canada from a shoulder position to be 54 t ha⁻¹ yr⁻¹ from a tillage sequence of moldboard plowing, tandem disk and a C-tine cultivator. In this case, tillage erosion, as estimated through resident Cesium-137, accounted for at least 70 % of the total soil loss. The net effect of soil translocation from the combined effects of tillage and water erosion is an increase in spatial variability of crop yield and a likely decline in soil C related to lower soil productivity (Schumacher et al., 1999).

Environmental Benefits of Soil Carbon

The main direct benefit of conservation agriculture or direct seeding is the immediate impact on SOM and soil C interactions. Soil organic matter is so valuable for what it does in soil, it can be referred to as “black gold” because of its vital role in physical, chemical and biological properties and processes within the soil system. Agricultural policies are needed to encourage farmers to improve soil quality by storing C that will also lead to enhanced air quality, water quality and increased productivity as well as to help mitigate the greenhouse effect. Soil C is one of our most valuable resources and may serve as a “second crop” if global C trading systems become a reality. While technical discussions related to C trading are continuing, there are several other secondary benefits of soil C impacting environmental quality that should be considered to maintain a balance between economic and environmental factors.

Soil C is so important that it can be compared to the central hub of a wheel as shown in Fig 1. The wheel represents a circle, which is a symbol of strength, unity and progress. The “spokes” of this wagon wheel represent incremental links to soil C that lead to the environmental improvement that supports total soil resource sustainability. Many spokes make a stronger wheel. Each of the secondary benefits that emanate from soil C contributes to environmental enhancement through improved soil C management. Soane (1990) discussed several practical aspects of soil C important in soil management. Some of the “spokes” of the environmental sustainability wheel are described in following paragraphs.

Increased SOM has a tremendous effect on soil water management because it increases infiltration and the water holding capacity. The primary role of SOM in reducing soil erodibility is by stabilizing the surface aggregates through reduced crust formation and surface sealing, which increases infiltration (Le Bissonnais, 1990). Enhanced soil water-holding capacity is a result of increased SOM that more readily absorbs water and releases it slowly over

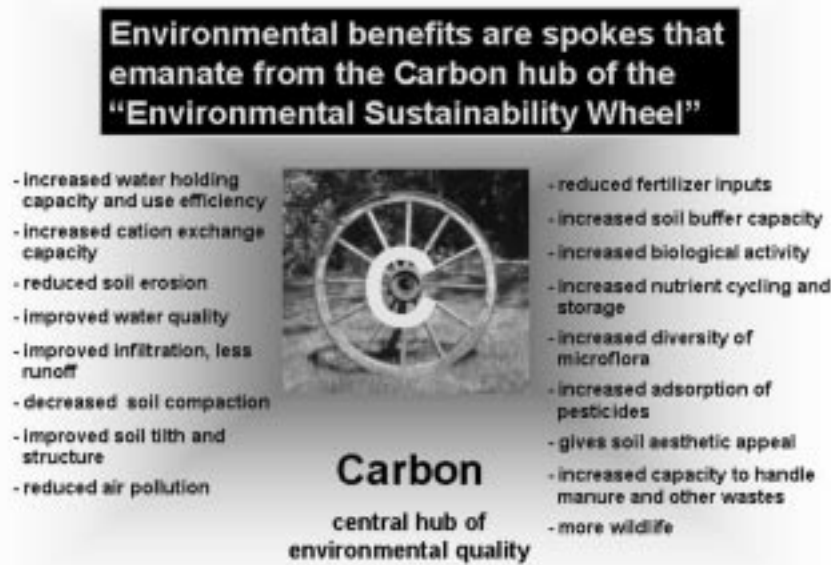


Figure 1. Environmental sustainability wheel with benefits emanating from the soil C hub

the season to minimize the impacts of short-term drought. In fact, certain types of SOM can hold up to 20 times its weight in water. Hudson (1994) showed that for each one % increase in SOM, the available water holding capacity in the soil increased by 3.7 % of the soil volume. The extra SOM prevents drying and improves water retention properties of sandy soils. In all texture groups, as SOM content increased from 0.5 to 3 %, available water capacity of the soil more than doubled. Other factors being equal, soils containing more organic matter can retain more water from each rainfall event and make more of it available to plants. This result plus the increased infiltration with higher organic matter and the decreased evaporation with crop residues on the soil surface all contribute to improve water use efficiency.

Ion adsorption or exchange is one of the most significant nutrient cycling functions of soils. Cation exchange capacity (CEC) is the amount of exchange sites that can absorb and release nutrient cations. Soil organic matter can increase CEC of the soil from 20 to 70 % over that of the clay minerals and metal oxides present. In fact, Crovetto (1996) showed that the contribution of the organic matter to the cation exchange capacity exceeded that of the kaolinite clay mineral in the surface 5 cm of his soils. Robert (2001) showed a strong linear relationship between organic C and CEC of his experimental soil. The CEC increased four-fold with an organic C increase from 1 to 4 %. The toxicity of other elements can be inhibited by SOM which has the ability to adsorb soluble chemicals. The adsorption by clay minerals and SOM is an important means by which plant nutrients are retained in crop rooting zones.

Soils relatively high in C, particularly with crop residues on the soil surface, are very effective in increasing SOM and in reducing soil erosion loss. Reducing or eliminating runoff that carries sediment from fields to rivers and streams will enhance environmental quality. Under these situations, the crop residue acts as tiny dams that slow down the water runoff from the field allowing the water more time to soak into the soil. Worm channels, macropores and plant root holes left intact increase infiltration (Edwards, Shipitalo & Norton, 1988). Water infiltration is two to ten times faster in soils with earthworms than in soils without earthworms (Lee, 1985). Soil organic matter contributes to soil particle aggregation that makes it easier for the water to move through the soil and enables the plants to use less energy to establish to root systems (Chaney & Swift, 1984). Intensive tillage breaks up soil aggregates and results in a dense soil making it more difficult for the plants to get nutrients and water required for their growth and production.

The reduction in soil erosion leads to enhanced surface and ground water quality, another secondary benefit of higher SOM (Uri, 1999). Crop residues on the surface help hold soil particles in place and keep associated nutrients and pesticides on the field. The surface layer of organic matter minimizes herbicide runoff, and with

conservation tillage, herbicide leaching can be reduced as much as half (Braverman et al., 1990). The enhancements of surface and ground water quality are accrued through the use of conservation tillage and by increasing SOM. Increasing SOM and maintaining crop residues on the surface reduces wind erosion (Skidmore, Kumar & Larson, 1979). Depending on the amount of crop residues left on the soil surface, soil erosion can be reduced to nearly nothing as compared to the unprotected, intensively tilled field.

Another key factor is SOM that can decrease soil compaction (Angers & Simard 1986; Avnimelech & Cohen, 1988). Soane (1990) presented different mechanisms where soil “compactibility” can be decreased by increased SOM content: 1) improved internal and external binding of soil aggregates; 2) increased soil elasticity and rebounding capabilities; 3) dilution effect of reduced bulk density due to mixing organic residues with the soil matrix; 4) temporary or permanent existence of root networks; 5) localized change electrical charge of soil particles surfaces, 6) change in soil internal friction. While most soil compaction occurs during the first vehicle trip over the tilled field, reduced weight and horsepower requirements associated with forms of conservation tillage can also help minimize compaction. Additional field traffic required by intensive tillage compounds the problem by breaking down soil structure. The combined physical and biological benefits of SOM can minimize the affect of traffic compaction and result in improved soil tilth.

Maintenance of SOM contributes to the formation and stabilization of soil structure. Another spoke in the wagon wheel of environmental quality is improved soil tilth, structure and aggregate stability that enhances the gas exchange properties and aeration required for nutrient cycling (Chaney & Swift, 1975). Critical management of soil airflow with improved soil tilth and structure is required for optimum plant function and nutrient cycling. It is the combination of many little factors rather than one single factor that results in comprehensive environmental benefits from SOM management. The many attributes suggest new concepts on how we should manage the soil for the long-term aggregate stability and sustainability.

A secondary benefit of less tillage and increasing SOM is reduced air pollution. CO₂ is the final decomposition product of SOM and is released to the atmosphere. Research has shown that intensive tillage, particularly the moldboard plow, releases large amounts of CO₂ as a result of physical release and enhanced biological oxidation (Reicosky et al., 1995). With conservation tillage, crop residues are left more naturally on the surface to protect the soil and control the conversion of plant C to SOM and humus. Intensive tillage releases soil C to the atmosphere as CO₂ where it can combine with other gases to contribute to the greenhouse effect. Thus a combination of the economic benefits of conservation tillage through reduced labor requirements, time savings, reduced machinery costs and fuel savings, combined with the environmental benefits listed above has universal appeal. Indirect measures of social benefits as society enjoys a higher quality of life from environmental quality enhancement will be difficult to quantify. Conservation agriculture, using direct seeding techniques, can benefit society and can be viewed as both “feeding and greening the world” for global sustainability.

Limits of No till for Carbon Sequestration

Carbon sequestration through continuous conservation agriculture is only a short-term solution to the problem of global warming. The amount of C that can be stored in the soil using no till techniques will plateau in 25 to 50 years (Lal et al., 1998). The time period depends on the specific geographic site, soil and climate parameters, and cropping practices that are followed. At some point, a new equilibrium will be reached where there is no further gain in soil C; however, the environmental benefits will continue. In the long-term, reducing CO₂ emissions from the burning of fossil fuels by developing alternate energy sources is the only solution. Soil C sequestration and potential associated C credit trading will allow major CO₂ emitters time to reduce their emissions, while developing economical long-term solutions. For the next 50 years, however, soil C sequestration can be a cost-effective option that buys society time in which to develop alternate energy options while still providing numerous environmental benefits.

Agricultural policy should play a prominent role promoting conservation agriculture in developing agro-environmental instruments to support a sustainable development of rural areas and respond to societies increasing demand for environmental services. Environmental protection and nature conservation require enhanced management skills that create extra work and cost for the farmers, but in no other sector can so much be achieved for the environment with so little input. We must no longer take for granted the contribution made to society by farmers through environmental measures but must compensate them appropriately through stewardship payments. Farmers using conservation agriculture techniques stand to gain from protecting the environment because it is in their fundamental economic interest to conserve natural resources for the future. It is in all our economic interests to have healthy and

sustainable ecosystems to enhance our quality of life. The true economic benefits can only be determined when we assign monetary values to externalities of environmental quality. It makes more economic sense to take account of nature conservation from the outset than to have to repair damage after it is done, and in many cases the repair may not even be possible. Conservation agriculture without intensive tillage can play a major role in sequestering soil C and providing long-term global economic and environmental benefits.

Conservation agriculture with enhanced soil C management is a win-win strategy. Agriculture wins with improved food and fiber production systems and sustainability. Society wins because of the enhanced environmental quality. The environment wins as improvements in soil, air and water quality are all enhanced with increased amounts of soil C. The win-win scenario will increase productivity, improve soil quality, and mitigate the greenhouse effect with major impact on our future quality of life.

References

- Angers DA, Simard R R. 1986. Relationships between organic matter content and soil bulk density. Relations entre la teneur en matière organique et la masse volumique apparente du sol. *Canadian Journal of Soil Science Revue Canadian Science Sol.* 66:743-746.
- Avnimelech Y, Cohen A. 1988. On the use of organic manures for amendment of compacted clay soils: effects of aerobic and anaerobic conditions. *Biological Wastes* 29:331-339.
- Chaney K, Swift R S. 1984. The influence of organic matter on aggregate stability in some British soils. *Journal of Soil Science* 35:223-230.
- Braverman MP, Dusky J A, Locascio S J, Hornsby A G. 1990. Sorption and degradation of thiobencarb in three Florida soils. *Weed Science* 38(6): 583-588.
- Crovetto Lamarca C. 1996. Stubble over the soil: The vital role of plant residue in soil management to improve soil quality. *American Society of Agronomy*, Madison, WI. 245 pp.
- Davidson EA, Ackerman I L. 1993. Changes in soil carbon inventories following cultivation of previously untilled soils. *Biogeochemistry* 20:161-193.
- Edwards W M, Shipitalo M J, Norton L D. 1988. Contribution of macroporosity to infiltration into a continuous corn no-tilled watershed: Implications for contaminant movement. *Journal of Contaminant Hydrology* 3:193-205.
- Grovers G, Vandaele K, Desmet P J J, Poesen J, Bunte K. 1994. The role of tillage in soil redistribution on hillslopes. *European Journal of Soil Science* 45:469-478.
- Houghton RA, Hackler J L, Lawrence K T. 1999. The U.S. carbon budget: contributions from land-use change. *Science* 285:574-577.
- Hudson B D. 1994. Soil organic matter and available water capacity. *Journal of Soil and Water Conservation* 49(2):189-194.
- Lal, R. 2000. A modest proposal for the year 2001: we can control greenhouse gases in the world..... with proper soil management. *Journal of Soil and Water Conservation* 55(4):429-433.
- Lal R, Kimble J M, Follet R F, Cole V. 1998. Potential of U.S. Cropland for Carbon Sequestration and Greenhouse Effect Mitigation. USDA-NRCS, Washington, D.C. Ann Arbor Press, Chelsea, MI.
- Le Bissonnais Y. 1990. Experimental study and modelling of soil surface crusting processes. In *Soil erosion: Experiments and models*, pp. 13-28. Ed RB Bryan. Catena Verlag: Cremlingen-Destedt.
- Lee K E. 1985. *Earthworms: Their ecology and relationship with soils and land use*. New York: Academic Press. 411 pp.
- Lindstrom, M J, Nelson W W, Schumacher T E. 1992. Quantifying tillage erosion rates due to moldboard plowing. *Soil Tillage Research* 24:243-255.
- Lobb DA, Kachanoski R G. 1999. Modelling tillage translocation using steppe, near plateau, and exponential functions. *Soil Tillage Research* 51:261-277.
- Lobb DA, Kachanoski R J, Miller M H. 1995. Tillage translocation and tillage erosion on shoulder slope landscape positions measured using ¹³⁷Cesium as a tracer. *Canadian Journal of Soil Science* 75:211-218.
- Papendick R I, McCool D K, Krauss H A. 1983. Soil conservation: Pacific Northwest. In *Dryland Agriculture*, Eds H E Dregne and W O Willis. Agronomy 23. ASA, Madison, WI.
- Poesen J, Wesenael B, Govers G, Martinez-Fernandez J, Desmet B, Vandaele K, Quine T, Degraer G. 1997. Patterns of rock fragment cover generated by tillage erosion. *Geomorphology*. 18:193-197.

- Reicosky D C. 1998. Strip tillage methods: Impact on soil and air quality. In *Environmental benefits of soil management*. pp. 56-60. Ed P Mulvey. Proceedings of ASSSI National Soils Conference, Brisbane, Australia.
- Reicosky D C. 1997. Tillage-induced CO₂ emission from soil. *Nutrient Cycling in Agroecosystems*. 49:273-285.
- Reicosky D C, Kemper W D, Langdale G W, Douglas Jr C W, Rasmussen P E. 1995. Soil organic matter changes resulting from tillage and biomass production. *Journal of Soil and Water Conservation* 50:253-261.
- Reicosky D C, Lindstrom M J. 1993. Fall tillage method: effect on short-term carbon dioxide flux from soil. *Agronomy Journal* 85:1237-1243.
- Reicosky DC, Lindstrom M J. 1995. Impact of fall tillage and short-term carbon dioxide flux. In *Soil and Global Change*. pp. 177-187. Ed R Lal Chelsea, MI: Lewis Publishers.
- Robert M. 1996. Aluminum toxicity a major stress for microbes in the environment. In *Environmental Impacts*, pp. 227-242. Eds P M Huang et al., Vol. 2, Soil component interactions. CRC press.
- Robert M. 2001. Carbon Sequestration in Soils: Proposals for land management. AGLL, FAO, United Nations, Rome. Report No. 96. 69 pp.
- Schlesinger W H. 1985. Changes in soil carbon storage and associated properties with disturbance and recovery. In *The changing carbon cycle: A global analysis*. pp. 194-220. Eds J R Trabalha and D E Reichle. New York: Springer Verlag.
- Schumacher T E, Lindstrom M J, Schumacher J A, Lemme G D. 1999. Modelling spatial variation and productivity due to tillage and water erosion. *Soil Tillage Research*. 51:331-339.
- Skidmore E L, Kumar M, Larson W E. 1979. Crop residue management for wind erosion control in the Great Plains. *Journal of Soil and Water Conservation* 34:90-94.
- Soane B D. 1990. The role of organic matter in the soil compactibility: A review of some practical aspects. *Soil Tillage Research* 16:179-202.
- Tebregge F, Guring R A. 1999. Reducing tillage intensity – a review of results from a long-term study in Germany. *Soil Tillage Research* 53:15-28.
- Uri N D. 1999. Conservation Tillage in U.S. Agriculture. In *Environmental, Economic, and Policy Issues*, p 130. Binghamton, NY: The Haworth Press, Inc.

Weathering the Storms - Conservation Agriculture in Africa's Potential to Ameliorate 21st Century Environments

R.M. Fowler

*Conservation Agriculture Capacitator, Musson Mews, Hayfields,
Pietermaritzburg 3201, KwaZulu-Natal, South Africa
(Email: rmfowler@iafrica.com)*

Practitioners of conservation agriculture (CA) render a number of services to humanity, present and future, in the community in which they live and the district where they farm as well as in the state, country, region and global environment in which they work. These services include the provision of cheaper more reliable supplies of food as well as a range of environmental services such as increased soil health, reduced water pollution and runoff and decreased 'greenhouse gas' emissions.

In recent years much attention has been given to the rewarding of farmers practicing CA and other reduced tillage systems for their reduction of Carbon emissions. The actual reduction, however, tends to be very site and tillage-system specific. Assessment and monitoring are therefore expensive and only really warranted on larger farms. As a result, especially with the current price of carbon credits, few if any systems exist which attempt to quantify benefits let alone reward African farmers for their part in these reductions, especially the small scale farmers who make up by far the majority of African agriculturists..

The price of carbon is currently very dependent on supply and demand, but that of other direct environmental benefits is often much easier to calculate, especially within a defined geographic area. If these benefits were to be 'bundled' with carbon a far more attractive package could be made available for marketing, either to governments to compensate farmers for direct savings in, for example, water storage and purification costs, or to commercial organizations wishing to improve their 'Triple Bottom Line' audit statements. Based essentially on area cultivated, such benefits could be assessed, marketed and monitored by farmer organizations, with the 'profit' which would normally be taken by a commercial organization being used, for example, to promote CA and establish and maintain CA Advisory Services, and the rest, far more than the amount which would normally accrue from carbon benefits alone, being paid to the farmers.

Innovations based on these principles could accelerate the adoption of CA in Africa, which in turn could slow, and equip African farmers to better adapt to, climate change. Some existing and possible options are explored and discussed.

Theme 4: Impact Assessment and Equity Issues

Session 4.1: Impact of Conservation Agriculture

Global Overview of Conservation Agriculture Adoption

Rolf Derpsch* and Theodor Friedrich

*Food and Agriculture Organization (*Email: rolf.derpsch@tigo.com.py)*

No-tillage/Conservation Agriculture (CA) has developed to a technically viable, sustainable and economic alternative to current crop production practices. While current crop production systems have resulted in soil degradation and in extreme cases desertification, the adoption of the No-tillage technology has led to a reversion of this process. Soil erosion has come to a halt, organic matter content, soil biological processes and soil fertility have been enhanced, soil moisture has been better conserved and yields have increased with time. Data presented ten years ago at the 10th ISCO Conference in West Lafayette, Indiana, showed a world wide adoption of the No-tillage technology of about 45 million ha (Derpsch, 2001). Since then the adoption of the system has continued to grow steadily especially in South America where some countries are using CA on about 70% of the total cultivated area. Opposite to countries like the USA where often fields under No-tillage are tilled every now and then, more than two thirds of No-tillage practiced in South America is permanently under this system, in other words once started, the soil is never tilled again. In the last years a big expansion of the area under No-tillage has been reported in Asia, especially in China and Kazakhstan where more than a million ha have been reported in each country. But also in Europe there is progress in the adoption. There are about 650.000 ha of No-tillage being practiced in Spain, about 200.000 ha in France and about 200.000 ha in Finland. No-tillage based conservation agriculture systems gain also increasing attention in Africa, especially in Southern and Eastern Africa. In many countries the area is still low due to the high percentage of small scale farmers, but the numbers are increasing steadily as well. Up to now No-tillage has expanded to more than 100 million ha world wide, showing its adaptability to all kinds of climates, soils and cropping conditions. No-tillage is now being practiced from the arctic circle over the tropics to about 50° latitude South, from sea level to 3000 m altitude, from extremely rainy areas with 2500 mm a year to extremely dry conditions with 250 mm a year. The wide recognition as a truly sustainable farming system should ensure the growth of this technology to areas where adoption is still small as soon as the barriers for its adoption have been overcome. The widespread adoption also shows that No-tillage can not any more be considered a temporary fashion, instead the system has established itself as a technology that can no longer be ignored by politicians, scientists, universities, extension workers, farmers as well as machine manufacturers and other agriculture related industries.

Key words: World wide Conservation Agriculture / No-till adoption

CA/No-till crop production systems are experiencing increasing interest in most countries around the world. There are only few countries where No-tillage is not practiced by at least some farmers and where there are no local research results on the technology available. No-tillage, synonymous of zero tillage has expanded to soils and climates earlier thought inadequate for practicing it successfully. No-tillage is now being practiced by farmers from the arctic circle (e.g. Finland) over the tropics (e.g. Kenya, Uganda), to about 50° latitude South (e.g. Malvinas/ Falkland Islands). From sea level in several countries of the world to 3000 m altitude (e.g. Bolivia, Colombia), from extremely dry conditions with 250 mm a year (e.g. Western Australia), to extremely rainy areas with 2000 mm a year (e.g. Brazil) or 3000 mm a year (e.g. Chile). No-tillage is practiced on all kind of farm sizes from half hectare (e.g. China, Zambia) to hundreds of ha in many countries of the world, to thousands of ha (e.g. Australia, Brazil, USA, Kazakhstan). It is practiced on soils that vary from 90% sand (e.g. Australia), to 80% clay (e.g. Brazil's Oxisols and Alfisols). Soils with high clay content in Brazil are extremely sticky but this has not been a hindrance to No-till adoption when appropriate equipment was available. Soils which are extremely sensitive to crusting do not present this problem under No-tillage because the mulch cover avoids the formation of crusts. No-tillage has even allowed expansion of agriculture to marginal soils in terms of rainfall or fertility (e.g. Australia, Argentina). All crops can be grown adequately in the No-tillage system and to the authors knowledge there has not yet been found a single crop that would not grow under this system, including root crops. The wide range of conditions where the No-tillage system is working successfully all around the world, its economic, social and environmental advantages as well as the recognition as a truly sustainable farming system should ensure the expansion of this technology to areas where adoption is still small as soon as the barriers for its adoption have been overcome. The main barriers to its adoption continue to be, knowledge on how to do it (know how), mindset (tradition, prejudice), inadequate policies as commodity based subsidies (EU, US), availability of adequate machines (many countries of the world) and availability of suitable herbicides to facilitate weed management (especially in developing countries). These barriers must be overcome not only by farmers but also by researchers, extension workers, university professors, politicians and all stakeholders involved in the farming industry if a greater adoption is aimed to be achieved. The widespread adoption of No-tillage under a great range of different conditions on more than a 100 million ha world wide shows, that the system can be made to work and function, it is only a matter of a firm determination to do so, after recognizing the superiority of this system in relation to unsustainable intensive tillage practices.

Definition of Conservation Agriculture/No-tillage

Because trying to put together numbers on the area under Conservation Agriculture in its broader understanding seems to be an impossible task, for the purpose of this paper we are concentrating on the area under No-tillage. As the understanding of No-tillage (synonymous of Zero Tillage) often varies we need to have a common understanding of what No-tillage means. For this paper we use the definition by Phillips and Young (1973) (with minor modifications), which to our knowledge is the most widely accepted one. “No-tillage is defined as a system of planting (seeding) crops into untilled soil by opening a narrow slot, trench or band only of sufficient width and depth to obtain proper seed coverage. No other soil tillage is done”. Permanent or continuous No-tillage should be aimed at, rather than not tilling in one season and tilling in the other, or occasionally not tilling the soil. The soil should remain permanently covered by crop residues from previous cash crops or green manure cover crops, and most of these residues will remain undisturbed on the soil surface after seeding. This definition comes fairly close to the definition of Conservation Agriculture provided by FAO (FAO 2008). Informants of the area under No-tillage in the different countries have been asked to provide information on the area under No-tillage under this understanding since so far no proper reporting mechanism for CA areas is in place.

At this stage we are not excluding those farmers that do rotational tillage, (e.g., tilling every third or fourth year). But we definitely need to exclude those farmers who practice No-tillage for one crop and regularly plow or till the soil for the following crop. We are aware, that this means excluding millions of hectares from our estimates as in many regions of the world production systems are used that include No-tillage in one season and intensive tillage in the next season.

Direct seeding is also excluded from our estimates. Direct seeding is defined for the purpose of this paper as a system where machines are used that are able to seed directly into the stubble of the previous crop, i.e. into unprepared ground, but because of the design of the seeding equipment produces high soil disturbance at seeding to prepare a “seedbed” in one pass, so that most of the soil surface and sometimes even the profile is tilled and disturbed.

To avoid double counting of hectares under No-tillage in the case of countries where double cropping is practiced, for the purpose of this publication only the real area under No-tillage is counted. In our understanding this distinction is important to be able to quantify the real number of hectares under Sustainable Agriculture.

Overview of Conservation Agriculture/No-till adoption in different parts of the world (mainly countries with more than 100.000 ha under No-tillage)

Development of No-tillage in North America

United States The United States has been among the few countries that conducted regular surveys on the area under No-tillage and other forms of Conservation Tillage. Unfortunately these surveys were discontinued in 2004. The data is published at the CTIC homepage www.conservationinformation.org The survey shows that by 2004 the area under No-till was 25.3 million ha. The surveys were based on the actual area under No-tillage found in the different regions in different years, but it did not consider the number of years a farmer had been not tilling the soil. According to CTIC (2005) it was estimated that only about 10 to 12% of the area under No-tillage in the USA was permanently under this system.

An amendment to the 2004 figures was done in 2007 which is shown in the CTIC homepage http://www.conservationinformation.org/?action=members_crm The CTIC CRM data collection shows the 2007 Amendment to the National Crop Residue Management Survey Summary which is based on 374 counties in 8 states. Here No-tillage appears with 65.48 million acres which is equivalent to 26.493.000 ha. The Amendment also shows that No-till acres have increased from 23.2% to 25.5% of total cropland acres. Although the percentage of adoption has increased the numbers still reveal that the majority of farmers in this country are still using conventional or reduced tillage practices.

Despite the fact that the growth of the area under No-tillage in the US was not dramatic, a continuous and steady growth could be observed in the last decade.

Canada is conducting an Agricultural Census every 4 years, the last one being performed in 2006. This Census also includes adoption of No-tillage practices. The regions with highest percentage of adoption of No-tillage are Saskatchewan (60.1%), Alberta (47.8%), Ontario (31.2%), Manitoba (21.3%) and British Columbia (19.0%).

Table 1. Area under No-tillage in the United States (CTIC, 2004)

Year	Area (million hectares)
1994	15.7
1996	17.3
1998	19.3
2000	21.1
2002	22.4
2004	25.3
2007	26.5

More detailed information under CRM data collection at http://www.conservationinformation.org/?action=members_crm

Table 2. Area under No-tillage in Brazil (FEBRAPDP, 2008)

Year	Area (million hectares)
1993/94	3.0
1995/96	5.5
1997/98	11.3
1999/00	14.3
2001/02	18.7
2003/04	21.8
2005/06	25.5

Full set of data from 1972 to 2006 under Área de Plantio Direto at <http://www.febrapid.org.br/port/plantiodireto.html>

According to the Soil Conservation Council of Canada No-tillage is now practiced on 13.48 million ha in Canada and on average the technology is used on 46.1% of the cropped area (Doug McKell, personal communication 2008). The Soil Conservation Council of Canada informs that in the year 2000 No-tillage was used on 8.8 million ha. This shows an average increase of 780.000 ha per year of No-till adoption in Canada throughout this period. According to Doug McKell the majority of the conventionally tilled land is in the hands of the older and/or smaller farmer who will likely not change their practices. Thus the change in adoption will take place when the land changes hands. The majority of no-tillage in Canada is performed with airseeders that are equipped with hoe-type openers.

Development of No-tillage in South America

Brazil: According to FEBRAPDP (The Brazilian Federation of No-till Farmers) in the season 2005/06 there were 25.5 million ha of No-tillage being practiced in this country. (<http://www.febrapid.org.br>) Brazil continues to be one of the leading countries in the world in terms of adoption of the No-tillage System. The first farmer to use the technology in Brazil started in 1972, ten years after the first farmer in the US was applying No-tillage. In Brazil about 70% of No-tillage is practiced permanently, this means that once started most farmers never till the soil again. While about 90% of farmers in the US practice rotational tillage (several years No-tillage and then they till again) this is the case only with a minority of farmers in Brazil. Most Brazilian farmers and technicians believe that those farmers using rotational tillage will never get to reap the full benefits of the No-tillage system as described in the evolution of a Continuous No-till System (Derpsch, 2005). Another aspect where Brazilian farmers are ahead of their peers in the US is in the use of GMCC (green manure cover crops). GMCC are used on millions of ha in Brazil and many farmers are convinced that they are a must in a sound No-tillage system. FEBRAPDP is now concerned about improving the quality of No-tillage and is aiming at certifying the quality of the system to farmers in order to qualify for carbon credits in the future.

The quick and steady growth of No-tillage in Brazil was possible because the machine industry engaged early in the production of specialized No-till equipment. Today Brazilian No-till seeding machines are exported all over the world. Brazilian machine manufacturers are not only engaged in producing equipment for motorized mechanization but produce also equipment for animal traction and manual operation. This equipment has been highly appreciated in many developing countries. FAO has played a mayor role in distributing Brazilian No-till equipment for small farmers throughout the world. The development of this industry in Brazil was possible because there are about 100.000 small farmers using No-till farming systems in this country needing specialized machines. No-tillage in Brazil is almost exclusively performed with disc seeders.

Argentina: The advent of the No-tillage technology caused a paradigm shift in Argentina as the idea that tillage was necessary to grow crops was abandoned. The concept of "arable" soils has been discarded after discovering that soils that cannot be ploughed can be seeded. According to AAPRESID in 2006 there were 19.7 million ha of No-tillage being practiced in this country (<http://www.aapresid.org.ar>). With almost 20 million ha under No-tillage Argentina is among the most successful countries in terms of No-till adoption. The first group of farmers started using No-till in 1977/78 after exchanging ideas with Carlos Crovetto, one of the most renowned No-till experts from Chile, as well as with Dr. Shirely Phillips and Dr. Grant Thomas from the US. At the beginning growth was slow because of lack of knowledge, experience, machines and limitations on the availability of herbicides. It took 15 years until 1992/93 when about a million ha under No-tillage were reached. Since then adoption increased year by year thanks to the intensive activities of AAPRESID (Argentinean Association of No-till Farmers) and in 2006 about 69% of all cropland in Argentina were under No-tillage.

The rapid growth of No-tillage in Argentina was possible because No-till seeding equipment manufacturers have responded to the increasing demand in machines. Among the many big and small No-till seeder manufacturers in Argentina there are at least 15 that are in conditions to export their equipment. No-tillage in Argentina is almost exclusively performed with disc seeders.

Similar to other countries in South America, farmers in Argentina like to do permanent No-tillage once they have started with the system. More than 70% of all No-tillage practiced in Argentina is permanently not tilled. At the beginning cover crops were not an issue for No-till farmers in this country because it was believed that these crops would take too much moisture out of the soil. This has changed in recent years when research could show, that water use efficiency can be enhanced when using appropriate cover crops.

Table 3. Area under No-tillage in Argentina (AAPRESID, 2006)

Year	Area (million hectares)
1993/94	1.81
1995/96	2.97
1997/98	5.00
1999/00	9.25
2001/02	15.10
2003/04	18.26
2005/06	19.72

More information under Institucional, Siembra Directa at
http://www.aapresid.org.ar/institucional_sd.asp

Paraguay has been experiencing a continuous and steady growth of No-till adoption. Whole landscapes have been transformed to country sides where tillage practices have disappeared almost completely. According to The Ministry of Agriculture and Livestock (MAG) and the grain exporting chamber of Paraguay (CAPECO), in tractor mechanized farming systems it is estimated that about 90% of all cropping area is under No-tillage, reaching about 2.4 million ha in 2008. Most farmers apply permanent No-tillage systems. But also in small farmer production systems with animal traction or manual No-till systems No-tillage practices have increased. It is estimated that about 22.000 small farmers apply No-tillage at least on part of their farms covering about 30.000 ha. The increased interest in small farmer No-till systems has been a result of efforts of the Ministry of Agriculture together with GTZ (German Technical Assistance) and KfW (Kreditanstalt für Wiederaufbau) from Germany that provides grants for buying No-till equipment. Small farmers have been able to successfully grow crops that initially were thought not to be appropriate for No-tillage as for instance cassava (*Manihot utilissima*). Planting cassava under No-tillage in combination with cover crops has resulted in substantial yield increases (sometimes doubling yields) compared to conventional farming systems. Reduction of drudgery (tillage, weed control) and the resulting improvement in the quality of life because of a dignified work is one of the main reasons for increased adoption under small farmers.

Bolivia: In Bolivia No-tillage practices have been increasingly adopted especially in the lowlands in the east of the country around the city of Santa Cruz. Main crop under No-tillage is soybeans. According to ANAPO (The soybean and wheat producers association of Bolivia) soybeans under No-tillage have increased from around 240.000 ha (39% adoption) in the year 2000 to 706.000 ha (72% adoption) in the year 2007. The occurrence of wind erosion in conventional tillage systems has been one of the major driving forces for adoption. Also the increased water use efficiency under No-tillage is appreciated by farmers in a region with low and erratic rainfalls.

Uruguay also belongs to the countries that have engaged predominantly in permanent No-tillage practices. According to AUSID (Uruguayan No-till Farmers Association), about 82% of cropland, that is 672.000 ha was under No-till systems in the 2006/07 growing season. This is a great progress compared to the 2000/01 season when only 119.000 ha of No-tillage were reported, corresponding to 32% adoption. These numbers have been provided by DIEA, (The Statistics Department of the Ministry of Agriculture, Livestock and Fisheries), and reflect the trend also seen in the other MERCOSUR countries (Brazil, Argentina, Paraguay and Uruguay). Another interesting fact is that in Uruguay, according to DIEA, 65% of crops are seeded on rented land for which contracts are renewed every year. This hinders the planning of medium term crop rotation and investment strategies. In Uruguay the integration of agriculture and livestock is very popular and No-tillage fits very well into the requirements of this production system. Pastures are grown for several years until they show signs of degradation. Then crops are grown for several years according to the needs of the farmers and the market situation.

Venezuela: Despite repeated efforts to obtain information about the area under No-till in Venezuela it has not been possible to obtain updated data on the progress in the adoption of this technique. Therefore the same numbers are used as in 2005 when No-tillage was applied on 300.000 ha.

Chile is a country where No-tillage has been practiced already for a long time. According to Carlos Crovetto, the Chilean No-till pioneer and author of several books about No-tillage, there are about 180.000 ha of No-tillage being practiced in this country, which is about 30% of the cropped area in rainfed farming systems. Unfortunately there is a relatively large amount of No-till farmers that have not yet understood the importance of soil cover in this system and burn their cereal residues regularly putting the sustainability of the system at risk. Official research institutions have taken little interest in this technology and have not been willing to study the long term detrimental effect of burning on soil health and yield.

Colombia: In Colombia the area under No-tillage has virtually remained static and no increase in the area under this system has been reported. This has little to do with the merits of this technology but more with the political situation of this country and the insecurity in rural areas. According to Fabio Leiva (personal communication, 2008) there are about 100.000 ha under No-tillage in Colombia.

Development of No-tillage in Australia and New Zealand

Australia has experienced a sharp increase in the area under No-till in the last years. According to Bill Crabtree, Consultant and member of WANTFA (Western Australia No-till Farmers Association) No-tillage now is reaching 12 million ha. The adoption of No-till by farmers in this country varies from 24% in northern New South Wales, to 42% in South Australia and 86% in Western Australia. During 2008 the percent of the area under No-tillage is expected to grow to 88% in Western Australia and to 70% in South Australia (Flower et al., 2008). Because of the water, time and fuel savings with this technology, as well as the other advantages of the system, No-tillage is expected to continue growing in this country, especially in those States with lower rates of adoption. In northern New South Wales the area under No-tillage is expected to increase from 24% in the year 2000 to 36% in 2010. Overall adoption of No-till in Queensland was approximately 50% with some areas as high as 75% (Flower et al., 2008).

In Australia most farmers use airseeders equipped with knife point openers, although some farmers use disc openers which in the last years seem to gain popularity. Also the use of cover crops is getting popular among no-till farmers. Combining cropping with livestock (generally sheep) is a common practice throughout the country. This often leads to insufficient crop residues left on the soil surface at seeding but more recently the importance of soil cover is increasingly recognized in Australian No-till. Another complementary technology used in Australia on No-tillage farms is controlled traffic farming to avoid soil compaction.

New Zealand is among the first countries in the world to use and develop the No-tillage technology. At the beginning pasture renovation without tillage was tried and practiced successfully. Later also annual crops were seeded with the No-tillage system. In the year 1995 only about 4% of the cropped area was under No-tillage and was virtually confined to pastures. According to John Baker (personal communication, 2008) there are about 160.000 ha under No-tillage in New Zealand, which corresponds to about 25% of all cropland hectares and includes pasture, forage crops as well as arable crops. Because in this country many farmers use double cropping systems, the total number of hectares seeded each year in No-tillage amounts to around 250.000 ha. But to avoid double counting of hectares under No-tillage, for the purpose of this publication only the real area under No-tillage is counted. The same as in South America the growth of the area under No-tillage has taken place without subsidies or outside incentives.

Development of No-tillage in Asia

China: An average a farmer in China only works about 0.08 ha and there are 3 to 5 persons on average in each family. Already this fact does not make it easy to estimate the area under No-tillage in this country and has to be taken into consideration when putting together numbers on tillage practices. But one thing is certain; the area under Conservation Agriculture has greatly increased in the last years in China. Conservation Agriculture is generally termed conservation tillage and includes mulch tillage and No-tillage. Conservation tillage is a term used for land that is not ploughed and where more than 30% cover with plant residues are left on the soil surface. No-tillage makes about 50% of conservation tillage in China and they allow for low disturbance subsoiling or ripping in their No-tillage fields. According to Li Hongwen from the Conservation Tillage Research Centre (personal communication,

2008) who has been committed by the Ministry of Agriculture to do a survey on conservation tillage practices every year, by the end of 2008 conservation tillage is practiced on about 2.66 million ha. As No-tillage makes 50% of conservation tillage he informs that there are 1.33 million ha under No-tillage being practiced in China. The data for No-tillage is conjectured according to their knowledge and report from different provinces and is based on talking to farmers and local administrative organizations. China is now producing many types of No-till seeders for smaller tractors and has difficulties to cover the high demand. Soil erosion by wind and water as well as scarce water, low levels of organic matter and declining productivity has been among the main driving forces for a quick adoption of No-tillage in this country. Another factor has been paradoxically limited labour availability because an increasing amount of young farmers have left for jobs in the cities leaving the older farmers (above 50 years) behind.

Kazakhstan is a big country that has experienced big changes in land tenure and farming systems in the last decades. No-till adoption has been promoted for some time by CIMMYT and FAO which introduced No-tillage systems in a Conservation Agriculture project from 2002 to 2004. CA has had an explosive development in recent years as a result of farmers interest, facilitating government policies and an active input supply sector. According to Mekhlis Suleimenov (personal communication 2008) No-till adoption started from 2004 in the north Provinces: North-Kazakhstan, Kostanai and Akmola, were the highest adoption rates have been registered. A survey in this country showed a total area of adoption in Kazakhstan of 600.000 ha in 2007 and 1.3 million ha in 2008. With this Kazakhstan places itself under the ten countries with the biggest area under No-tillage in the world.

Indo-Gangetic-Plains: The Indo-Gangetic-Plains include four countries in South Asia, India, Pakistan, Nepal and Bangladesh. In 2005 about 1.9 million ha were reported under No-tillage in this region. As was found out later this refers only to the wheat crop in a double cropping system with rice. For rice virtually all farmers plough the land or use intensive tillage practices. As this can not be, in our view, termed No-tillage, we are not including it in our overview. According to Raj Gupta (personal communication, 2008), the area of No-tillage wheat in that region has increased to about 5 million ha with still very few farmers practicing permanent No-tillage systems.

India: The adoption of No-tillage practices by farmers in India has occurred mainly in the rice – wheat double cropping production system and has been adopted primarily for the wheat crop. The main reason is that tillage takes too much time resulting in delayed seeding of the wheat crop after rice. It is well established that for each day of delayed sowing beyond the optimum date wheat yields are reduced by 1 to 1.5%. This timely planting of wheat after rice is critical and that is the reason for the quick uptake of No-tillage wheat. The Rice – Wheat consortium for Indo-Gangetic-Plains, an initiative of CGIAR that involves several National Agricultural Research Centres has been promoting No-tillage and it is mainly their efforts that have resulted in the massive uptake of No-tillage wheat in the region. The uptake of the technology was rapid in the north-western states which are relatively better endowed with respect to irrigation, mechanization and where the size of holdings is relatively large (3 – 4 ha) compared to the eastern region which is less mechanized and where the average land holding is small (1 ha) (Inder Pal Abrol, personal communication, 2008).

Also other efforts have been made to estimate the area under No-tillage. Some estimates on the area under No-till that have been undertaken in the region have been based on the sales of No-till drills and the average coverage per drill. As seen in other countries (e.g., Mexico) this method greatly overestimates the area under No-tillage because the drills are also used in reduced and some times even in conventionally tilled fields. For this reason one has to be cautious when alleged areas under No-tillage are mentioned based on the number of sold drills.

Development of No-tillage in Europe and in Russia

Spain is the leading country in terms of No-till adoption in Europe. According to AEAC/SV (Spanish Conservation Agriculture Association – Suelos Vivos), No-tillage on annual crops is practiced on 650.000 ha in Spain. Main crops under No-tillage are wheat, barley and much less maize and sunflowers. Besides annual crops grown in the No-tillage system in Spain many olive plantations and fruit orchards have turned to No-till systems. AEAC/SV reports 893.000 ha of No-tillage being practiced in perennial trees in most cases in combination with cover crops. Main tree crops in No-tillage in combination with cover crops are olives and much less apple, orange and almond plantations. Because this report is only based on No-till systems on annual crops we are not including No-tillage practices in tree crops in our global estimates. In total it is reported that Conservation Agriculture is applied on about 10% of arable land in Spain.

France is among the more advanced countries in Europe in terms of Conservation Agriculture/No-till adoption. APAD (The French No-till farmers association) estimates that No-tillage is practiced on about 200.000 ha in this

country. Some farmers have developed superior No-till systems with green manure cover crops and crop rotation which are working very well. The 2008 IAD International Conference on Sustainable Agriculture under the High Patronage of Mr. Nicolas Sarkozy and the following launching of the IAD Charter for Sustainable Agriculture is expected to show results in terms of greater acceptance of CA/No-till practices at all levels and especially at the political level. A greater acceptance of CA/No-till at political level is needed in the EU in order to increase farmer acceptance.

Finland has also managed to advance to one of Europe's leading No-till countries. The adoption of No-tillage technologies was very fast in Finland. According to FINCA (Finnish Conservation Agriculture Association) in less than ten years No-tillage grew from some hundred hectares to 200.000 ha in 2008. The reason for this rapid adoption was that those farmers that believed in the No-till system and made it work communicated their experiences to their peers. The extension service and research organizations as well as agribusiness took interest in this development only later. FINCA has played a mayor role in spreading No-tillage in Finland. One No-till seeders manufacturer in Finland took interest in No-tillage very early and claims to have sold almost a thousand No-till seeding machines until 2007, having about 50% of the market share in this country. About ten No-till seeders manufacturers from around the world have been able to place their No-till machines in the Finnish market and four of them are made in Finland. Another interesting fact about No-tillage in Finland is that No-tillage is practiced successfully from the far South of the country up to the Arctic Circle in the North. (66° N).

Ukraine is a country where estimates on the adoption of No-tillage vary greatly depending on the source of information. They go from less then 30.000 ha to more than a million ha. Official government statistics on No-tillage state an adoption of 250,000 ha. Unfortunately No-tillage systems as understood by the authors of this paper (see definition above) has not progressed as much as some people wish. According to Agrosoyuz (a big cooperative in Dnipropetrovsk) there are about 1.1 million ha of Direct Seeding technology being practiced in Ukraine. Direct Seeding is a technique were a specially designed machine seeds directly after the harvest of the previous crop into undisturbed soil. This type of machine, which is very widely used in Ukraine, does a virtually complete disturbance of the soil surface in the whole width of the seeding machine because they use wide tines and duckfoot openers. For this reason this form of seeding can not be termed No-tillage and can only be classified as reduced tillage or mulch tillage. Agrosoyuz has organized several No-till conferences in Dnipropetrovsk inviting many renowned international speakers and since then understanding has been growing that only low disturbance systems bring additional benefits, justifying the focussing on No-tillage. As there seems to be a substantial amount of low disturbance No-tillage being practiced in Ukraine the authors of this paper, after carefully balancing information, have estimated the area under No-tillage provisionally at 100.000 ha.

Russia: In Russia No-tillage is often referred under the umbrella term Resource Saving Technology. Despite all the efforts made to get at least some information on the area under No-tillage in Russia it was not possible to get realistic numbers for this country. We need to recognize that in this huge country it is difficult to get reliable data on the area under No-till. On the other hand those people that have closer contact with Russia will know that several machine manufacturers have exported No-till machines to Russia in significant numbers. For this reason there should be a considerable area under No-tillage being practiced in this country. We hope to be able to get reliable estimates on the area under No-tillage in Russia in the future.

Development of No-tillage in Africa

No-tillage in Africa is in a state of intensive promotion for the last decade. Reporting levels are still low, even where some massive large scale adoption is taking place, like in Sudan. Adoption is in the early stages of building capacities and setting up structures for upscaling (FAO 2008a).

South Africa has experienced only a modest growth in the area under No-tillage since the last World Congress on Conservation Agriculture in 2005 in Nairobi. According to Richard Fowler (personal communication, 2008) in 2008 about 368.000 ha under No-tillage have been reported in this country. Although research and practical results have identified that CA techniques can be applied with beneficial outcomes, this obviously has not been communicated in an appropriate form to farmers and technicians. South Africa needs to make bigger efforts to promote and spread No-tillage systems to overcome erosion problems and limited rainfall in many regions. The authors of this paper believe that this country presents excellent conditions for applying No-tillage technologies, e.g., adequate infrastructure, the presence of No-till clubs and government programs to promote Conservation Agriculture adoption.

Southern and Eastern Africa: For the last decade many African Countries, particularly in Southern and Eastern Africa have been exposed to No-tillage systems and CA and some of them have included this into their

government policies. A number of emergency rehabilitation projects promoted CA in several countries, such as Zambia, Zimbabwe and Swaziland. Conservation Agriculture activities and promotion programmes exist especially in Kenya, Tanzania, Zambia, Zimbabwe, Lesotho, Swaziland, Mozambique and Malawi and CA has also been incorporated into the regional agricultural policies by NEPAD (New Partnership for Africa's Development) and more recently by AGRA (Alliance for a Green Revolution in Africa). So far the area in ha is still small, since most of the promotion is among small farmers, but there is a steadily growing movement involving in the region already far more than 100,000 small scale farmers, with an adoption area in Kenya and Tanzania of about 20,000 ha.

Northern Africa: No-tillage systems have been promoted particularly in Morocco and Tunisia. In Tunisia the promotion and development was farmer centred and the area under No-tillage increased from 27 ha on 10 farms in 1999 to nearly 6000 ha on 78 farms in 2007 (Baccouri,2008).

General Overview of Conservation Agriculture/No-tillage Adoption World Wide

Data presented ten years ago at the 10th ISCO Conference in West Lafayette, Indiana, showed a world wide adoption of the No-tillage technology of about 45 million ha (Derpsch, 2001). Since then the system has continued to grow steadily especially in South America where the MERCOSUR countries (Argentina, Brazil, Paraguay and Uruguay) are using the system on about 70% of the total cultivated area. More than two thirds of No-tillage practiced in MERCOSUR is permanently under this system, in other words once started, the soil is never tilled again.

It is well known that only a few countries in the world conduct regular surveys on CA/No-till adoption. The data presented in this paper is mainly based on estimates made by farmer organizations, agro industry, well informed individuals, etc. The authors have been careful to only include data that seems well founded and reliable. Table 4 shows an overview of CA/No-till adoption in those countries that have more than 100.000 ha of the technology being practiced by farmers and table 5 shows the area under No-tillage and the percent of adoption by continent.

It is estimated that at present no-tillage is practiced on more than 105 million hectares world wide. As table 5 shows 46.8% of the technology is practiced in South America, 37.8% is practiced in the United States and Canada, 11.5% in Australia and New Zealand and 3.7% in the rest of the world including Europe, Asia and Africa. The latter are the developing continents in terms of CA/No-till adoption. Despite good and long lasting research in these continents showing positive results for no-tillage, this technology has experienced only small rates of adoption.

Interesting Developments in Some Other Countries

Switzerland has made remarkable progress in terms of research, development and adoption of No-tillage practices. Research performed in Switzerland over more than ten years has shown equal or better yields under No-tillage in a variety of crop rotations. No-till tends to be more and more accepted in Switzerland. This is because conventional tillage (and also reduced tillage practices as chisel ploughing) expose the soil to erosion under the topography prevailing in this country. According to Swiss No-till <http://www.No-till.ch> No-tillage is applied on about 12.500 ha and this corresponds to about 3.5% of arable land in this country. The Swiss No-till website offers very useful information on No-tillage in French and German. The No-till ABC offers answers from practitioners to frequent questions posed by farmers.

North Korea: Since 2002 FAO has been supporting Conservation Agriculture/No-till through a TCP project in the Democratic People's Republic of Korea (DPRK). The FAO project showed that "No-tillage is a technically viable, sustainable and economic alternative to current crop production practices. After some years the scientific community, the ministry of agriculture and the farmers directly involved in the FAO project have been fully convinced of the economic benefits of crop rotation, No-tillage and straw mulching, which increased yields and reduced inputs. The project demonstrated the value of these CA practices for weed control, soil moisture retention and improvement of soil conditions for crop development" (FAO, 2007). During this period Korean farmers adopted No-tillage techniques also for rice growing with great success as well as for potatoes, integrating both crops into CA crop rotations with permanent No-tillage. Starting on 3 cooperative farms CA is now practiced on about 30 cooperative farms on an area of about 3,000 ha the limitation being the availability of No-tillage equipment. In Sukchon County, which has been declared CA-model county by the Ministry of Agriculture, the No-tillage rice area in 2008 was 70% of the total rice area (personal communication from the Sukchon County Farm Management Committee).

Germany: Despite long term research in No-tillage systems that goes back to the 1970's, with positive results for the technology, adoption in Germany is still very small when the definition applied in this paper is used (see

Table 4. General overview of Conservation Agriculture/No-tillage adoption

Country	Area under No-tillage (ha) 2007/2008
USA ¹	26.593.000
Brazil ²	25.502.000
Argentina ³	19.719.000
Canada ⁴	13.481.000
Australia ⁵	12.000.000
Paraguay ⁶	2.400.000
China ⁷	1.330.000
Kazakhstan ⁸	1.200.000
Bolivia ⁹	706.000
Uruguay ¹⁰	672.000
Spain ¹¹	650.000
South Africa ¹²	368.000
Venezuela ¹³	300.000
France ¹⁴	200.000
Finland ¹⁵	200.000
Chile ¹⁶	180.000
New Zealand ¹⁷	162.000
Colombia ¹⁸	100.000
Ukraine ¹⁹	100.000
Russia ²⁰	?
Others (Estimate)	1.000.000
Total	105.863.000

Source: Derpsch, R. and Friedrich, T., 2008, unpublished data.

Information provided by: 1) CTIC, 2007; 2) FEBRAPDP, 2005/06; 3) AAPRESID, 2006; 4) Dr. Doug McKell, Soil Conserv. Council of Canada, 2006; 5) Bill Crabtree, 2008, 6) MAG & CAPECO, 2008; 7) Li Hongwen, 2008; 8) Mekhlis Suleimenov, 2007; 9) ANAPO, Bolivia, 2007, 10) Miguel Carballal AUSID, 2007; 11) Emilio González-Sánchez, AEAC/SV, 2008; 12) Richard Fowler, 2008; 13) Rafael E. Perez, 2004; 14) APAD, 2008; 15) Timo Rouhianinen, FINCA, 2008; 16) Carlos Crovetto, 2008; 17) John Baker, 2008; 18) Fabio Leiva, 2008; 19) Estimate by the authors

Table 5. Area under No-tillage by continent

Continent	Area (hectares)	Percent of total
South America	49.579.000	46.8
North America	40.074.000	37.8
Australia & New Zealand	12.162.000	11.5
Asia	2.530.000	2.3
Europe	1.150.000	1.1
Africa	368.000	0.3
World total	105.863.000	100%

definition above). Well informed scientist, farmers and experts with a thorough understanding of CA/No-till as practiced in most parts of the world coincide, that probably there are no more than 5000 ha of this technology being practiced by farmers in Germany. At the same time one can recognize that there are outstanding farmers practicing No-tillage in Germany like for instance Thomas Sander who farms in Oberwinkel, Saxony and receives many visitors every year. <http://www.infofarm.de/sn/BetriebSander/index.html> The quality of his No-tillage operation with crop rotations and cover crops has earned his farm the Environmental Award of the State of Saxony 2006. With boosting fertilizer and fuel prices, erosion problems in some regions and regular droughts in others, the interest in No-tillage is growing steadily and adoption is increasing. Some farmers like Alfons Bunk from Suabia are using continuous No-till for more than 10 years successfully.

Concluding Remarks

With increasing awareness that sustainability of agricultural production is a must if sustainable development at national and global level is to be achieved, Conservation Agriculture/No-tillage systems will continue to grow world wide. But for sustained growth to take place the main barriers to No-till adoption have to be overcome.

- Mindset (tradition, prejudice)
- Knowledge on how to do it (know how).
- Availability of adequate machines
- Availability of adequate herbicides
- Adequate policies to promote adoption

These barriers must be overcome by politicians, public administrators, farmers, researchers, extension agents and university professors. With adequate policies to promote Conservation Agriculture/No-till, it is possible to obtain what is called the triple bottom line, economic, social and environmental sustainability, while at the same time improving soil health and increasing production.

The wide recognition as a truly sustainable farming system should ensure the growth of this technology to areas where adoption is still small as soon as the barriers for its adoption have been overcome. The widespread adoption also shows that No-tillage can not any more be considered a temporary fashion, instead the system has established itself as a technology that can no longer be ignored by politicians, scientists, universities, extension workers, farmers as well as machine manufacturers and other agriculture related industries.

References

- AAPRESID, 2008. <http://www.aapresid.org.ar> consulted in December 2008
- Baccouri, S. 2008. Conservation Agriculture in Tunisia. Conservation Ag. Carbon Offset Consultation, West Lafayette/USA, October 2008. FAO-CTIC
- CTIC, 2005. Conservation Technology Information Center, CTIC, National Crop Residue Management Survey 2004.
- Derpsch, R. 2001: Frontiers in Conservation Tillage and Advances in Conservation Practice. In: D.E.Stott, R.H.Mohtar and G.C.Steinhardt (eds). 2001, Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24 -29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory, p 248-254
- Derpsch, R., 2008. No-tillage and Conservation Agriculture: A Progress Report. In: Goddard, T., Zebisch, M.A., Gan, Y.T., Ellis, W., Watson A. and Sombatpanit, S. (eds) 2008. No-Till Farming Systems. Special Publication N°3, World Association of Soil and Water Conservation, Bangkok, p 7-39.
- FAO, 2007. Conservation agriculture in China and the Democratic People's Republic of Korea. FAO Crops and Grassland Service Working Paper. FAO,2007, 23 p.
- FAO, 2008. What is Conservation Agriculture. in: Conservation Agriculture website of FAO, <http://www.fao.org/ag/ca/1a.html>
- FAO, 2008a. Towards Alleviation of Poverty in the Tropics: An International Technical Workshop on Investing in Sustainable Crop Intensification: The Case for Improving Soil Health. Proceedings FAO, Rome: 22-24 July 2008
- FEBRAPDP, 2008. <http://www.febrapdp.org.br> consulted in December 2008.
- Flower, K., Crabtree, B. and Butler, G., 2008. No-till Cropping Systems in Australia, In: Goddard, T., Zebisch, M.A., Gan, Y.T., Ellis, W., Watson A. and Sombatpanit, S. (eds) 2008. No-Till Farming Systems. Special Publication N°3, World Association of Soil and Water Conservation, Bangkok, p 457-467.
- Phillips, S.H. and Young, H.M., 1973. No-tillage Farming. Reimann Associates, INC., Milwaukee, Wisconsin.

Adoption and Impact of Conservation Agriculture-based Resource Conserving Technologies in South Asia

Olaf Erenstein

*International Maize & Wheat Improvement Centre (CIMMYT), NASC Complex, Pusa Campus, New Delhi, India
(Email: o.erenstein@cgiar.org)*

The stagnation of productivity growth in South Asia's rice-wheat systems has led to increased calls for conservation agriculture based resource conserving technologies. To date, most significant progress has been made with addressing the challenge of reducing tillage. After an initial rapid spread of tractor-drawn zero tillage drills particularly in the north-west Indo-Gangetic Plains, the zero/reduced tillage wheat area seems to have stabilized there between a fifth and a fourth of the wheat area. Conventional tillage for wheat continues to decline, with an increased use in rotavator making up the difference – but its intensive shallow tillage goes against the conservation agriculture tenets. Zero tillage wheat allows for a drastic reduction in tillage intensity with significant costs savings as well as potential wheat yield increases. The cost-saving effect alone makes zero tillage profitable and is the main driver behind its spread. Zero tillage impacts so far have been primarily limited to the wheat crop. Moving rice-wheat systems towards conservation agriculture also implies tackling the challenges of reducing tillage for the subsequent rice crop, crop residue retention and diversification. Equity poses a final challenge and calls for a better understanding of livelihood implications and stakeholder dialogue/participation.

Keywords: Adoption; Impact; Zero tillage; Conservation agriculture; Indo-Gangetic Plains; rice-wheat systems

The Green Revolution transformed the Indo-Gangetic Plains (IGP) - spreading from Pakistan, through northern India and the Nepal terai region to Bangladesh - into the cereal basket of South Asia. The technological packaging of improved wheat and rice seed, chemical fertilizer and irrigation in an overall supportive environment for agricultural transformation led to rapid productivity growth and the advent of rice-wheat systems, which now cover an estimated 14 million ha in the region. Over the past decade productivity growth has however stagnated (Kumar et al., 2002; Ladha et al., 2003), leading to concerns over national food security and lagging rural economic growth. This has led to a quest for resource conserving technologies (RCTs) that reduce production costs, save water and improve production. Zero tillage (ZT) is one such promising technology as it typically saves energy, helps revert soil and land degradation (soil organic matter decline, soil structural breakdown, soil erosion) and leads to more efficient use of water and other inputs (Erenstein and Laxmi, 2008).

An RCT is any practice that conserves and/or enhances resource- or input-use efficiency (Erenstein et al., 2008b). 'Conservation agriculture' (CA) is a wider concept and involves minimal disturbance of the soil, retention of residue mulch on the soil surface and a rational use of crop rotations (FAO, 2007; Harrington and Erenstein, 2005; Hobbs, 2007). The CA principles -minimal soil disturbance, surface residue retention and crop rotation- along with profitability at the farm level, are increasingly recognized as essential for sustainable agriculture. Alternatively, ZT alone is an insufficient condition for CA. Indeed, competing crop residue uses and residue management practices impose significant challenges for surface residue retention across the tropics and sub-tropics (Erenstein, 2002; 2003). The distinction between CA and RCTs like ZT is important because ZT alone, while attractive in the near-term, may be unsustainable in the longer-term (Harrington and Erenstein, 2005). For instance the use of ZT without residue retention and without suitable rotations, under some circumstances, can be more harmful to agroecosystem productivity and resource quality than a continuation of conventional practices (Erenstein et al., 2008b).

Another problem with CA is that, in contrast to seed, it is not an embodied tangible technology. Instead, it is a basket of cultural practices around a common concept that implies the need for supporting component technologies and knowledge. This also makes the measuring of adoption and impacts of CA more problematic. The present paper synthesizes a number of issues and challenges related to the adoption and impacts of CA-based RCTs in the rice-wheat systems in the IGP.

Adoption of Reduced Tillage in Rice-Wheat Systems

To date, most significant progress in terms of CA-based RCTs in South Asia has been made with addressing the challenge of reducing tillage in the rice-wheat systems of the IGP. In a separate paper we have reviewed the

estimated adoption of ZT in India, where most of the adoption in S Asia is concentrated (Erenstein and Laxmi, 2008). ZT adoption for wheat in S Asia started in the second half of the 1990s and accelerated in the early years of the 21st century. Experts estimated the zero tillage/reduced tillage (ZT/RT) wheat area in the IGP amount to some 2 million ha in 2004-05 (www.rwc.cgiar.org).

Farm household surveys in 2003-04 confirmed significant adoption of ZT wheat in the rice-wheat systems of NW IGP: 34.5% of farmers in India's Haryana and 19% in Pakistan's Punjab (Erenstein et al., 2007b; Erenstein et al., 2007a; Farooq et al., 2007). The ZT adopter farms typically were partial adopters – i.e. only a share of their wheat area was put under ZT, with the remaining still under conventional tillage (Erenstein et al., 2007a; Farooq et al., 2007). This implies the actual area under ZT is typically less than the rate of adoption in terms of farmers. In winter/rabi season 2007-08 we revisited the same rice-wheat villages in Haryana surveyed earlier by Erenstein et al. (2007a). These visits show the ZT wheat area continued to increase, albeit at a slow pace, from an average share of village wheat area of 18% in 2004-05 to 24% in 2007-09 (Figure 1). As reported earlier (Erenstein et al., 2007a), reduced tillage area in these villages was still marginal, with farmers using either zero tillage or conventional tillage. Worryingly however, there has been a rapid increase in another new tillage system (OT), primarily using a tractor drawn rotavator (Figure 1). The rotavator typically implies a single pass of shallow intensive tillage which incorporates crop residues and pulverizes the soil. It thereby may be a RCT but it goes against the conservation agriculture tenets.

In winter/rabi season 2007-08 we also conducted a wheat tillage monitoring survey across 120 randomly selected villages Haryana and Indian Punjab. This study provided a more representative random sample of wheat cultivating villages, and included non-rice-wheat systems. Compared to the Haryana rice-wheat study area (Figure 1) the results show some marked divergences (Figure 2). First, the ZT area share is significantly lower – both in Haryana and Punjab – and showed a small decline over the period 2005-06 to 2007-08. Second, the reduced tillage (RT) area was a multiple of the ZT area and showed a small increase in both states. Extrapolating these estimates would imply a combined ZT/RT wheat area of 1.26 million ha in Haryana and Indian Punjab in 2007-08. The results also suggest that after the initial rapid spread of ZT in the NW IGP, the ZT/RT wheat area seems to have stabilized there between a fifth and a fourth of the wheat area. The study also shows that, particularly in Haryana (Figure 2), and similar to the other study (Figure 1), there was a marked increase in other tillage systems (primarily rotavator). The advent of the rotavator merits follow up research and active engagement with regional stakeholders as it offsets much of the gains implied by more CA-based RCTs like ZT and RT.

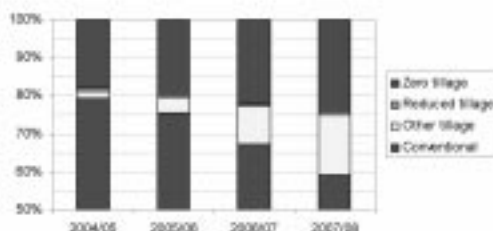


Figure 1. Recent evolution of wheat tillage in rice-wheat systems in Haryana, India (village survey findings, n=50)

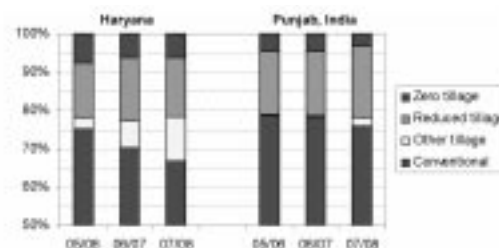


Figure 2. Recent evolution of wheat tillage systems in Haryana and Punjab, India (village survey findings, n=120)

Impacts of Reduced Tillage in Rice-Wheat Systems

ZT wheat has a number of advantages in rice-wheat systems by alleviating system constraints: earlier wheat planting, helping control obnoxious weeds like *Phalaris minor*, reducing costs and saving water (Erenstein and Laxmi, 2008). Erenstein and Laxmi (2008) provide a comprehensive review of the impacts of ZT wheat in India's rice-wheat systems. The review shows that ZT wheat after rice generates substantial benefits at the farm level (nearly US\$100/ha) through the combined result of a 'yield effect' and a 'cost-saving effect' (Erenstein and Laxmi, 2008).

The 'cost saving effect' primarily reflects the drastic reduction in tractor time and fuel for land preparation and wheat establishment. The tractor-drawn ZT drills allow tillage intensity to be drastically reduced for the wheat crop from eight tractor passes to a single tractor pass (Erenstein et al., 2007b; Erenstein et al., 2008a). This implies a significant, immediate and recurring cost saving which makes adoption profitable (Figure 3, corresponding with a 15-16% saving on operational costs – Erenstein et al., 2007b).

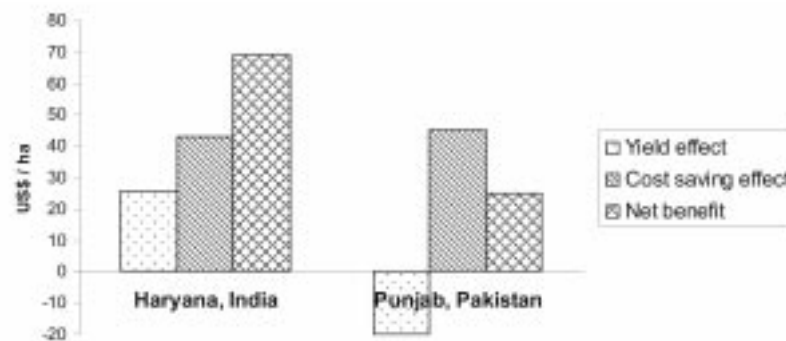


Figure 3. Financial advantage of ZT over conventional tillage for wheat in ZT adopter farms in 2003-04 in Haryana, India and Punjab, Pakistan (farmer survey findings, adapted from Erenstein et al., 2007b).

The review of ZT in India found a 'yield effect' amounting to a 5-7% yield increase for wheat being reported across studies (including on station trials, on farm trials, surveys - Erenstein and Laxmi, 2008). This provides a further boost to the returns to ZT. Farm survey results reported a 4% yield increase for wheat in Haryana (Figure 3 - Erenstein et al., 2007b; Erenstein et al., 2008a). The yield effect, if any, is closely associated with enhanced timeliness of wheat establishment after rice. Terminal heat implies that wheat yield potential reduces by 1-1.5% per day if planting occurs after mid November (Hobbs and Gupta, 2003; Ortiz-Monasterio et al., 1994). Approximately 30% of wheat cultivation is under late sowing in the Indian IGP, and ZT allows for timelier establishment. ZT adoption is closely associated with the farm resource base and rice-wheat specialization (Erenstein et al., 2007b). The significant wheat area of ZT adopters implies larger annual benefits, lower relative learning costs and earlier payback to a ZT drill investment.

In spite of the ZT success in irrigated agriculture in the IGP, the full environmental benefits offered by CA are yet to be fully utilized (Gupta and Sayre, 2007; Laxmi et al., 2007). Survey results show that the use of ZT in wheat had limited spillovers on the productivity and management of the subsequent rice crop (Erenstein et al., 2007b; Erenstein et al., 2008a). For the rice crop in the IGP, intensive and wet land preparation followed by transplanting still prevails. The reduction of tillage in rice-wheat systems has thus only been partially successful reflecting the increasing acceptance of ZT for wheat. Reducing tillage intensity for the subsequent rice crop still presents a challenge, particularly in terms of water and weed management and available germplasm (Erenstein, 2007).

The success of reducing tillage for wheat had much to do with the adequate development of delivery pathways of ZT drills: a mechanical tractor mounted seed drill that can seed wheat into an untilled rice field. Several factors proved crucial to its success in India (Seth et al., 2003:67). A local manufacturing capacity was developed to produce and adapt ZT drills at a competitive cost. The private sector could see substantial market opportunities for their products, whereas the involvement of several manufacturers ensured competitive prices, good quality, easy access to drills by farmers along with guarantee for repairs and servicing. Close linkages of scientists and farmers with the private manufacturers including placement of machines in villages for farmer experimentation allowed rapid feedback and refinement of implements. Private ZT service providers have made the lumpy technology divisible. Recent adoption surveys revealed that 60-74% of ZT adopters did not own a ZT drill (Erenstein et al., 2007b). Service providers have the added advantage of having hands on experience and having the self-interest in promoting the technology. Strong support from State and Local government officials helped with dissemination, including the provision of a subsidy to lower the investment cost and laying out extensive on-farm demonstrations and trials. The Rice Wheat Consortium (RWC) for the Indo-Gangetic Plains (www.rwc.cgiar.org) played a crucial catalytic role in promoting the public-private partnership, nurtured it through its formative stages and facilitated technology transfer from international and national sources (Seth et al., 2003). It has been estimated that the investments made by RWC and CIMMYT accelerated adoption of ZT/RT by five years and yielded significant economic benefits (a net present value of US\$ 94 million; a benefit-cost ratio of 39 and an internal rate of return of 57% - Laxmi et al., 2007).

The Crop Residue Management Challenge

Moving the rice-wheat system toward CA also implies tackling the challenge of crop residue management so as to ensure adequate retention of soil cover. In South Asia crop residues are an integral part of rural livelihoods.

Their utilization provides coherence to the prevailing smallholder crop-livestock systems (Devendra, 2007; Erenstein et al., 2007d), being important sources of livestock feed for the dominant species in the region (cattle, buffaloes and goats) and sometimes having other productive uses such as fuel, construction material and mulch. The relative importance of each use varies geographically and by crop, and is associated with poverty incidence (Erenstein et al., 2007d; Parthasarathy Rao and BIRTHAL, 2008; Singh et al., 2007; Thorpe et al., 2007; Varma et al., 2007). The intensity of residue utilization as feed thereby has an inverse association with farm size and a positive association with rural poverty in South Asia's IGP (Teufel et al., 2008).

The prevailing crop residue management practices in the IGP are largely incompatible with residue retention as mulch despite significant biomass production (Erenstein et al., 2007d). The *ex situ* use of crop residues as livestock feed is near universal and rigorous, whereas the increasing mechanization of rice and wheat harvesting practices has trade-offs in terms of residue use and management. Wheat is the traditional food crop in the northwest IGP and wheat residues are the corresponding basal feed for ruminant livestock. This implies significant imbalances in terms of seasonal residue extraction in the NW IGP, with surplus rice straw being burned *in situ* during land preparation (Bijay-Singh et al., 2008; Erenstein et al., 2007e; Gupta et al., 2004; Samra et al., 2003). This is particularly so after combine harvesting of non-fragrant rice (74% of rice straw according to farmers' estimations), compared to 22% burnt after manual rice harvesting, while in wheat, even after combine harvesting, only 10% is burnt (Teufel et al., 2008). Proceeding to the eastern plains, rice becomes the traditional food crop and rice straw the preferred basal feed. In the lower Gangetic plains where manual harvesting still prevails only an estimated 4% of the rice straw is burnt whereas 62% is fed, whereas in the same area straw from the less widely cultivated wheat crop is primarily burnt (71% according to farmer estimates) either as household fuel or on the field (Teufel et al., 2008). The widespread use as feed implies that crop residues have significant value and residue markets and institutional arrangements have developed accordingly. There are also significant regional variations in nonfeed residue uses (e.g., fuel, construction material).

Retention of crop residues as soil cover is imperative in continuous no-tillage systems (Erenstein, 2002). The widespread use of ZT wheat without necessarily maintaining some soil cover in the IGP has so far had limited perceivable negative consequences. This is, however, a consequence of the seasonal nature of ZT use, with plots still being seasonally tilled for the subsequent rice crop. However, with the year-round—or double no-till—rice-wheat system, residue retention becomes imperative.

Crop Rotation and Equity Implications

The rice-wheat system is characterized by a public incentive structure geared toward these staple foods of the subcontinent, including widespread public intervention in produce chains with assured produce prices and marketing channels in India. These provide a major obstacle for the third component of CA — the need for crop rotation. The combination of secure produce markets and irrigation-ensured yield stability makes rice and wheat production a low-risk venture that has proven difficult to displace. The rapidly evolving domestic markets in response to economic growth, urbanization, and emerging marketing chains imply promising opportunities for diversification of the rice-wheat system with selected vegetables, legumes, feed/fodder crops, and livestock products (e.g., dairy, poultry). Technological developments further enhance the scope for diversifying (Jat et al., 2006). There are, however, some challenges to capital- and knowledge-intensive diversification options that still need to be addressed in the IGP, for example, access to land and resources, and market chain development *vis-à-vis* bureaucracy and transaction costs (Erenstein, 2007).

Equity poses a final challenge and we need to recognize its implications—both geographically and within rural communities. In fact, references to the rice-wheat system in the IGP tend to be based on extrapolations of the NW situation, which is better documented. However, behind the apparent similarity are significant variations across the IGP—both in biophysical terms (Narang and Virmani, 2001) and socioeconomic indicators such as poverty and population density (Erenstein et al., 2007c). The NW IGP typically has more intensive and productive rice-wheat systems and a more favourable institutional support (Erenstein et al., 2007d). Rural development indicators in the Indian states of Punjab and Haryana now compare well with those of middle-income countries. Yet, large tracts of the IGP remain marred in dire poverty despite their agricultural potential. The main exponent of this is the poverty pocket of the eastern IGP, an area with 500 million people, typically characterized by smallholders (i.e., < 2 ha, >70–90% of farm households) and widespread poverty (>30% below the official poverty line, but more than two-thirds surviving on less than US\$2 per day). ZT wheat so far primarily benefited the northwest IGP and larger farmers (Erenstein et al., 2007a; Farooq et al., 2007; Laxmi et al., 2007). Although the early focus in the case of ZT R&D in

the rice-wheat system is in part justified in view of the risks inherent in technology development, there is an increasing need to directly target poorer areas and poorer households, particularly the poverty pocket of the eastern IGP (Erenstein, 2007).

A techno-centric approach and inherent diversity among stakeholders have often resulted in only partial stakeholder analysis, if any. Agricultural scientists have increasingly started to recognize the need to acknowledge the differential resource base of our target group—yet boundaries between what is considered a large farmer and a smallholder are often blurred. And, more worryingly, the implications for disadvantaged segments of society are often forgotten. This calls for a better understanding of livelihood implications and a broader stakeholder dialogue/participation in technology development (Erenstein, 2007).

Conclusion

The vast majority of farmers in South Asia's IGP have adopted RCTs like ZT because they provide immediate, identifiable and demonstrable economic benefits such as reductions in production costs and timely establishment of crops resulting in improved crop yields. But, in spite of the clear benefits and recent adoption of RCTs, most farmers, especially the small and medium scale farmers, have difficulties in following the wider basic tenets of CA, particularly residue retention and crop rotation. Most farmers do not retain crop residues on the soil surface as they use crop residues for other purposes, particularly to feed livestock. Therefore, building on the success of ZT/RT wheat, R&D still faces the challenge of adapting and developing sound, economic CA practices that all types of farmers will adopt year round and across crops in the system.

References

- Bijay-Singh, Shan, Y.H., Johnson-Beebout, S.E., Yadvinder-Singh, Buresh, R.J. 2008. Crop Residue Management for Lowland Rice-Based Cropping Systems in Asia. *Advances in agronomy* **98**, 117-199.
- Devendra, C. 2007. Small farm systems to feed hungry Asia. *Outlook on Agriculture* **36**, 7-20.
- Erenstein, O. 2002. Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological implications. *Soil & Tillage Research* **67**, 115-133.
- Erenstein, O. 2003. Smallholder conservation farming in the tropics and sub-tropics: a guide to the development and dissemination of mulching with crop residues and cover crops. *Agriculture, Ecosystems & Environment* **100**, 17-37.
- Erenstein, O. 2007. Resource conserving technologies in rice-wheat systems: Issues and challenges. In: *Science, technology, and trade for peace and prosperity. Proceedings of the 26th International Rice Research Conference, 9-12 October 2006, New Delhi, India* (P.K. Aggarwal, J.K. Ladha, R.K. Singh, C. Devakumar and B. Hardy, Eds.), pp. 523-530. International Rice Research Institute, Indian Council of Agricultural Research, and National Academy of Agricultural Sciences, Los Baños (Philippines) and New Delhi (India).
- Erenstein, O., Laxmi, V. 2008. Zero Tillage Impacts in India's Rice-Wheat Systems: A review. *Soil & Tillage Research* **100**, 1-14.
- Erenstein, O., Malik, R.K., Singh, S. 2007a. *Adoption and Impacts of zero tillage in the irrigated Rice-Wheat systems of Haryana, India*. Research Report. CIMMYT & RWC, New Delhi, India.
- Erenstein, O., Farooq, U., Malik, R.K., Sharif, M. 2007b. *Adoption and Impacts of Zero Tillage as a Resource Conserving Technology in the Irrigated Plains of South Asia*. Comprehensive Assessment of Water Management in Agriculture - Research Report 19. IWMI, Colombo, Sri Lanka.
- Erenstein, O., Farooq, U., Malik, R.K., Sharif, M. 2008a. On-farm impacts of zero tillage wheat in South Asia's rice-wheat systems. *Field Crops Research* **105**, 240-252.
- Erenstein, O., Hellin, J., Chandna, P. 2007c. *Livelihoods, poverty and targeting in the Indo-Gangetic Plains: a spatial mapping approach*. Research Report. CIMMYT & RWC, New Delhi, India.
- Erenstein, O., Thorpe, W., Singh, J., Varma, A. 2007d. *Crop-livestock interactions and livelihoods in the Indo-Gangetic Plains, India: A regional synthesis*. Crop-livestock Interactions Scoping Study - Synthesis. CIMMYT-ILRI-RWC, New Delhi, India.
- Erenstein, O., Thorpe, W., Singh, J., Varma, A. 2007e. *Crop-livestock interactions and livelihoods in the Trans-Gangetic Plains, India*. Crop-livestock interactions scoping study-Report 1. Research Report 10. ILRI, Nairobi, Kenya.
- Erenstein, O., Sayre, K., Wall, P., Dixon, J., Hellin, J. 2008b. Adapting no-tillage agriculture to the conditions of smallholder maize and wheat farmers in the tropics and sub-tropics. In: *No-till farming systems* (T. Goddard, M. Zoenisch, Y. Gan, W. Ellis, A. Watson and S. Sombatpanit, Eds.) Special Publication 3, pp. 253-278. World Association of Soil and Water Conservation (WASWC), Bangkok.

- FAO 2007. *Conservation Agriculture Website*. Available online at <http://www.fao.org/ag/ca/> (verified 16/4/07).
- Farooq, U., Sharif, M., Erenstein, O. 2007. *Adoption and Impacts of zero tillage in the Rice-Wheat Zone of Irrigated Punjab, Pakistan*. Research Report. CIMMYT & RWC, New Delhi, India.
- Gupta, P.K., Sahai, S., Singh, N., Dixit, C.K., Singh, D.P., Sharma, C., Tiwari, M.K., Gupta, R.K., Garg, S.C. 2004. Residue burning in rice-wheat cropping system: Causes and implications. *Current Science* **87**, 1713-1717.
- Gupta, R., Sayre, K. 2007. Conservation agriculture in South Asia. *Journal of agricultural science* **145**, 207-214.
- Harrington, L., Erenstein, O. 2005. Conservation agriculture and resource conserving technologies - A global perspective. *Agromeridian* **1**, 32-43.
- Hobbs, P.R. 2007. Conservation agriculture: what is it and why is it important for future sustainable food production? *Journal of agricultural science* **145**, 127-137.
- Hobbs, P.R., Gupta, R.K. 2003. Resource-Conserving Technologies for Wheat in the Rice-Wheat System. In: *Improving the productivity and sustainability of rice-wheat systems: Issues and impacts* (J.K. Ladha, J.E. Hill, J.M. Duxbury, R.K. Gupta and R.J. Buresh, Eds.) ASA Special Publication Number 65, pp. 149-172. ASA-CSSA-SSSA, Madison, Wisconsin, USA.
- Jat, M.L., Gupta, R.K., Erenstein, O., Ortiz, R. 2006. Diversifying the Intensive Cereal Cropping Systems of the Indo-Ganges through Horticulture. *Chronica Horticulturae* **46**, 27-31.
- Kumar, P., Jha, D., Kumar, A., Chaudhary, M.K., Grover, R.K., Singh, R.K., Singh, R.K.P., Mitra, A., Joshi, P.K., Singh, A., Badal, P.S., Mittal, S., Ali, J. 2002. *Economic Analysis of Total Factor Productivity of Crop Sector in Indo-Gangetic Plain of India by District and Region*. Agricultural Economics Research Report 2. Indian Agricultural Research Institute, New Delhi, India.
- Ladha, J.K., Hill, J.E., Duxbury, J.M., Gupta, R.K., Buresh, R.J., (Eds.) 2003. *Improving the productivity and sustainability of rice-wheat systems: Issues and impacts*. ASA Special Publication Number 65. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, Wisconsin, USA.
- Laxmi, V., Erenstein, O., Gupta, R.K. 2007. *Impact of zero tillage in India's rice-wheat systems*. CIMMYT and RWC, New Delhi.
- Narang, R.S., Virmani, S.M. 2001. *Rice-Wheat Cropping Systems of the Indo-Gangetic Plain of India*. Rice-Wheat Consortium Paper Series 11. RWC, New Delhi, India.
- Ortiz-Monasterio, J.I., Dhillon, S.S., Fischer, R.A. 1994. Date of sowing effects on grain yield and yield components of irrigated spring wheat cultivars and relationships with radiation and temperature in Ludhiana, India. *Field Crops Research* **37**, 169-184.
- Parthasarathy Rao, P., BIRTHAL, P.S. 2008. *Livestock in mixed farming systems in South Asia*. National Centre for Agricultural Economics and Policy Research & International Crops Research Institute for the Semi-Arid Tropics, New Delhi & Patancheru, India.
- Samra, J.S., Singh, B., Kumar, K. 2003. Managing Crop Residues in the Rice-Wheat System of the Indo-Gangetic Plain. In: *Improving the productivity and sustainability of rice-wheat systems: Issues and impacts* (J.K. Ladha, J.E. Hill, J.M. Duxbury, R.K. Gupta and R.J. Buresh, Eds.) ASA Special Publication Number 65, pp. 173-196. ASA-CSSA-SSSA, Madison, Wisconsin, USA.
- Seth, A., Fischer, K., Anderson, J., Jha, D. 2003. *The Rice-Wheat Consortium: An Institutional Innovation in International Agricultural Research on the Rice-Wheat Cropping Systems of the Indo-Gangetic Plains (IGP)*. The Review Panel Report. RWC, New Delhi.
- Singh, J., Erenstein, O., Thorpe, W., Varma, A. 2007. *Crop-livestock interactions and livelihoods in the Gangetic plains of Uttar Pradesh, India*. Crop-livestock Interactions Scoping Study-Report 2. Research Report 11. ILRI, Nairobi, Kenya.
- Teufel, N., Erenstein, O., Samaddar, A. 2008. *Impacts of Technological Change on Crop Residue Management and Livestock Feeding in the Indo-Gangetic Plains*. Paper presented at Tropentag, October 7-9, 2008, Hohenheim, Germany.
- Thorpe, W., Erenstein, O., Singh, J., Varma, A. 2007. *Crop-livestock interactions and livelihoods in the Gangetic plains of Bihar, India*. Crop-livestock Interactions Scoping Study - Report 3. Research Report 12. ILRI, Nairobi, Kenya.
- Varma, A., Erenstein, O., Thorpe, W., Singh, J. 2007. *Crop-livestock interactions and livelihoods in the Gangetic plains of West Bengal, India*. Crop-livestock Interactions Scoping Study-Report 4. Research Report 13. ILRI, Nairobi, Kenya.

Session 4.2: Equity Issues (Employment, Drudgery and Regional Disparities, etc.)

Conservation Agriculture for Drudgery Alleviation in SSA

Josef Kienzle¹, Amelie Berger², Brian Sims³ and Tom Apina⁴

¹FAO, Rural Infrastructure and Agro-industries Division, Rome Italy

²FAO Consultant, Plant Production and Protection Division, Rome, Italy

³Engineering for Development Consultant, Bedford, UK

⁴African Conservation Tillage Network (ACT), Nairobi, Kenya

At the beginning of the new millennium, rural livelihoods in many parts of the world, and especially in sub-Saharan Africa (SSA), are under considerable stress and poverty remains endemic. Agriculture lies at the core of rural livelihoods and has a major influence on the standard and quality of lives of millions of people. In SSA, the viability of rural livelihoods is threatened by many factors that reduce agricultural productivity, these include: a decline in soil fertility, farm power shortage, frequent droughts and extreme climatic events, low access to input and output markets. The low asset base level of rural households is also an important feature. In SSA, smallholder farmers often rely on a very small cultivated area, have no (or low) investment possibilities and produce food mainly for subsistence. Generally SSA smallholder farmers wish to avoid risk taking and this can hinder change.

There is a worrying shortage of farm power in SSA. In this context, developing innovative labour-saving practices is very relevant and conservation agriculture (CA) may have the potential to provide forward looking solutions. Several SSA studies have shown that CA saves labour and reduces drudgery for smallholder farmers.

Although CA has been widely adopted in other regions, adjustments are required for it to fit with the specific constraints of smallholder farmers in Africa. Indeed while adopting CA, smallholder farmers will face inevitable constraints: technical (especially maintaining soil cover and weed control), financial (especially investment in equipment) and social (especially free-grazing and peer pressure related to traditional customs).

A comparison between the significant Latin American experience and the beginnings of CA adoption in SSA may shed some new light on CA suitability for smallholder farmers. Lessons can be learned from the more widespread adoption of CA in parts of Latin America, to promote CA in Africa. The potential of CA to save labour and reduce drudgery, while producing food and protecting natural resources is real. It is worth while to undertake efforts (principally institutional and financial support) to support CA systems that are adapted to smallholder farmers' real life situations in SSA.

Description of the Situation

In SSA, agriculture is an essential sector¹ and the vast majority of people living in rural areas work on farms. However, smallholder agriculture remains a low-profit activity: produce prices tend to be variable and low; governments withdraw from trading in agricultural input and produce marketing; markets and services are not available for farmers in remote areas; and external shocks like droughts, floods and cattle diseases are hitting production. In SSA, the agricultural sector faces difficulties in providing a basis for wider economic development, as it remains more at a subsistence level rather than commercially viable production.

But the main concern is that today food security is not ensured in SSA. African food production is not enough to feed the continent and the number of people suffering from hunger is still growing. According to FAO, 212 million people in Africa, or 30% of the continent's population, were chronically hungry in 2003 - 2005 (FAO, 2008a).

In SSA, agriculture is mainly done by smallholder farmers, who rely on very little cultivated area (often less than 2ha) and often struggle to produce food for their household. Their economical balance is fragile with a very weak financial base, and so they have low investment capacity. They have also insufficient farm power and a little equipment. Farming mostly, relies on family labour and hand tools. FAO estimated that, in the late 1990s, 65% of the cultivated area in SSA was prepared by hand, 25% by draught animals, and 10% by tractors (FAO, 2003). A typical farm family in the region, that is reliant on human power, can only cultivate up to 1.5ha per year. This will rise

¹For example, in Ethiopia, Malawi, Uganda, and United Republic of Tanzania, agriculture is the backbone of the economy, generating more than 35% of GDP (World Bank, 2000) and employing more than 80% of the workforce (FAO, 2001).

to 4ha if draught animal power (DAP) is available and to 8ha if tractor power can be accessed (Sims and Kienzle, 2006).

Farm power, which includes the availability of human labour, work animals, engine power, tools and equipment to carry out work, is a crucial input in the agricultural production process. In SSA, the availability of farm power is often a limiting factor that hinders the productivity of the farm. Many households respond to power farm shortages by scaling down their activities, reducing the area under cultivation and growing a limited range of less labour-intensive crops (Sims and Kienzle, 2006). In so doing food security decreases and the household becomes increasingly vulnerable to external shocks. Today in SSA, farm power availability, that is to say the capacity to cultivate the land by whatever means, is a greater constraint to production than access to land.

The Shortfall of Farm Power in SSA

- Improved access to education and persistent urban migration are drawing children and young adults away from farming. The human workforce is also severely hit by HIV/AIDS and malaria, which reduces the number of healthy people available for farm work. In eastern and southern Africa the impact of HIV/AIDS on the agricultural sector is already noticeable. Losses in agricultural workforce due to HIV/AIDS vary from 5% in Ethiopia, Malawi and Tanzania to 12% in Uganda. As a consequence, the number of rural households headed by widows, orphans and the elderly is growing and they tend to be among the poorest households of the community. The erosive impact of illness and death on family labour and other assets is severe: the sick are weak or cannot work on the farm anymore, taking care of the sick requires time and large sums of money, savings are spent and equipment or draught animals may be sold to get cash for medical expenses and funerals (Bishop-Sambrook, 2005). This downward poverty spiral increases the vulnerability of fragile households.
- The stock of draught animals has been severely restricted by diseases (especially trypanosomiasis and East Coast fever) in some regions. Other factors such as droughts and lack of fodder, distress sales and theft also have an impact on the viability of DAP.
- From the 1980s to 1990s, government tractor-hire services were closed and support for private-sector tractor purchases and hire services were gradually abolished (Bishop-Sambrook, 2005). Today it is difficult to obtain spare parts and repairs are expensive, so tractors in an operational state are rare. Generally the failure of tractor-services has resulted in a reduction of the area cultivated, as communities revert to draught animals and human power.

All these factors that reduce the availability of farm power and so compromise the ability to cultivate sufficient land have long been recognized as source of poverty in the region (Iliffe, 1987).

Given that hand tools and human power predominate, in SSA many aspects of smallholder farming are drudgery, especially for women. The roles of men and women in farming are well defined, with men responsible for land clearing and soil preparation and women responsible for planting, weeding, harvesting and post harvest activities (World Bank, FAO, IFAD, Gender in Agriculture Sourcebook, 2009). Weeding with the hand-held hoe is the most punishing and time consuming task, causing fatigue and backache. Mechanization has been mainly developed for high-power requirement tasks such as primary tillage and land preparation so mostly benefits men. Mechanization could even generate additional workloads for women: tractor- and animal-drawn ploughs are used by men to increase their labour productivity, and so the area cultivated, with negative consequences for women who then have more weeding and harvesting work using only handheld tools.

In short, land preparation requires most farm power in the production cycle and weeding takes the most time. When power and equipment are limited, the subsequent tasks become bottlenecks in the production system. Farm power is one of the most crucial inputs in the agricultural production process, because it determines in part the area under cultivation, the timeliness of operations and the productivity of the system. Farm power shortage is becoming a serious concern in SSA and two strategies can be proposed to counter the challenge:

- Making existing tasks easier and increasing the productivity of existing labour and draught power,
- Changing farming practices to methods that use less farm power.

Conservation Agriculture is a potential solution to save labour and reduce drudgery in both these scenarios.

CA as a Potential Solution

One way to reduce the labour and farm power demand for small-scale agricultural production systems is to shift from conventional farming practices (such as ploughing, planting and hand weeding by hoe) to more innovative

practices that use labour more efficiently. CA, while maintaining or improving the production level, offers a set of practices that may save labour and farm power: no- (or reduced) tillage; direct-seeding; cover crops and rotations that suppress weeds and restore fertility. CA overcomes the critical labour peaks of land preparation and weeding by planting directly into mulch or cover crops, with weed control being achieved by soil cover as well as by hand tools and herbicides.

CA as a Labour Saving Practice

Studies in SSA have shown that CA practices can significantly reduce labour and farm power needs for smallholder farmers when compared with traditional plough- or hoe-based practices (Bishop-Sambrook *et al.*, 2004).

The first observation is that CA practices usually require less time and fewer labourers than the traditional ones (especially after weed problems have been eliminated in the first few seasons). The jab planter requires only one person to make the holes and plant the seeds (the two operations are performed simultaneously) whereas other methods require at least two people (one for digging, one for planting). Similar observations can be made with respect to DAP systems. Two persons are required for leading the animal and operating the equipment. With the DAP no-till planter, these two operators are sufficient (and even one is enough with practice), whereas with the traditional plough, a third person is required to plant seeds in the furrows and cover them (Bishop-Sambrook *et al.*, 2004).

In the case of hoe cultivators, it has been shown that significant savings in labour can be realized in all activities (Table 1).

Table 1. Comparison of labour inputs between conventional and conservation agriculture systems, for hoe cultivators (Bishop-Sambrook *et al.*, 2004)

Activity	System (hours/ha)		Labour saved by CA over conventional	
	Conventional	Conservation agriculture	Hours saved/ha	%
Land clearance	Slash and carry off the field 115	Slash and one herbicide application at planting time 52	63	55
Land preparation and planting	Digging with hand hoe and planting 120	Planting with jab planter 47	73	60
Weeding	Hoe and panga, roguing 172	Hoe and panga, roguing 54	118	70
Total	407	153	254	60

A study on the impact of conservation tillage and cover crops on soil fertility and crop production in northern Tanzania verified that the saving of labour days through the adoption of CA practices reaches 54% in the fourth year of CA practice (Mariki, 2003). While the labour requirements for conventional tillage maize remained stable at about 65 person-days/season, the labour requirement for no-tillage maize plus cover crop was halved from 72 to 35 person-days/season in year four (Mariki, 2003).

Table 1 shows that every operation requires a shorter time under CA, giving an overall labour saving of 60%, which can be vitally significant in a farm power shortage scenario, such as a widow-headed household.

Similar conclusions can be drawn from DAP farming systems. The use of a DAP no-till planter gives a 50% of labour saving. The task (land preparation and seeding) is completed more quickly and requires fewer draught animals: two oxen instead of the four needed for the traditional plough.

CA avoids tillage; it makes land preparation and planting quicker and easier, using specific implements to plant or seed directly through a vegetative mulch into an untilled soil. But weeding is also significantly reduced eventually: one herbicide application at planting time and permanent soil cover make weeding easier. This is an important factor in order to reduce women's labour burden, and it is also important for yields, because a late and incomplete weeding can account for more than 40% of yields losses for small scale farmers (Bishop-Sambrook *et al.*, 2004).

CA may Reduce the Burden of Women's Labour

Manual land preparation, traditionally done by men in much of SSA, is now often the job of women. It's a very laborious and time consuming job, and the necessary hand tools are often not well adapted to women as they are too heavy (IFAD, FAO, Japan, 1998).

Planting with a jab planter is definitely less tiring than tilling with hand hoe. Most of time the jab planter is welcomed by women, who perceive it as a sign of progress compared with the hand hoe, even if they struggle to master it initially (Bishop-Sambook *et al.*, 2004)

The main benefit of CA as perceived by farmers (and especially by women) is the reduction in weeds and consequently in the amount of time spent weeding (Bishop-Sambook *et al.*, 2004).



Figure 1. Traditional hoe vs jab planter

Clearly if weed control is achieved with herbicides the labour requirement, compared with hoeing and roguing, will be markedly different. However if traditional and CA systems using hand hoeing are compared then there is little difference, especially in the initial seasons. But in CA systems, without soil inversion, the weed burden is reduced with time. Several SSA case studies have reported this effect. For instance, a study from Tanzania showed that in Arumeru, after 2 or 3 cycles, weeding can be reduced from three per season to two. In Karatu the relation is 3:1 (Shetto and Owenya, 2007).

The weed control qualities of good soil cover have been noted by farmers. The employment of a dual approach with mucuna and glyphosate was able to control spear grass (*Imperata* spp.) in Ghana (Boahen, *et al.*, 2007). And in Siaya, Kenya, rotations including lablab or desmodium were able to reduce dramatically the incidence of witch weed (*Striga hermonthica*) in cereal crops (Kaumbutho & Kienzle, 2007).

Women in particular may benefit from this reduced weeding aspect when switching from traditional farming to CA.

CA may not Save Labour Immediately

Some aspects of the CA system are labour demanding rather than labour saving. In particular, the management of the cover crop requires additional labour to establish and then for controlling it before planting the main crop. This additional work can be a serious hurdle if the household is already suffering from labour scarcity. But it is often readily overcome if cover crops show particularly interesting benefits, for example if they provide food for the household, fodder for livestock, or have positive effects on weed control and soil fertility.

The benefits of CA are not immediate: a few years of CA good practice (suitable cover crops, rotations and abundant mulch) are necessary to get the full benefits of this system, that is to say better yields, labour savings and restoration of soil fertility. Indeed the production system changes and a new stable equilibrium situation only establishes after several (three or so) years. Furthermore the farmer has to learn the characteristics of the new system before mastering it.

Particularly, as noted earlier and emphasized now, during the first years of CA weeding requirements may increase, especially if the soil cover is not sufficient and if herbicides are not used, which is often the case in SSA. In Ghana for example, weed control remains a challenge, especially when farming is done manually. As most farmers do not manage to keep their soils adequately covered, reducing tillage tends to allow aggressive weed

growth. Controlling weeds then requires hand-weeding numerous times or the use of herbicides. For many resource-poor farm families, neither option is feasible (Boahen *et al.*, 2007).

This feature hinders the adoption of CA especially among vulnerable farming households.

Inevitable Constraints

Even if CA seems really interesting because of its potential to reduce drudgery and to save labour and farm power, while ensuring an important level of production, it is not a miracle solution. In SSA, CA is facing new challenges to adapt to smallholder farmers' specific constraints.

A) Technical Constraints

- The difficulty of achieving permanent soil cover is one of the principle barriers to achieving full CA in many African smallholder farming situations.

In SSA, livestock is often an integral part of the farming system, and traditionally crop residues are used for feeding livestock. It is a common practice to allow livestock to graze in the harvested crop fields or to slash the crop residue and store it for fodder. But CA requires a critical level of crop residues to remain on the soil surface, therefore in the CA adoption process, competition can arise for their use. Farmers have to strike a balance between maintenance of mulch for the next crop and feeding livestock, and it could be a serious issue for vulnerable households.

The problems of establishing and maintaining soil cover are summarised by the Karatu, Tanzania case (Shetto & Owenya, 2007) where the struggle that farmers have is one of too little biomass, inadequate knowledge of how to establish fodder plots (to ease grazing pressure) and persistent conflict of interests (between grazing and soil cover).

There are other pressures on vegetative soil cover: e.g. burning crop and weed residues prior to soil preparation is a common practice and individual attempts to maintain soil cover are risky; termites are voracious consumers of surface organic material and can make achieving permanent soil cover extremely difficult.

It is definitely a real challenge to achieve a suitable soil cover or cover crop stand to avoid problems of weed infestation.

- Weed control is one of the most important requirements in CA, and remains challenging in smallholder farming systems.

"Managing weeds with minimal soil disturbance is probably one of the biggest agronomic challenges that CA adopters have to contend with." (Kaumbutho & Kienzle, 2007).

Often in CA systems, either herbicides are used or weeding remains an arduous operation, tiring and time-consuming. Herbicides are a useful tool for weed management, particularly in the first years after shifting from conventional farming to no-till farming. It is much easier to do no-till farming with herbicides than without, both for weed control and cover crop management.

A crucial constraint to good weed control in CA systems is the cost involved for labour and/or sprayers and herbicides. Inputs for CA, and especially herbicides, sometimes are simply not available to farmers. They could be available in towns or in market centres, but not at local level for farmers living in the remote countryside. Even when inputs or equipment are available they are often too expensive and thus unaffordable for small-scale farmers (Kaumbutho & Kienzle, 2007).

Other problems associated with weed control include:

- Persistent weeds. These can be species that develop a resistance to glyphosate (e.g. couch grass and amaranthus) or weeds that thrive under the new conditions produced by CA, e.g. water grass which prospers under the higher soil water regimes with soil cover.
- Free grazing of livestock removes cover crops and crop residues and makes the maintenance of permanent soil cover difficult to achieve. This will, of course, undermine the effect of soil cover on weed suppression.

- The use of sprayers requires operator training on calibration and safe use. Smallholder farmers are notoriously cavalier about the need for applying correct application doses to ensure optimum efficacy and cost efficiency.

B) Economic Constraints

A few inputs and/or investments are necessary to practise CA: seeds for cover crops, herbicides and new implements for direct seeding like the job planter or animal-draught direct planter. The positive outcome may not be immediate, as CA benefits are medium- and long-term. So in the first years CA may not lead to clear benefits while requiring more labour and investments up front. This feature hinders the adoption of CA especially among vulnerable farming households which have very little investment capacity. Smallholder farmers can rarely afford to risk adopting a farming practice that requires them to invest much without a guaranteed immediate positive outcome, especially if they have no access to technical assistance.

The unavailability of specific implements (direct seeders, sprayers) is also a serious problem. For the introduction of CA in a new area, tools have been imported, often from Brazil, to be tested by farmers in their fields. As a second step they should be manufactured locally, as they are quite simple equipments. But in reality local artisans are not willing to make a new tool without being sure they could sell it easily. So the specified equipments for CA are lacking, slowing down or preventing the adoption of CA (Kaumbutho & Kienzle, 2007).

C) Social Constraints

Community peer pressure is also a serious hurdle to overcome, as it requires conformity from the whole community and sometimes a change in traditional ways of thinking.

Farmers are considered good and hard-working by their peers if they keep their fields clean and plough them. Farmers who keep crop residues as soil cover on their fields and use no-till practices are considered lazy (WorldBank, FAO, IFAD, Gender in Agriculture Sourcebook, 2009).

Free grazing of livestock after crop harvest means that it is difficult for an individual CA farmer to maintain soil cover. Changes in local customs and byelaws are not usually easy to arrive at in a mutually amicable way as different groups may have vastly different views on the matter. Nomadic herders, for example, are unlikely to respect local rules which curtail their customary grazing practices. The reality for smallholder farmers in South Africa (Bolliger *et al.*, 2008) is that a very small proportion of no-till farmers are able to maintain >30% soil cover for more than two months after harvest.

Land tenure is another sensitive feature in traditional rural communities. The retention of residues and not ploughing may not be recognised as “farming”, and sometimes conflicts can arise between CA adopters and other farmers. It may happen that a neighbour ploughs a field that is under no-till, because they think it is not cultivated (Bishop-Sambook, 2004). An enforcement of land rights may be required to protect CA adopters while introducing CA.

Regional Disparities

It is possible that the success story of CA in South America may not be immediately replicated in SSA. This section analyses some of the disparities between the situations in the two regions.

The Success Story of CA in South America

CA has been evolving in Brazil (and to some extent in other Latin American countries). The very good environmental and economic performances of CA systems and the implementation of supporting policies led to a fast and wide adoption of this system. In the southern states of Brazil, CA has been promoted by public bodies for research and rural extension services (maintained by the state government with the support of municipalities). The implementation has always been done with a participative strategy, including farmer groups at the watershed level. Farmers contributed to finding agronomic solutions (by adapting cover crop management and rotations) suitable for their farming systems and by designing specific implements for direct planting in collaboration with local machinery industries. Even private companies like cooperatives, agro-industries and small rural industries have been involved in CA expansion. This multi-stakeholder strategy has been very effective and successful, as CA is now reaching 60% of the total agricultural area in the south of Brazil (Derpsch, 2005).

In South America, CA has been promoted and widely adopted mainly because it was an efficient solution for the soil erosion problems. But then CA also shows additional benefits regarding labour savings and reduction of drudgery. A study of the economic impacts of CA adoption in smallholder farms in Paraguay has shown that improved yields and labour savings resulting from CA improve farm incomes and hence the living conditions of the households (Lange, 2005). Agriculture becomes a profitable activity. The reduced drudgery and the improved profitability bring concrete benefits to the living standards of CA-adopting households: they are able to buy more goods (TV, fridge, motorcycle, horses), they are able to invest and to diversify their farm activities, the school-aged children can attend school (thanks to labour savings), and the sons no longer wish to migrate to urban areas in the same numbers and are willing to stay to work on the farm (Lange, 2005).

What are the Differences between South America and SSA that could Prevent the Successful Adoption of CA in Africa?

The Brazilian experience should inspire extension agencies to promote and extend CA in smallholder farming situations in Africa. But the South American and African contexts are very different and so maybe Brazilian solutions or development patterns cannot be immediately and easily replicated.

Smallholder farmers in SSA have lower asset-bases, lower investment capacities than farmers that are considered to be smallholders in Brazil. For example, smallholder farmers in Africa often cultivate less than 2ha, whereas in Brazil they could have between 5 and 20ha (de Freitas, 2000). Less than 30% of African smallholder farmers use draught animal power, whereas in Brazil farm power (either from draught animals or tractors) is rarely a major constraint. Therefore African smallholder farmers have less possibility to take risks in farming, which hinders change and innovation. They would need more technical assistance and financial support from extension and credit services to share in this risk-taking whilst new practices are being tested.

In SSA the economic context is also not particularly favourable for the development of the agricultural sector (ACT, 2008):

- The infrastructure for linking farmers to markets is poorly developed (with difficult access to input and output markets). Facilities for value addition (e.g. crop processing) are lacking too.
- The lack of agricultural finance services to support investment in agriculture hinders farmers' ability to adopt innovations.
- Advisory services are weak, and smallholder farmers have no or little access to technical assistance or information (ACT, 2008).

On the other hand, in Brazil, the market for inputs and agricultural produce, the rural infrastructure and the private sector (especially the agricultural machinery manufacturing sector) are well-developed. This dynamic private sector played an important role in the implementation of CA, as the manufacturers collaborated closely with farmers and researchers to design CA equipments. This is a key feature in the Brazilian success story.

Furthermore in Brazil, a strong support system is in place, especially finance and extension services, and they were very effective for supporting CA adoption.

For the particular case of small-scale farmers in Brazil who use animal traction, hand-tools and micro-tractors, there were substantial grant schemes and other financial incentives provided by the public sector that enabled them to obtain direct seeding equipment for these power sources. This in turn facilitated the development and strengthening of the family based small scale agricultural equipment industries especially those focussing on planters and small sprayers (Kienzle and Sims, 2008).

In SSA people are also facing severe pandemics (malaria, HIV/Aids, tuberculosis), droughts and animal diseases that restrict the use of draught animals. These features have a negative impact on agricultural production. In Brazil, there is to date less impact of pandemics to contend with, so farm families tend to be healthier.

To conclude, the contexts are very different but lessons can still be learned from the South America experience to spur adoption in the SSA context. The innovative participatory and flexible approach, which involves multiple stakeholders interacting among themselves (farmers, manufacturers, researchers, input supplier, development agencies) should work also in Africa. But it requires the general development of a strong public support system: strengthening of the infrastructure; grants and incentives for farmers; technical and business training for manufacturers

Table 2. Key issues for CA development and adoption in Brazil and East Africa

Issues	Brazil	East Africa
Support systems in place (especially finance and extension)	quite well developed	weak conditions of support system especially the finance
Knowledge and networking	strong links between different actors	networking and knowledge sharing is beginning to evolve through various channels
Synergy between public and private sectors	very active	not yet well developed but strong efforts are being made
Developed private sector agricultural machinery manufacturing sector	well developed	very weak due to perceived lack of demand (affordability)
Rural infrastructure	support infrastructure in place	weak infrastructure support systems (roads, electricity, services) in place
Markets for inputs and agricultural produce	functioning input and output market system	pro-active interventions from government and development agencies needed to establish and sustain markets
Availability of adequate farm power	available	severe farm power shortage
Health care system	functioning with to date no severe pandemics to contend with	Under stress and with limitations due to multiple reasons

and other key supply chain stakeholders; and training at every level (farmers, extension agents, policy makers). Table 2 summarises some of the key issues and contrasts the situation in Brazil and East Africa

The Role of the CA-SARD Project and the African Conservation Tillage Network (ACT)

The ACT has been established to coordinate CA efforts at a continent-wide level in Africa. Its prime role is to promote synergistic networking between key stakeholders in the CA development chain with the goal of bringing the benefits of CA to millions of smallholder families in SSA. The role of networking is to create a platform that stimulates and facilitates dialogue on issues related to CA to enhance the exchange of knowledge, information and experiences among stakeholders. ACT has evolved to be key broker in knowledge and information sharing².

In addition to being a broker for the dissemination of CA knowledge and information, it also plays a key role in coordinating FAO's flagship CA project in East Africa, the CA-SARD³ project which is being implemented in Kenya and Tanzania. It is an important development which has led to awareness creation and adoption of CA in the East African region by smallholder farmers. The project uses a farmer field school (FFS) methodology to introduce the CA concept to farmer groups and the project has created awareness at the local, national and regional levels through training, farmer to farmer exchange visits, farmer field days and workshops/seminars. Through the FFS approach, the project has so far reached almost 10 thousand smallholder farmers and has resulted in a 60% adoption rate covering nearly 28 thousand acres under CA. The project has also focused on training agricultural extension workers and by doing so has become a reference point for other projects in the region. The project has stimulated collaboration with the private sector, especially with regard to CA equipment manufacturers and importers some of whom are now supplying the emerging East African market.⁴

The situation in Africa is in stark contrast to the achievements in South America. CA equipment is being imported (from Brazil principally) to countries such as South Africa. But the indigenous manufacturing industry is in its infancy. In East Africa there are several manufacturers making simple equipment, mainly based on Brazilian concepts – although the Zamwibe herbicide applicator made in Zambia is a notable exception to this. These include jab planters, animal-drawn planters and knife rollers. International development organizations, especially FAO, have mounted several pilot projects for CA (FAO, 2008b). These have included the provision of imported machinery for no-till planting, knife rollers and herbicide application sprayers for human and animal traction. However in order

²An aim inspired by the former Secretary General to the UN, Dr Koffi Annan, when calling for a “uniquely African” Green revolution in Addis Ababa on 5 July 2004: “ Knowledge is not lacking. The basic policy directions are well established and widely accepted. What is lacking, as ever, is the will to turn this knowledge into practice”.

³Sustainable Agriculture and Rural Development

⁴ For more information see also: <http://www.fao.org/sard/en/sard/754/2322/2317/index.html>
<http://www.act-africa.org>

to make the adoption of the CA approach more sustainable, it is envisaged that procurement of such equipment would be better handled through the private sector. Looking further ahead, there is a desire that, in a long term, such equipment should be manufactured in the East African Region in order to boost the rural industrial sector and create skilled employment (Apina and Sims, 2008).

The second phase of the CA-SARD Project has been designed to fulfil the following objectives (Apina and Sims, 2008) :

- Expanded adoption of profitable CA practices in Kenya and Tanzania
- Enhanced supply and availability of CA tools and equipments for farmers, -especially through improved private sector participation and networking between Brazil and East Africa.
- Strengthen knowledge sharing and networking between Brazil and East-Africa.

In this context, FAO organized a study tour and trade mission in 2008 to take would-be East African entrepreneurs to Brazil to interact with their Brazilian homologues. The purpose was to energize the East African CA equipment manufacturing sector to produce equipment adapted to their local conditions. Reduced tillage animal-drawn rippers are made extensively in East African countries together with sub-soilers for removing hardpans as a prerequisite to CA. Of course hoes and machetes are made industrially in a range of African countries, and are also imported into the region from China and India.

The small African manufacturers' study tour to Brazil highlights that (Kienzle and Sims, 2008):

- Project farmer groups trigger demand; they also participate in testing and proposing modification of the equipment.
- CA farmers need constant updating on the most appropriate practices of crop rotation, crop establishment, soil cover maintenance and management. It is only when these principles are put into practice that the CA equipment manufacturers will have a viable market for their products.
- An increasing demand is essential for batch production, and then to switch from batch production to mass production.
- A functioning support system (inputs, services, technical assistance, farm power availability) is needed, and on long term.

Conclusions

In SSA, CA **can** reduce drudgery and enhance women's equity even if there are serious potential constraints for smallholder farmers:

- a. Technical (especially weed control and soil cover)
- b. Economic (especially investment in inputs and equipment)
- c. Social (especially competition with livestock and community peer pressure).

The role of networking and knowledge sharing is essential to overcome the regional disparities and especially to boost the support systems for agriculture and CA to facilitate its evolution in SSA in the same way as in other regions.

The potential of CA for reducing drudgery, while producing food and protecting natural resources is real. It is worth while to undertake efforts (in the areas of institutional and financial support) to support CA systems that are adapted to smallholder farmers' real life situations in SSA.

Learning from the South American experience, we can conclude that:

- There is a real need for investing in agricultural support systems in general. Investment in the creation and dissemination of CA knowledge and information will contribute to a more stable food security situation and subsequently more stable livelihoods for many people in rural areas.
- Long-term commitments are needed from national and international technical support organizations.
- The need for capacity building concerns all levels (small farmers, small entrepreneurs, service providers, policy makers). Figure 2 gives an indication of the ingredients needed for a successful regional capacity building effort.



Figure 2. The CA 'Knowledge Wheel' which indicates the interactions and outputs needed at a regional level to promote the dissemination and adoption of CA practices amongst smallholder farmers in SSA

References

- ACT. 2008. "Linking production, livelihoods and conservation", Proceedings of the third world congress on conservation agriculture, 3-7 October 2005, Nairobi, African Conservation Tillage Network.
- Apina T, Sims B. 2008. "Proceedings of the East African and Brazilian Conservation agriculture manufacturers' trade mission workshop", IAPAR, Londrina, Paraná, Brazil, 19-21 May 2008. FAO, Rome.
- Boahen P, Addo Dartey B, Delali Dogbe G, Asare Boadi E, Triomphe B, Daamgard-Larsen S, Ashburner J. 2007. "Conservation Agriculture as practised in Ghana"; African Conservation Tillage Network, Centre de coopération internationale de recherche agronomique pour le développement (CIRAD) and FAO.
- Bishop-Sambrook C, Kienzle J, Mariki W, Owenya M, Ribeiro F. 2004. "Conservation agriculture as a labour saving practice for vulnerable households _ Suitability of reduced tillage and cover crops for households under labour stress in Babati and Karatu districts, Northern Tanzania", IFAD – FAO, Rome.
- Bishop-Sambrook C. 2005. "Contribution of farm power to smallholder livelihoods in sub-Saharan Africa", Agricultural and food engineering technical report 2, FAO, Rome.
- Bolliger A, Magid J, de Neergaard A. 2008. Why South African smallholders are not embracing zero-till : exogenous and endogenous constraints to smallholder zero-till adoption in KwaZulu-Natal. Unpublished report.
- Bot A, Benites J. 2001. Conservation Agriculture. Case studies in Latin America and Africa.; FAO Soil Bulletin 78, FAO, Rome.
- de Freitas, V.H. 2000. Soil management and conservation for small farmers. Strategies and methods of introduction, technologies and equipment. Rome, FAO Soils Bulletin 77. page 2
- Derpsch R. 2005. The extent of conservation agriculture adoption worldwide: Implications and impact, Proceedings of the 3rd world congress on conservation agriculture, Nairobi, Kenya, 3-7 October 2005; ACT, Harare
- FAO, 2008a. The State of Food Insecurity in the World 2008; High food prices and food security – threats and opportunities
- FAO, 2008b, Conservation agriculture website: www.fao.org/ag/ca
- FAO, 2003. World agriculture towards 2015/2030, an FAO perspective. Rome.
- IFAD, FAO, Japan Development Assistance. 1998. Agricultural implements used by women farmers in Africa
- Iliffe, J. 1987. "The African poor, A history". African studies series n°58, Cambridge, United Kingdom, Cambridge University press.
- Kaumbutho P ; Kienzle J. 2007. Conservation agriculture as practised in Kenya : two cases studies; African Conservation Tillage Network, Centre de coopération internationale de recherche agronomique pour le développement (CIRAD) and FAO. 109 p.
- Kienzle J, Sims B. 2008. Back To Office Report – Brazil mission 7 – 25 May 2008; FAO, Rural Infrastructure and Agro-industries Division (AGS)
- Lange D. 2005. "Economics and evolution of smallholdings conservation agriculture ; in Paraguay – Mid-term experiences", Asuncion, Paraguay; FAO, GTZ
- Mariki W.L. 2003. The impact of conservation tillage and cover crops on soil fertilità and crop production in Karatu and Hanang districts of Northern Tanzania (1999-2003); Selian Agricultural Research Institute (SARI), TFSC/GTZ technical report.
- Sims B and Kienzle J. 2006. "Farm power and mechanization for small farms in sub-Saharan Africa", Agricultural and food engineering technical report 3, FAO, Rome.
- Shetto and Owenya. 2007, Conservation agriculture as practised in Tanzania: three case studies; African Conservation Tillage Network, Centre de coopération internationale de recherche agronomique pour le développement (CIRAD) and FAO.
- World Bank, FAO, IFAD . 2009. Gender in Agriculture Sourcebook

Session 4.3: Common Property Resources

Contribution of Commons to Conservation Agriculture in Mountain Areas

Narpat S. Jodha

*International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal
(Email: njodha@icimod.org)*

Conservation agriculture (CA) in simple and practical terms implies conservation (including protection and upgrading) of natural resources base that sustains the diversified and inter-linked activities comprising agriculture. Conservation of the natural resources base (and therefore agriculture) is determined by pattern and processes of resource use (e.g. land use) under comprehensive or broad based agricultural systems, involving crops, livestock, farm forestry, water-moisture management etc. One of the components of agricultural systems particularly in developing countries, is the provision of village commons or common property resources (CPRs), especially in fragile and marginal lands with limited and high risk crop production potential. In such situations one of the community responses (or adaptations to bio-physical limitations) is to have provision of CPRs. The CPRs, broadly speaking are community resources (land, water, forest etc.) where whole community has access but no one has exclusive right to the resources. Besides collective access or usage rights, there are collectively evolved/designed obligations and responsibilities toward managing such resources. Thus CPRs are institutional arrangements, largely at community levels, to use and manage land resources (particularly fragile, marginal lands) unsuited for individually operated crop farming, but with significant contributions to the latter through multiple products and services available and used by the agriculturists.

This may be further added that the diversity, extent and contributions of CPRs on the one hand and combinations of community responses to them on the other, vary according to the features of landscapes or agro-ecological regions, such as the tropical deserts or mountains. In keeping with this fact, the present paper looks at the CPRs and their contribution to CA in mountain (including hill) areas of Himalayas. The paper is largely based on inferences and understanding generated by different studies carried out for over a decade by ICIMOD and its partner institutions in different locations in the ICIMOD's regional member countries including Bhutan, China, India, Nepal and Pakistan (Jodha et. al. 1992).

Furthermore, to understand the place and role of CPRs in facilitating conservation agriculture two additional issues are focused. First, we look at agriculture as a broad based phenomenon, where diversified, interlinked activities – annual and perennial cropping, livestock, farm forestry, horticulture and water – moisture management etc. are treated as pillars of agricultural system. Though for illustrations greater focus will be on crop based farming systems.

Degradation: Proximate Causes and Driving Forces

The second issue relates to the process of conservation agriculture, which in practical terms implies conservation of resource base of agriculture. To address this aspect, in the first place one has to look at the process of resource degradation and its indicators (e.g. rapid soil erosion, declining soil fertility or moisture retaining capacity). Finally, to evolve remedial measures against degradation process one has to address the factors causing and accentuating the degradation process. To effectively address these resource degrading factors or causes one has to distinguish between what are identified as (i) proximate causes of degradation and (ii) driving forces behind the process of degradation, which also activate the proximate causes of degradation. The following example will help. The crop land is degraded through inappropriate intensification of land use or planting of crops unsuited to particular area, causing rapid depletion of plant nutrition. In these cases inappropriate intensification or choice of inappropriate crops are identified as directly visible, immediate or proximate causes of degradation.

However, these causes themselves are a product more fundamental driving forces, such as increased population pressure on land causing inappropriate intensification of land use; or market, policy or technology driven pressures inducing not very appropriate crop choices. There are several examples of such processes in mountain and other areas.

In the situation described above, any options that can help the farmer to focus on alternatives to the above mentioned inappropriate responses to driving forces behind degradation, can help to minimize the resource degrading steps. In subsequent discussion we will comment on possible role of CPRs as potential contributor to reduction of resource degradation and promotion of CA in mountain areas, through reducing the impacts of driving forces.

Commons in Mountains: Centrality of Mountain Specificities

To understand the role and relevance of CPRs in CA (or for that matter understanding the relevance and effectiveness of any intervention in mountain areas) one has to look through the lens of specific conditions or circumstances of mountain areas, termed as “mountain specificities”. These inter-related mountain features with some intra-mountain differences in their operational extent, included limited accessibility, high degree of fragility, marginality (both biophysical and social), diversity, specific niche opportunity (including human adaptation practices to the above features). Table 1, which is quite self explanatory briefly summarises the bio-physical foundations of these conditions; their manifestations; and their operational implications or imperatives, in terms of possible approaches to manage constraints created by them and harness opportunities associated with them. Based on the contents of Table 1, one can identify the issues and areas of constraints and opportunities for restraining resource-degradation and thus helping conservation agriculture in mountain context, where CPRs play important role.

To understand the potential role of CPRs, it will be helpful to reiterate the already mentioned point on the process of resource degradation, namely the role of driving forces behind the degrading practices and patterns of resource use. Accordingly, the compulsions or motivations for specific resource use practices or their changes are rooted in scarcities (i.e. gaps between demand and supplies of agriculture products due to increased population pressures and consumer demands) or market and profit driven incentives to over extract the potential opportunities without concern for health and sustainability of the resource base. Other supportive factors such as state policies and a variety of vested interests also play important role in promoting inappropriate approaches and practices contributing to resource degradation.

Based on the implications or imperatives of different mountain specificities, one can indicate the situations where possibilities of resource degradation exist and where CPRs can help in reducing such possibilities. This is presented with reference to individual mountain specificities.

1. Inaccessibility or limited accessibility

Relative isolation, remoteness and limited dependability of external links compel strong focus on local production causing over exploitation and degradation of crop lands, when demand increases.

CPR Contributions

- a) Provision of vast areas for less intensive use (e.g. pastures, herbal collection etc.) reducing degradation;
- b) Despite poor accessibility incomes through rangeland – migratory livestock system, emerging new earning options through herbal collection, eco-cultural tourism etc. reducing pressure for crop intensification.

2. Fragility/Marginality

Both bio-physical and socio-economic marginality with limited and high risk agricultural (cropping) options, vulnerability to disaster risks etc. act as compulsions to over extract and deplete fragile resources.

CPR Contributions

- a) Provision of less intensive (i.e. non-cropping) usage of more fragile areas.
- b) CPR, as a part of diversified and more conservation friendly land use systems
- c) Diversified sources of non-covariate incomes (i.e. activities with different periods of input needs and output flows) promoting stability and reducing risk; other ways of collective sharing through CPR reducing the compulsions for inappropriate cropping intensities causing resource degradation.

3. Diversity

High potential for diversified, interlinked land based activities (including temporally and spatially appropriate crops and their sequencing/rotating; farming-forestry-livestock linkages and complementarities etc) minimizing the chances of resource degradation.

Table 1. Mountain specificities and their imperatives

1. Limited Accessibility	
a) Product of	• Slope, altitude, terrain conditions, seasonal hazards, etc.
b) Manifestations and implications/ imperatives	• Isolation, remoteness semi-closedness, poor mobility. • High cost of mobility, infrastructural logistics • Limited access to, and dependability of, external support. • Local resource centred, diversified production. • Local resource regeneration, protection, regulated use, recycling. • Nature and scale of operations as permitted by the degree of mobility and local resource availability.
2. Fragility and Marginality	
a) Product of	• Combined operations of slope/altitude, and geologic, edaphic, and biotic factors; biophysical constraints create socio-economic marginality.
b) Manifestations and implications/ imperatives	• Resources highly vulnerable to rapid degradation, unsuited to high intensity uses: low carrying capacity, low input absorption. • Limited, low productivity, high risk production options. • High overhead cost of resource use: obstacles to infrastructural development, under-investment, subsistence orientation of economy. • People's low resource capacity preventing use of high cost, high productivity options. • Resource upgrading possibilities(e.g. by terracing, water harvesting). • Diversification involving a mix of high and low intensity land uses, a mix of production and conservation measures, low cost, local resource use. • Local resource regeneration, recycling, regulated use, dependence on nature's regenerative processes, and collective measures.
3. Diversity	
a) Products of	• Interactions between different factors ranging from elevation and altitude to geologic and edaphic conditions, as well as biological and human adaptations to them.
b) Manifestations and implications/ imperatives	• A basis for spatially and temporally diversified and interlinked activities, heterogeneity-induced strong location specificity of production and consumption activities. • Limited applicability of activities meant for wider application, and limits to scale-associated benefits. • Small scale, interlinked diversified production/consumption activities: temporally and/or spatially differentiated for fuller use of environment. • Location-specific integrated, multiple activities with a focus on performance of total production system.
4. 'Niche' Opportunities	
a) Product of	• Unique environment and resource characteristics of biophysical conditions (people's traditional practices for adaptation to specific mountain conditions also part of 'niche').
b) Manifestations and implications/ imperatives	• Potential for unique products/activities (hydropower production, tourism, horticulture, timber, medicinal herbs, indigenous knowledge systems etc.), with significant comparative advantages to mountain areas. • The bulk of the potential remains under-utilized for want of resources and infrastructure (or selective over-extraction by external agencies).

Source: Table adapted from Jodha (1997), based on evidence and inference from over 20 studies from mountain areas of different countries, referred by Jodha and Shrestha (1994).

CPR Contributions

- a) CPRs as important component of diversified land use especially marginal parts of land.
- b) CPR as source of organic inputs, moisture-flow/management for crops indicating crop land – CPR complementarities.
- c) Overall diversification as defense against resource degradation

4. Niche

Unique opportunities usable at local as well as macro-levels; human adaptation experiences (folk engineering, folk agronomy, collective informal institutional arrangements) to manage and harness resources and opportunities.

CPR Contributions

As a part of human adaptations, presence of community initiatives helping:

- a) Multiple/diverse sources of earning, reducing the pressures for agricultural intensification and consequent resource degradation.
- b) Traditions and culture of collective risk sharing and resource management systems, rooted in the institution of CPRs, with scope for replicating in other contexts.
- c) Organic components of niche (sustained through CPRs) help enrich the resource base of agriculture.

Dynamics of CPR change

The scope and opportunities through which CPRs can contribute to CA or help prevent resource degradation practices (or their underlying compulsions) summarized above, largely characterized the traditional systems of natural resource use systems in mountain areas with several location specific variations. However, under the changed current situation, they are slowly marginalized. The factors that contributed to agricultural resource degradation also had their role in marginalization of CPRs in most of the regions.

The major high lights of this change at regional, community and individual household levels are present under Tables 2 and 3 below. These Table are quite self explanatory. However, the key driving forces behind this change can be briefly commented upon. This may help in designing approaches and measures not only to revive CPRs but can also contribute towards promoting agricultural systems with reduced resource degradation.

Mountain CPRs: The Traditional Context

As already alluded to the traditional situation in mountain areas was characterized mainly by very limited external links and largely local resource centred subsistence oriented resource use systems (by relatively smaller populations), on the one hand and crucial dependence of village community on diverse and fragile resources requiring balancing of production and conservation needs. This created the circumstances that favoured the provision of CPRs. The resource use systems or people's adaptation to high risk, low productivity environment was driven more by supply side limitation rather than demand side compulsions (Jodha 1998). The relevant inferences from details under Table 3, could be summarized as indicative circumstances favouring provision of CPRs at regional, community and household levels. These circumstances (summarized under Table 3 reduced the efficacy of individual – centred (or fully) private property led strategies for risk reduction and harnessing of fragile, marginal, diverse resources. The collective efforts to ensure low intensity usage of fragile lands/steep slopes through a variety of CPRs became unavoidable. Hence greater reliance on activities based on complementarity between CPR and PPR (private property resumed) based resource use systems. Low population and absence of land market for fragile, marginal lands as private property also favoured CPRs. More importantly, low pay off and practical difficulties in using fragile lands intensively as private crop lands etc. further induced the need and action for collective strategies and group action to regulate the usage of such resources to fit in to the diversified farming systems linking crops, livestock and forest etc. Thus both demand and supply side factors favoured the use of fragile lands as CPRs. The customary rights or local resource autonomy as well as (people's) practical and intimate knowledge of resource limitations to guide land use, further helped it (Jodha et.al. 1992, Jodha 2001, Dove and Carpenter 1992).

Gradual Marginalization of Traditional Arrangements

As indicated by Table 4, the traditional arrangements guiding natural resource use systems including protection and management of CPRs in mountain areas, were slowly made less effective and more difficult. The process of this change is closely associated with closer integration of mountain areas with outside mainstream economic, political and administrative situations. The closer integration (despite its several benefits), had some side-effects in terms of marginalizing or disregarding the customary rights and norms as well as mechanisms and practices, which were evolved overtime to manage CPRs and NRB in general. The overall impact of the involved changes

Table 2. Circumstances Historically Associated with CPRs in Mountain Areas

Features of Natural Resource Base and Traditional Human Adaptations¹		
(High extent of fragile resources, vulnerable to degradation with intensive use; dominance of low productivity – high risk production options, limited surplus generation and reinvestment; isolation and semi-closed situation; mutually reinforcing environmental, socio-economic vulnerabilities and poverty; human adaptation to above through group action and local institutions in predominantly subsistence oriented systems)		
Regional Level	Implications and Imperatives at: Community Level	Farm Household Level
a. Low population pressure; relative market isolation; limited technological and institutional interventions. b. Limited incentives and compulsions for privatization of CPRs. c. Overall circumstances (a,b) favourable to high extent of CPRs and transhumance.	a. Heterogeneity, fragility and marginality of resource base; inadequacy of private risk strategies; need for group action to protect collective stake in local resources. b. Balancing extensive-intensive land uses; focus on collective risk sharing and supportive local institutions. c. Community responses to (a,b): provision of CPRs (their protection, access, usage, etc.).	a. Narrow, unstable production base; diversified, biomass centred, land extensive farming systems. b. Reliance on collective measures against seasonality and risk. c. Induced by (a,b) stronger focus on complementarity of: CPR-PPR (private property resources)-based activities, annual-perennial based activities etc.

1) For details on mountain specificities promoting the adaptations involving CPRs and NRB in general (Jodha 1998, 2007).

Table 3. Changed Circumstances Adversely Affecting CPRs in Mountain Areas

Economic, Institutional and Technological Changes Influencing the Patterns of Resource Use¹		
Increased physical, administrative and market integration, increased extent and changed nature of public interventions, increased demographic pressure, etc. shaping the pace and pattern of rural development affecting CPRs		
Regional Level	Implications and Imperatives at: Community Level	Farm Household Level
a. Population growth accentuating land hunger. b. Public policies enhancing legal/ illegal private and public encroachment on CPR/ privatization. c. Technologies and market forces activating the land market, extending even to fragile/marginal lands. d. Over all circumstances (a,b,c) unfavourable to CPRs.	a. Development and market led differentiation of rural community and decline of collective strategies for resource management, risk sharing etc. b. Usurpation of community's mandates, initiatives by the state through legal, administrative and fiscal means. c. Emphasis on acquiring CPRs as private property, rather than use collectively. d. Due to (a,b,c) rapid erosion of community concerns and group action for CPRs.	a. Reduced area and productivity of CPRs, marginalizing their contribution to diversified and biomass-centred production strategies. b. Individualization of adjustment measures against risk vulnerability and seasonality etc. c. Reliance on private resource, public relief, non-biomass oriented technologies, etc. d. Due to (a,b,c) reduced reliance on complementary of PR-PPR (private property resources) activities/products.

1) For details of the process of changes and their consequences. See Jodha (1998, 2007).

(Sanwal 1989, Jodha 1992, Jiyuan et.al. 2002) was in terms of altering the circumstances that favoured CPRs. The key drivers behind this change were population growth (directly or indirectly induced by integration) inducing land hunger; enhanced role of market forces encouraging privatization of CPR; public interventions (administrative, fiscal and technological measures) with little sensitivity to CPRs in fragile areas and disregard of traditional institutional and folk-agronomic measures to manage fragile lands (Jodha 2001, Somanathan 1991, Jodha and Partap 1993).

The most effective combined effect of all these developments has been the decline of culture and practice of collective action and autonomy of community arrangements relating to local resource management (Jodha 1998). The attitudinal and other societal changes led to replacement of collective strategies by individualised, privately focused approaches and activities involving the commons (e.g. grabbing CPRs as private property or overexploiting them). Various tendencies promoted by economic globalization also significantly contributed to the above changes (Jodha 2007).

Table 4 summarises the key variables of the above process. Accordingly, while the biophysical factors and processes supporting need for CPRs remain broadly unchanged, the socio-economic pressures and processes have acquired primacy and have significantly contributed to the decline of CPRs in terms of both their extent and productivity as well as local knowledge and management systems. The pace and pattern of the above is much greater in developed and better accessible mountain areas compared to the others. Similarly, in the villages with strong traditional leadership and greater social cohesion, situation is better in terms of health of CPRs. However, the general situation is broadly as indicated by Table 4, (which is quite self explanatory). The table puts together the indicative changes at regional, community and individual farm household levels, which portrays the picture that is completely opposite of the situation i.e. circumstances and their consequences, presented in Table 3. The obvious result of this change is reduced concern for and actions about promoting and protecting CPRs.

Emerging Scenarios: Impact of Globalisation

Concerned with the decline of the commons, there has been several efforts to salvage the situation. Apart from the research and advocacy to rehabilitate CPRs, there have been several public policy-programme interventions (such as user group forestry and joint forest management programme in Nepal and India respectively). Besides, NGO, donors and community supported activities focused on revival of individual CPR types and CPR units are also multiplying. These efforts however show rather mixed success (Jodha 2001).

While the positive efforts to rehabilitate CPRs are yet to make significant dent on the situation, the new challenges to sustain CPRs as productive social assets are emerging fast. They result from the more stronger market forces associated with the process of economic globalization rapidly covering the mountain areas (Gupta 2006).

The Globalisation Process

Economic Globalisation, with primacy to market friendly and market driven processes, is one of the most debated and yet rapidly promoted phenomenon of the world today. There is hardly any sector or region of the world unaffected by globalization. Mountains commons are no exception. Before we illustrate this, a word on visible or invisible incompatibilities between the central thrusts and operating mechanisms of globalization and imperative of already alluded mountain specificities, which necessitated and facilitated the provision of CPRs. While mountain specificities favoured diversification of resource use and production systems (including CPRs), globalization encourages selectivity and narrow specialization; while mountain specificities call for supply condition-driven adaptations, globalization pushes for enhanced demand-driven over exploitation of resources including fragile lands; and their selected products such as herbs; finally globalization promotes privatization of activities, which are better suited to collective/group initiatives. In the process of promoting the above, globalization tends to marginalize the state as well as the communities vis-à-vis market forces. To understand the manifestation of the above with reference to CPRs, one should look at the globalization induced changes in the role of agencies/driving forces adversely affecting CPRs. These agencies and their operational mechanisms directly or indirectly and individually or jointly affecting the present situation of CPRs are: (Jodha 2007).

- (i) **The state:** operating through its policies and programmes including through transfer of CPR lands to corporate sector or environmental agencies discarding customary rights and livelihoods of the locals
- (ii) **The market forces:** promoting privatization or elimination of CPRs and with the state help (marginalizing the role of communities vis-à-vis the local commons and traditional systems).
- (iii) **The increasing differentiation of rural communities:** depleting the collective stake in CPRs; encouraging privatization through encroachment rather than focusing on collective use, specially when strong incentives from market are available.

- (iv) The CPRs themselves (representing nature or natural resource base) with their largely degraded status inducing little hope and action on the part of rural communities to rehabilitate CPRs, specially when there are incentives and compulsions to ignore them (Jodha 2001).

The extent or intensity of tendencies unfavourable to CPRs, on the part of the above agencies, accentuated due to globalization process are discussed below. The discussion is based on an exploratory study of globalization and its impacts on mountain areas and communities in selected mountain areas of China, India, Nepal and Pakistan by ICIMOD and its country-partners (Jodha 2002). The study revealed a number of emerging trends. Ones relating to CPRs vis-à-vis the above mentioned agencies i.e. state, rural community, market forces and 'nature' itself, are discussed below. However, one of the central findings of the explorations was that the imperatives of mountain specificities (see Annex A and Table 1) which favoured the provision and protection of CPRs are by passed under the activities and processes promoted by globalization through the above agencies.

Reclaiming CPRs

For those concerned with the contributions and crisis as well as future of CPRs, the account presented above is not very encouraging. Yet one can search for salvage possibilities. The latter could be based on potential adaptations to the emerging circumstances, which are adversely affecting CPRs. Following the percept that every problem also carries seeds of its solution, the elements of remedial approaches to the current problems of CPRs could be identified from within the complex of factors affecting them. Accordingly, we can mention the indicative areas, where search for potential solutions could be focused accordingly.

Closer observation and understanding of the factors and processes characterizing the pace and pattern of changes in CPR situation suggest the need for addressing the following, (often interrelated) issues while searching the revival options for CPRs.

- (i) Reviving the community's collective stake in CPRs to help rehabilitate them.
- (ii) Recognising the emerging centrality of market mechanisms and harnessing their potential for CPR revival.
- (iii) Changing the priorities and preferences regarding CPR products and services and designing natural resource management/development interventions accordingly.
- (iv) Changing the role and responsibilities of state in keeping with the needs and imperatives of the above (i) to (iii).

The above mentioned issues are elaborated by (Jodha 2007).

References

- Berkes, F. (1989) Editor. *Common Property Resources: Ecology and Community-Based Sustainable Development*. London: Belhaven Press.
- Bijonness, I.M. (1983) 'External Economic Dependency and Human Adjustment to Marginal Environments in High Himalaya, Nepal.' *Mountain Research and Development* 3(3): 263-72.
- Dove, M.R. and C. Carpenter (eds.) (1992) (editors) *Sociology of Natural Resources in Pakistan and Adjoining Countries*. Lahore: Vanguard Books Pvt. Ltd.
- Ghate, R., N.S. Jodha and P. Mukhopadhyay (eds.) (2008) *Promise, Trust and Evolution: Managing the Commons of South Asia*. London, Oxford University Press.
- Gupta, R. (2006) *The Dynamic between States, Resources and Indigenous People in South Asia: Implications for Common Property Resource Governance (Paper for the 11th Biennial Conference of IASCP, in Bali)*.
- Jiyuan, L., Yansui, L., Xiangzheng, D. (2002). *Management and Use of Natural Resources for Poverty Alleviation in Mountainous Areas of Western China*. In: N.S. Jodha, B. Bhadra, R. Khanal, and J. Richter (eds). *Poverty Alleviation in Mountain Areas of China* (Proceedings of the International Conference held in Chengdu, China, November 2002).
- Jodha, N.S. (1992) 'Rural Common Property Resources: A Missing Dimension of Development Strategies.' *World Bank Discussion Paper No. 169*. Washington, D.C.: The World Bank.
- _____ (1998) 'Reviving the Social System-Ecosystem Links in the Himalayas.' In *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*, edited by F. Berkes and C. Folke. Cambridge, UK: Cambridge University Press.

- _____. (2001) 'Poverty and Environmental Resource Degradation: An Alternative Explanation and Possible Solutions.' In *Life on the Edge: Sustaining Agriculture and Community Resources in Fragile Environments*, edited by N.S. Jodha. Delhi: Oxford University Press.
- Jodha, N.S., M. Banskota and T. Partap (eds) (1992). *Sustainable Mountain Agriculture, 2 vols*. Delhi: IBH Publishing Company.
- Jodha, N.S. and T. Partap (1993) 'Folk Agronomy in Himalayas: Implications for Research and Extension.' In *Rural People's Knowledge, Agricultural Research and Extension Practices*. IIED Research Series 1(3). London, IIED.
- Jodha, N.S. and S. Shrestha, (1994). Sustainable and More productive Mountain Agriculture: Problems and Prospects. A paper presented at ICIMOD's 10th Anniversary, International Symposium on '*Mountain environment and development*'. Kathmandu, Nepal.
- Jodha, N.S. (2007) Mountain Commons: Changing Space and Status at Community Levels in the Himalayas. *Journal of Mountain Science*, Vol. 4(2), Chengdu, China.
- Sanwal, M. (1989) 'What We Know about Mountain Development, Common Property, Investment Priorities and Institutional Arrangements.' *Mountain Research and Development*, 9(1).
- Somanathan, E. (1991) 'Deforestation, Property Rights and Incentives in Central Himalaya.' *Economic and Political Weekly* 26(1).
- Tamang, D., G.J. Gill and G.B. Thapa (1996) Editors. *Indigenous Management of Natural Resources in Nepal*. Kathmandu: Winrock International Nepal.

Governance and Institutional change in Traditional Commons: Lessons from Chhattisgarh, India

Dinesh K. Marothia

*Vice-President, National Institute of Ecology, 50-B Pocket C, Sidhartha Extension, New Delhi 110 014, India
Corresponding address: 19, Professor Colony, Krishak Nagar, Raipur, 492 006, Chhattisgarh, India
(Email: dkmarothia@yahoo.com)*

Chhattisgarh, an Indian state, has innumerable multi-use common water bodies (MUCWBs). These water bodies are being administered and controlled under different property rights regimes by different state departments. Fisheries in MUCWBs dates back to time immemorial in Chhattisgarh and have been traditionally managed under common property regime. In recent past fisheries in MUCWBs have been managed under cooperative governance structure – an internal institutional structure model of distributed governance system. Fishermen communities/resource users groups and the state or local village government shared the responsibility of managing fisheries by combining appropriate institutional skills of local resource users/local committees and technical, administration and financial resources available with the states. Fisheries cooperative societies (FCSs) have been assigned usufruct rights to use MUCWBs for fisheries subject to certain socio-economic and administrative conditions. Under the Fisheries Policy of Government of Chhattisgarh, first preference has been/is being to FCSs to leased in MUCWBs irrespective of water spread area. MUCWBs can only be leased out to fisherman groups and individual fisherman if FCSs do not bid for leasing in MUCWBs or FCSs are not existing in a particular village. Further, in order of priority, fisherman community is being given first preference to lease out MUCWBs. The issues related to management of traditional MUCWBs by FCSs are complex due to different categories and characteristics of these common water bodies, scale, size and coverage of FCSs and multiple stakeholders and agencies involved in governing the water resources. Looking to the importance of MUCWBs for fish culture, irrigation, and other domestic uses in Chhattisgarh this study was undertaken to provide an overview of governance structure of fisheries in MUCWBs and to discuss outcomes of an indepth analysis of four FCSs, which have covered different categories of MUCWBs administered under different property rights regimes. This study has also discussed performance of individual fisherman who have leased in MUCWBs. Findings of a quick well focused case study of Self Help Groups is also presented. The study has suggested workable institutional arrangements for sustainable management of MUCWBs to reduce poverty and vulnerability of poor stakeholders.

Key words: Multi-use common water bodies, fisheries, fish cooperatives, property rights regimes, distributed governance, institutions

A sizable proportion of the people in rural India depend directly for their livelihood on traditional common pool renewable natural resources like soils, water, fisheries, forests, pasture, wildlife, and biodiversity. India is endowed with extensive multi use common water bodies (MUCWBs) in the form of small water storage bodies, village ponds irrigation and multipurpose tanks MUCWBs constitute an important component of community assets in India. These water bodies have been used as traditional commons by the village communities since centuries to meet their domestic needs and practicing fish farming.

In India fish farming in MUCWBs dates back to time immemorial and still plays a fundamental role in sustaining the livelihoods of millions of rural poor, providing food and nutritional security and opportunities for diverse and variable categories of income and employment generation. Governance and institutional structures of MUCWBs for culture fisheries hold considerable potential to contribute to poverty alleviation. In recent years there has been a spurt in the growth of fresh water aquaculture in the country. The present production level of about 2.2 tons/ha/year from fish farming can be raised considerably by streamlining the production from inland culture fisheries and enhancing productivity and production including diversifying aquaculture practices with well design institutional arrangements for governing inland fisheries in MUCWBs. In a few Indian states, including Chhattisgarh, efforts have been made to design more efficient policies and governance regimes for sustaining culture fisheries in MUCWBs in view of devolution process of Panchayat Raj Institutions (PRIs) or local governing institutions in terms of function, functionaries, and funds. MUCWBs are being administered and controlled by different State Departments and local village governments under different property rights regimes in the state of Chhattisgarh. A few evidences are available in the state of Chhattisgarh when ponds and tanks degraded under open access system brought under a state or private or community management regime through appropriate changes in institutional arrangements and authority system (Marothia 1992a, b, 1993, 1995, 1997a, 1997b, 2002, 2004a). In recent years fish culture in ponds and tanks has been managed under internal institutional structures of distributed governance or shared management system in India including in the state of Chhattisgarh.¹ Fishermen communities/resource users groups and the state or local government (panchayat) shared the responsibility of managing fresh water aquaculture by combining

appropriate institutional skills of local resource users/local committees and technical, administration and financial resources available with the states. In the state of Chhattisgarh freshwater aquaculture has been managed under cooperative governance structure – an internal institutional structure model of distributed governance system.² Fisheries cooperative societies (FCSs) have been assigned usufruct rights to use these water bodies for culture fisheries subject to certain socio-economic and administrative conditions (Marothia 2004b, 2006, 2007). Under the Fisheries Policy of Government of Chhattisgarh first preference has been/is being to FCSs to leased in village ponds /village irrigation tanks irrespective of water spread area of these water bodies. The village ponds/tanks can only be leased out to fisherman groups and individual fisherman if FCSs do not bid for leasing in the MUCWBs or FCSs are not existing in a particular village. Further, in order of priority, fisherman community is being given first preference to lease out ponds/tanks. The issues related to management of tanks and ponds by FCSs are complex due to different categories and characteristics of these common water bodies, scale, size and coverage of FCs and multiple agencies involved in governing the water resources. Looking to the importance of ponds and tanks for fish culture in the state of Chhattisgarh this study was undertaken to provide an overview of governance structure of culture fisheries in ponds and tanks in the state and to discuss outcomes of an indepth analysis of four fish cooperative societies, which (FCs) have covered different categories of ponds and tanks administered under property rights regimes. This study has also discussed performance of individual fisherman who have leased in panchayat ponds. Findings of a quick well focused case study of Self Help Groups (SHGs) is also presented.

MUCWBs and fish farming in Chhattisgarh: An Overview

MUCWBs in the form of village ponds, irrigation and multipurpose tanks are extensively distributed in all the villages of the state of Chhattisgarh (Marothia 2004b). Fisheries in MUCWBs is an old age livelihood activity for a large number of poor people in Chhattisgarh. MUCWBs have traditionally been managed and controlled for fish culture under the common property regime. However after 1952 most of the MUCWBs have been transferred to panchayat (local village government) or irrigation department depending on water spread area. Nevertheless these MUCWBs are still multipurpose and multifunctional in nature with inherent interdependencies.. MUCWBs cover 52211 village ponds and 1616 irrigation tanks with 70000 ha. and 83873 ha. water spread area respectively in the state. Of the total water spread area (153873 ha.) available in the state, 79 percent and 87 percent area has been developed under 40967 village ponds and 1462 irrigation tanks respectively for fish culture in the state.

Chhattisgarh state has well structured organizational network to manage freshwater aquaculture in the village ponds, irrigation tanks and reservoirs. The state has two tier cooperative structure to manage and develop freshwater aquaculture. At apex level Chhattisgarh State Fish Cooperative Federation (CSFCF) is responsible to manage reservoirs, fish farms and hatcheries for fisheries development. At second level of cooperative structure again three tier panchayat organizational setup (Village Panchayat, Janpad Panchayat and District Panchayat) is working for assigning fishing rights or lease of village ponds and irrigation tanks. The administrative and functional jurisdiction of Village Panchayat, Janpad panchayat and District panchayat are restricted according to water spread area of ponds/tanks. Lease of ponds or tanks with water spread area of below 10 ha, 10 ha. to 100 ha. and 100 ha. to 200 ha. is assigned by village panchayat, Janpad and district panchayat respectively. The State Department of Fisheries assigned lease to all ponds/tanks above water spread area of 200 ha. The lease amount is used for promoting fishers activities by panchayat institution and State Department of Fisheries (SDF). The SDF is engaged in coordinating state - central government schemes, capacity building of fishermen communities, and assisting cooperative societies in promoting fisheries activities and fish production. Lease of ponds/tanks are being assigned on priority basis to registered fish cooperative societies (FCS), fishermen group (FG) and individual fishermen (IF). It is important to mention here that in case if FCSs are not existing in a particular village or do not bid for village ponds/tanks, *only then* these water bodies can be leased out to fishermen groups or individual fisherman or SHGs by respective panchayats. A large number of ponds and tanks are used for fish culture by the fish cooperative societies in the state. Fisheries cooperative societies in the state has nearly 50964 active members (GOC 2003-04).

For FCS, FG and IF the maximum water spread area per member/person of village pond and irrigated tank is restricted to 0.50 ha and 4.00 ha. respectively. However pond with 1 ha water spread area can be given on lease to local fishermen. The lease duration for ponds/irrigation tanks is for five year. The ponds/ tanks can be leased to the same FCS, FG, IF based on performance. In case FCS, FG, IF are not interested to take ponds/tanks on lease the same can be leased out to self help groups of the local village. A FCS can be given more than one pond/tank on lease with the restricted norms of water spread area per member. Similarly, based on size of water spread area of ponds and tanks, lease can be assigned to more than one FCS. Village panchayat, Janpad panchayat and district

panchayat make wide publicity in village and also issue notification in local news papers for allotment of ponds/tanks on lease within their working zones. The Representatives of SDF, Fish Farmers Development Agency (FFDA) and panchayat scrutinize the application before assign the ponds/tanks on lease to FCS, FG and IF.

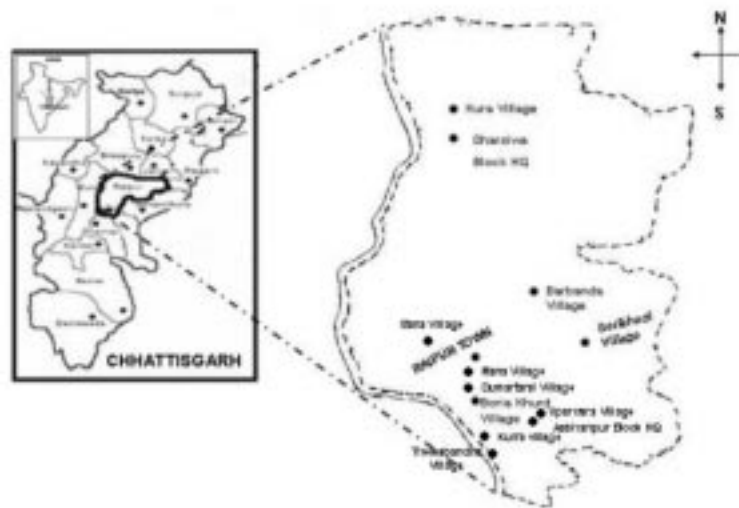
The lease amount for village ponds and irrigation tanks is currently fixed at Rs.1000 per ha. and Rs.240 per ha. per year respectively with provision of 10 per cent increase after every two years. The lease amount can be deposited in three installments in the proportion of 35 per cent, 30 per cent, 35 per cent respectively during the same financial year. The lower lease rent for irrigation tank is due to restriction imposed by the State Department of Water Resource Development (SDWRD) on use of feed and manure in all departmental tanks. The FCS, FG, IF have to deposit lease money in stipulated time. Interest rates of 2.5 per cent on lease money is charged for the late deposit of lease money. Lease can be cancelled after 3 months, in case of non-payment of lease, after serving three notices. For the seasonal irrigation tank lease amount is fixed on availability of water during a year, and fish production levels (maximum fish production level achieved during last five years is taken in to account). It is worth mentioning here that panchayats (village, janpad and district) earn in the range of Rs16 to 31 million per year from leasing out ponds/tanks. State Department of Fisheries earn in the tune of Rs 3.20 to 4.6 million from leasing out tanks of above 200 ha. water spread area Chhattisgarh state produces 1.11 lakh tone fish production with average fish yield of 2373 kg. and 69 kg from village ponds and irrigation tanks respectively. Fisheries sector has created nearly 80 lakhs man days gainful employment during 2003-04 through 785 cooperative societies and 1336 fishermen group and individual fishermen.

Data Base and Converge of the Study

This study was confined to village ponds and irrigation tanks situated in Boriya Khurd, Barbanda, Serikhedi, Kura, Uparwara, Thelkabandha villages of Dharsiwa block and Mana, Bana, Kurra, and Dumartarai villages of Abhanpur block of Raipur District in Chhattisgarh, India. These ponds and tanks have been used for culture fish farming by FCSs, IFs, and SHGs. The study area in which the selected FCSs, IFs and SHGs are located, represents fairly well agro-climatic socio-economic condition of Chhattisgarh plain. The climate of the study area is characterized by sub-tropical parameters. The average rainfall of the study area varies between 1187 mm to 1200 mm. The onset monsoon season extend from the mid June to early October, which accounts for more than 90 percent of the total precipitation of the rainfall during the month of July-August. The winter season (November to February) is relatively warm and short with mean temperature of 25° to 30°C between December and March followed by very hot and dry weather in May to June 40°C to 45°C (summer season). In the study area four general classes of soil are found i.e. gravely sand, sandy loam, loam and loamy clays corresponding to the locally known names Bhata, Matasi, Dorsa and Kanhar. Seventy percent of the soil comprise of Kanhar. Dorsa, Matasi and Bhata consist of twenty, five and two per cent respectively.

A set of three questionnaires were designed and pre tested to collected required information for fisheries cooperative societies, fishermen household, and profile of tanks and ponds covered by respective FCSs, IFs, and SHGs. Four fisheries cooperative societies, located in the four villages (Boriya Khurd, Barbanda, Serikhedi, and Kura) of Dharsiwa Block of Raipur District were selected for in-depth analysis (see Map-1. for location of water bodies covered by four FCSs, and individual fisherman, and SHGs). All the four FCSs functioning in the rural areas have usufruct rights over village water bodies. The FCSs, IFs and SHGs selected for this paper have covered different categories of ponds and tanks administered under different property rights regimes. We could not include FGs for our analysis, as they are not existing in the study area. However, four community ponds which were leased in by individual fisherman from village panchayat were included for comparative analysis. Also six SHGs are involved in fish culture in the study villages (three each in Dharsiwa and Abhanpur blocks), we have included all of them for comparative analysis.

All the above tanks/ponds covered by four FCSs, IFs, and SHGs are multiuse and multifunctional in nature involving multiple stakeholders. Information regarding profile of fisheries cooperative societies, IFs and SHGs (including salient features of management structures, decision making arrangements, output and distributing gains), physical and technical attributes of ponds and tanks, and general characteristics of fisherman households was collected from respective FCSs, IFs and SHGs. Information of fish yield and input use, disposal pattern and distributive gains were collected for three years from the record of FCSs and SHGs. However, this information was available for one year for pond/ tanks leased in by IFs from village panchayats. The required information to analyze the performance of fisheries cooperative societies, IFs, and SHGs was gathered from the all the four fisheries cooperative societies, IFs, and SHGs during June-August 2004. Audit reports of the FCSs were the main source for obtaining information



Map 1. Location map of stud area

on yield, income, input use, disposal pattern, and distributive mechanism. Data of audit reports were cross checked with information gathered during focused discussion sessions with members of the FCSs. The basic information regarding physical and technical characteristics of irrigation tanks was collected from the State Department of Water Resource Development and Soil and Water Conservation wing of State Dept. of Agriculture. Data regarding ponds/ tanks constructed during *Ex-Zamidars*(landlords) tenure were collected from village panchayats. Details of types of ponds /tanks used for culture fisheries along with ownership, management and leasing authority structure are given in table 1. Features related to categories of irrigation tanks, village common ponds, duration of availability of water, multiple institutions involved in water use and management, ownership and leasing authority structure, variation in lease rents and restrictions on application of feed, manure, and medicines to cure or prevent fish diseases are also provided in table 1.

Conceptual Framework

To analyse the strength and weakness of cooperative governance structures primarily adopted in the state of Chhattisgarh for sustainable use of tanks/ponds for fish culture, an institutional framework was applied. Institutional framework was also used to understand the performance of SHGs. We have basically applied the institutional framework³ developed in a number of analytical models (Marothia and Phillips 1985, Oakerson 1986,1992, Ostrom 1992, Tang 1992, Townsend and Pooley 1995). The attributes of the conceptual framework for institutional analysis developed in these models have also been used in Indian conditions to understand the efficiency of alternative governance in managing common pool resources (Arnold and Stewart 1991 Marothia 1993, 2002,2004b,2006,2007). These models essentially have four attributes namely, physical and technical attributes of a resource, characteristics of resource users community, external and internal institutional arrangements patterns of interaction and outcome which may affect freshwater aquaculture management in case of the present study. The institutional framework used herein has assessed physical and technical attribute of tanks/ponds, characteristics of fishermen community in relation to other stakeholders using common water bodies, external and internal institutional arrangements, impact and outcome (in terms of fish catch, input use pattern, disposable pattern and distributive gains). Each component of the conceptual framework has sub-sets attributes. Each set of attribute is related to the others. For example, characteristics of resource (attributes of ponds and tanks) and resource users (Fishermen characteristics) and arrangements, alternative property regimes, distribution of authority system collectively affect external and internal institutional arrangements, interaction patterns and outcomes and impacts. To this end we discuss comparative performance of FCSs, SHGs and IFs within their categories

A Profile of FCSs and Attributes of Fisherman Households

Salient features and management structure of the selected fish cooperative societies is shown in table 2. The basic objective of all the FCSs is to enhance livelihood and generate year round employment. In terms of social

Table 1: Types of Ponds/Tanks, Management, Ownership and Leasing Authority Structure of the Selected Water bodies.

S. No.	Name of tank	Type of tank	Source of water	Availability of water	Major uses of water in order of priority	Local institutions involved in water uses	Ownership	Leasing authority	Lease rent (Rs./ HWSA)	Restriction/ Conditions to use water for fish culture
(A)	Village Ponds/Tanks Leased in by FCS									
	Boriya Khurd (Boriya Khurd FCS)	Perennial irrigation tank (65 ha.)	Canal-fed	Adequate, year round	Irrigation, domestic use, fish culture	FCS, WUAs, Panchayat	SDWRD	Janpad Panchayat	240.00	Feed and manure can't be used by FCS, other users can't be excluded to use water
	Bundha Tank (Senkhedi FCS)	Perennial irrigation tank (200 ha.)	Canal-fed	Adequate, year round	Irrigation, domestic use, fish culture	FCS, WUAs, Panchayat	SDWRD	District Panchayat	243.00	Feed and manure can't be used by FCS, other users can't be excluded to use water
	Raipuriha Pond (Serikhedi FCS)	Perennial (0.60 ha.)	Rainfed	Upto Feb.-March	Domestic and fish culture	Village Panchayat	Village Panchayat	Village Panchayat	2000.00	No restriction to use fish feed
	Kura Ponds (Kura FCS)	Perennial (8)* (1.15 ha.)	Canal-fed	Throughout the year	Irrigation, domestic use, fish culture	Krishi Samiti of Panchayat, Panchayat, FCS	Village Panchayat	Village Panchayat	252.00	No restriction to use fish feed
	Kura Ponds (Kura FCS)	Seasonal (9)* (1.15 ha.)	Canal-fed	Upto Feb.-March	Irrigation, domestic use, fish culture	Krishi Samiti of Panchayat, Panchayat, FCS	Village Panchayat	Village Panchayat	252.00	No restriction to use fish feed
	Barbanda Tank-1 (Barbanda FCS)	Perennial (2.88 ha.)	Canal-fed	Upto Feb.-March	Irrigation, fish culture, domestic use	Panchayat	Panchayat	Village panchayat	857.00	Restriction on feed and manure
	Barbanda Tank-2 (Barbanda FCS)	Perennial (2.30 ha.)	Canal-fed	Upto Feb.-March	Irrigation, fish culture, domestic use	Panchayat, Krishi Samiti	Panchayat	Village Panchayat	857.00	Restriction on feed and manure
	Barbanda Tank-3 (Barbanda FCS)	Perennial (17 ha.)	Canal-fed	Upto Feb.-March	Irrigation, fish culture, domestic use	Panchayat	Panchayat	Janpad Panchayat	857.00	Restriction on feed and manure
	Matwa Talab (Barbanda FCS)	Perennial (0.40 ha.)	Rainfed	Upto December	Domestic use, fish culture, Irrigation,	Village Panchayat, FCS	Village Panchayat	Village Panchayat	2600.00	Limited restrictions
	Dev Talab (Barbanda FCS)	Perennial (0.90 ha.)	Canal-fed	Adequate	Domestic use, fish culture, Irrigation	Village Panchayat, FCS	Village Panchayat	Village Panchayat	2600.00	Limited restriction

Contd..

S. No.	Name of tank	Type of tank	Source of water	Availability of water	Major uses of water in order of priority	Local Institutions involved in water uses	Ownership	Leasing authority	Lease rent (Rs./ HWSA)	Restriction/ Conditions to use water for fish culture	
(B)	Village Owned Ponds Leased in by IF										
	Boriya Khurd Pond (Boriya khurd village)	Rainfed (0.60 ha.)	Tubewell	Upto March	Domestic use and fish culture	Panchayat	Panchayat & individual fishermen	Panchayat	10000.00	No restriction on fish feed and manure application	
	Chhagar Pond (Barbanda village)	Rainfed (3.50 ha.)	Canal	Upto December	Irrigation, fisheries and domestic use	Panchayat, Krishi Samitee, FCS	Panchayat	Panchayat	4928.00	No restriction	
	Jogi Bandh (Barbanda village)	Seasonal (0.40 ha)	Canal, Rain	Upto December	Fish culture, irrigation and domestic	Panchayat Krishi Samitee	Panchayat	Panchayat	2600.00	No restriction	
	Ledara pond (Barbanda village)	Perennial (4.50 ha)	Canal, Rain	Upto Feb.March	Fish culture, irrigation and domestic	Panchayat Krishi Samitee	Panchayat	Panchayat	2600.00	No restriction	
(C)	Village tanks leased in by SHGs										
	Mana Pond	Seasonal (1.256 ha)	Rainfed	Upto December	Domestic use, fish culture	SHG and Village Panchayat	Village Panchayat	Village Panchayat	2229.00	No restriction	
	Bana Pond	Seasonal (0.75 ha)	Rainfed	Upto December	Domestic use, fish culture	SHG and Village Panchayat	Village Panchayat	Village Panchayat	2000.00	No restriction	
	Dumartarai Pond	Seasonal (1.00 ha)	Rainfed	Upto December	Domestic use, fish culture	SHG and Village Panchayat	Village Panchayat	Village Panchayat	3000.00	No restriction	
	Kurra Pond	Seasonal (0.802 ha)	Rainfed	Upto December	Domestic use, fish culture	SHG and Village Panchayat	Village Panchayat	Village Panchayat	2369.00	No restriction	
	Upanwara Pond-1	Seasonal (1.051 ha)	Rainfed	Upto December	Domestic use, fish culture	SHG and Village Panchayat	Village Panchayat	Village Panchayat	2379.00	No restriction	
	Upanwara Pond-2	Seasonal (0.80 ha)	Rainfed	Upto December	Domestic use, fish culture	SHG and Village Panchayat	Village Panchayat	Village Panchayat	2000.00	No restriction	
	Theikabandh Pond	Seasonal (1.40 ha)	Rainfed	Upto December	Domestic use, fish culture	SHG and Village Panchayat	Village Panchayat	Village Panchayat	2143.00	No restriction	

* Kura FCS leased in 29 ponds (12 perennial and 17 seasonal) out of these 8 perennial and 9 seasonal (2 seasonal ponds are use for nursery hatching) were used for fish production.

Note: Figures in brackets indicate water spread area of respective tanks.

HWSA = Water Spread Area in hectare.

structure of members, membership criteria, management system, and external institutional support all the four FCSs have more or less similar pattern. All the members of the society belong to fishermen community with domination of sub-castes according to their population in a particular village. Members from sub-caste dominates, based on their numbers in a particular FCS, in the management or executive committee. Some time small hidden groups are formed on the basis of these sub-castes to dominate the decisions of FCS. The president, vice-president, secretary and executive members were elected by the members. All FCSs are male dominated. The details regarding membership fees, working capital, assets, lease period and rents are given in table 2. The lease rents for common rural ponds are many times higher than irrigation tanks, this due to the fact that in irrigation tanks application of fish feed, manure and medicine is prohibited.(refer also table 1 for related features of FCSs)

Table 2. Common Features of Fish Cooperative Societies

S.No.	Particulars	Features of FCSs
1.	Name of the society	Primary Matsya Sahakari Samiti Maryadit,
2.	Primary objectives of the society	To enhance livelihood through fish culture and generate the employment.
3.	Leasing Authority	Janpad/village panchayat under three tier panchayat institutions systems.
4.	No. of members	12-70
5.	Social structure of members	Fishermen community(Kewat,Dhimar, Nishad) *
6.	Current membership fees	Rs. 51.00
7.	Membership criteria	Member should belong to fishermen community, above 18 years, after the death of member, membership transferred to one of the family members.
8.	Working capital (Rs.)	
	(a)Members share capital	1548.00
	(b) Borrowed capital	
	(i) From members and money lenders (for purchase of seed etc.)	11588.00
	(ii) From district central cooperative Bank	39214.00 (for purchase of net, boat, rope, repair of tanks etc.)
	(c) Saving account deposit (DCCB)	10884.00
	Total	52350.00
9.	Assets	
	(a) Boat	1 to 4 nos.
	(b) Net	2 to 3 nos.
	(c) Others (Rope)	21.67kg.
10.	Management committee set-up	
	(a) President/ treasurer	1
	(b) Vice-president	1
	(c) Secretary	1
	(d) Executive members	4
11.	No. of ponds/tank taken on lease for fish culture (range)	1-9
12.	Duration of lease (year)	5
13.	Average lease rent per year/ha. (Rs.) with 10% increase every year on the basic lease amount	397.67

*Sub castes of fisherman community in Chhattisgarh. Kewat sub-caste dominates the fishing profession

General characteristics of fisherman households (FHs) are given in table 3. All members of FCSs belong to fisheries community (locally known as *dhimers* or *kewats* or *nishads*) and their main source of livelihood is freshwater aquaculture. Agriculture and wage earnings are the other sources of FHs income. Majority of the FHs are illiterate and fall under the age group of 18-50 years. A large proportion of economically active/adult fishermen population is engaged in freshwater activities in the target areas of FCSs. Most of the fisheries activities are carried out by male members of FHs.

However, in case of a few FCS female of fisherman households also involved in stocking, netting and marketing activities. A few members of FCSs have leased in village ponds on individual basis from village panchayat. We will discuss this aspect further in the section on performance of IFs utilizing individual ponds for fish culture.

Table 3. General Characteristics of Fishermen Households in FCSs

S.No.	Particulars	Average
1.	Number of fishermen household per village	77.50
2.	Number of fishermen household in FCS	26.25
3.	Occupation (%)	
	a. Main : Fisheries	100
	b. Supplementary	
	i. Agriculture *	34.92(4.20)
	ii. Wage earner	72.38
4.	Yearly income per member/year (Rs.)	9761
	a. Farm income (%)	31.17
	b. Income from (%) agricultural wages (%)	33.57
	c. Other income (%)	28.69
	d. Fisheries	44.27
5.	Educational background (%)	
	a. Illiterate	80.25
	b. Upto 5th class (upto primary level)	17.89
	c. 5-8 th class (upto middle)	9.63
	d. 8-12th class (upto H.S.S.C)	6.06
6.	Age (% of Total members)	
	a. Above 18-30 years	39.14
	b. 30-50 years	53.59
	c. 50-70	12.08
7.	Fishermen population (in village)	561
	a. Male (%)	58.29
	b. Female (%)	41.71
8.	Family size	8.00
	(i) Male	2.50
	(ii) Female	2.00
	(iii) Children	3.50
9.	Number of economically active members per village	264
	(a) Male (%)	81.62
	(b) Female (%)	18.38
10.	% of Adult family member working full time per village (Male)	27.96
11.	Active fishermen/women (Nos./family)	1.50
12.	Male dominated fisheries activities with allocation of time (days or hours)	1. Pond preparation – 1 day. 2. Stocking – 3 days. 3. Manuring – 3 days. 4. Netting & selling 74 days
13.	Female dominated activities with allocation to time(days or hours)	1. Pond preparation – 1 day 2. Stocking – 3 days. 3. Manuring – 2 days 4. Netting and selling – 19 days
14.	% of License holder for selling fish seeds	5.55

* Cultivable land under command area of tanks/ponds (in ha.)

1-adult=2 children

Decision making Mechanism and Outcomes

A general framework of decision making mechanism adopted by FCSs and its effects on pattern of collective interactions is presented in table 4. Since the decision making mechanisms across the four FCSs are more or less same as they are all registered FCSs and had to governed under a set of institutional arrangements. A synthesis of common decision parameters are presented table 4, which have been adopted by all FCS. The description of the governing parameters are presented in table 4 and these are self explanatory.

Performance of selected FCSs

Performance of FCS in relation to members implicit goal of enhancing livelihood and generating employment through fish culture is evaluated in terms of fish yield per ha water spread area, net income, and man days

Table 4. Decision-making Arrangement and Patterns of Interaction FCS

Particulars	Fish Cooperative
A. Decision Making Arrangements	
1. Legal and administrative relation with state	Registered fisheries cooperative society under the Cooperative act and managed under three tier panchayat institution system
2. Harvesting period of fish in a year	Through out the year, maximum during March to June
3. Days of intermediate fishing catches	Twice a week
4. Harvesting method	Collective operations
5. Reasons of harvesting fish	Growth of risk and need based
6. Arrangement for inputs netting, marketing and distribution	Largely all members of fish cooperative society collectively make the net and decide the marketing of fish with support from State Department of fisheries.
7. Price fixation	At village level, village panchayat fixes the price according to market and at mandi level depends upon market forces – prices vary from day to day.
8. Mode of sale of fish	Village level (members/villagers/village merchant) and mandi (wholesaler)
9. Time and mode of payment	Spot payment in cash at cooperative office site/pond site.
10. Ability to raise funds	1. By selling fish, contribution of members, can take loan from bank/moneylenders. 2. Financial assistance from department of fisheries upto Rs. 25000 for 3 years (share capital 8% , lease rent 22% , purchase of seed and stocking 20% , nylon rope and boat 50%)
11. <i>Ability of society to influence other panchayat/government activities</i>	Members of co-operative society requested to panchayat /Janpad Panchayat/Water Resource Department to maintain minimum water level for fish culture. Panchayat/Janpad Panchayat/Water Resource Department puts restriction on farmers using ponds water to maintain minimum level of water.
12. <i>Technical assistance from external organization</i>	State Fisheries Department and FFDA assist in supply of fish seeds, rearing of fish and arrangement of net, boat and nylon rope
13. <i>Competition and conflict over water use and conflict resolving mechanism</i>	Community village has long tradition to share ponds water without conflict. Panchayat ensures minimum level of water required for fish culture and coordinate between Krishi Samitee (responsible for maintaining irrigation water use) and FCS. With lease money panchayat repairs bunds of the ponds to stop outflow of fish. In case of water stress condition in rainfed ponds, FCS transfer fishes to perennial ponds. In case of irrigation tanks with multiple use. Due to protective nature of irrigation system and field to field method of irrigation there were some case of conflicts were observed among head, middle and tail end farmers during low rainfall years. Since SDWRD and panchayat ensures minimum level of water required for fish culture there is no conflict between fisherman community (FCS) and farmers. In case of decline of water level in the tank which may affect fish culture, FCS collectively forces to village and Janpad panchayat, and SDWRD to release additional water. With the additional release of water, fish growth period continuous upto month of June. The FCS can't use fish feed and manure in the tank, panchayat resolves conflicts if any, between domestic users of tank water and FCS.
B. Pattern of interaction	
1. <i>Membership, legitimacy and outsiders</i>	Only fishermen are members of society, president, vice-president, secretary and executive members are elected by members. In some cases secretary honorarium to maintain records of the society. Outsiders are not involved in any activities of co-operative societies. Extremely high stake and control of the member over FCS.
2. <i>Reciprocal interactions</i>	Collective action by the members of FCs through collective interaction
3. <i>Rules of protection of fish and tank by members</i>	Members watch against poaching and killing of fish. Societies in many cases announce cash award for providing information of poaching of fish. Offenders are fined by village panchayat. If the offender is from the members themselves, the executive body heavily punishes that member or excludes him from the fisheries co-operative. Every year 2-3 cases of poaching have occurred, FCS punished the offenders.
4. <i>Use regulation of fishes</i>	Members and non-members can buy fish for consumption. Member must participate in all activities of FCS, for netting members get wages (Rs.30-40/day).

employment /member/year. The other parameters of performance evaluation include pattern of distribution of benefits, and mechanism to sale out the fish produced (table 5). Although the pattern of distribution of benefits varies across the four FCS in terms of wages paid to members, fund kept aside for next year investment and asset creation, but general pattern emerged from all for FCs in presented herein. The disposal pattern of fish produced across the FCSs centered around to members non members ,retailers and whole sellers with visible price differentiation at different levels. For members and non members of the same village prices are generally not too different (see table 5.).

Table 5. Outcomes of Governance Structures in FCS

S.No.	Particulars	FCS
1.	Economic gains/ha	
	i. Yield (qtl./ha)	3.84
	(a) Rohu, Katla, Mrigal	3.07
	(b) Local	0.77
	ii. Price Rs./qtl.)	
	(a) Rohu, Katla, Mrigal	2417
	(b) Local	1008
	(c) Gross return (Rs./ha)	8196
	(d) Total operating cost (Rs./ha)	5695
	(e) Net return (Rs./ha)	2501
	(f) Net income/kg (Rs.)	6.51
	(g) Input-output ratio	1:1.44
	(h) Employment generated for members (man-days)	74
2.	Distributive gains	
	Pattern of distribution of benefits (per cent)*	
	(a) Wages paid to members	38.96
	(b) Share of benefits kept aside for next year expenditure on fish rearing	36.17
	(c) Remaining amount for creating assets (fishing boats/nets/community building, recreation, etc.	24.46
	(d) Sustainable development of fish and tank resources	0.41
3.	Disposal pattern (% to total produce)	
	At village level	
	a. Member	5.75
	b. Non-Member	30.92
	c. Village merchant	5.00
	d. Whole seller	32.50
	e. Retailer	25.83
	f. Net price to the fishermen (Rs./kg.)	20
	g. Whole sellers purchase price (Rs./kg.)	25
	h. Whole sellers sale price (Rs./kg.)	30
	i. Retailers purchase price (Rs./kg.)	30
	j. Retailers sale price (Rs./kg.)	35

*Based on net income

Performance of IFs

Village common ponds have been leased out by village panchayat to individual fisherman belongs to fishermen community. These individual fishermen are also member of the FCSs working in the respective villages. The lease rents of all these ponds are several times higher than other water bodies existing in these villages. Since there is no restriction on use of feed, manures, medicine, and higher prices fixed by individual fishermen and assured availability of minimum required water; the yield levels, net income and employment generated from these ponds are much higher than collectively managed tanks by FCS in these villages. Even in lower fish producing ponds employment opportunities generated were higher in comparison to a few FCS working in the area (see table 6).

Performance of SHGs

Self Help Groups (SHGs), as per the directives of Reserve Bank of India, started functioning in 1996 through Swarna Jayanti Gram Swarojgar Yojana (SGSY), Syam Sidha, and Swa Shakti to uplift the poor families during the

Table 6. Fish Culture in Panchayat Ponds

S.No.	Particulars / Village	Panchayat owned
2.	Leasing Authority	Panchayat
3.	Leased in by	Fisherman *
4.	Water spread area (ha.)	2.23
5.	Leased rent (Rs./ha.)	5032
6.	Source of water (tube well, rainfed/canal)	Tubewell***/canalfed/rain
7.	Production (in quintal/ha.)	9.95
8.	Net Income per ha.	10884.50
9.	Employment days	
	(i) Male	96.5
	(ii) Female	9.25
10.	Conflict with village community	Nil

*Lessee belongs to fisherman community.

**Only in case of one pond.

period of three years from BPL to APL by providing them income generating assets through a mix of bank credit and government subsidy. SHGs have emerged in the state of Chhattisgarh during 1999-2000 under different schemes. At present Chhattisgarh state has more than 43,000 SHGs working in different sectors of livelihood based activities. Out of these groups 711 groups were formed in fisheries sector. However, a few of them (105 SHGs) cleared the first criterion to be entitled to receive bank loan and subsidy. For example in Raipur District 82 fisheries SHGs have been formed (Technical Report2003-04. Directorate of Fisheries, GOCG), but only 12 SHGs have passed through first and second grading. Development process of SHGs is categorized into three period i.e. from 0 to 6 months, 6 to 18 months, and 18 to 36 months. In the initial period regular meetings, election of representatives, preparation of bye-laws, and regular savings are the main functions of SHGs. Inter-loaning and bank account also start in this period. With the completion of all these activities a particular SHG passes through first grading. After first grading SHGs are provided Rs.15000 as credit limit and Rs.10000 as revolving fund and receive training for capacity building. After second grading SHGs received bank loan and subsidy. For an interactive survey carried out for the present project ,of the total 12 SHGs working in Raipur district, 6 fisheries SHGs were selected. Analysis of 6 SHGs(see table 7) reveals the following facts: (i) the size and composition of the groups is largely heterogeneous dominated by OBC, SC and ST (ii) number of members per SHG is around 14. (iii) largely Banks are promoting agency (iv)main occupation of more than 85% members is agriculture,(v) members per month collection is in the tune of Rs.82 and members meet every month to discuss various issues related to fisheries activities,(vi)inter loaning among members is largely for agriculture, business and home needs, and recovery is almost in the tune of 53%.(vii) the cumulative saving is about Rs 22000. (viii) fisheries contributes nearly 14% against 76% agriculture share in the total income per SHG. However fisheries generate 22% mandays employment for the group against 66% in the crop sector.(ix)the average water spread area available to fisheries SHGs is 1.08 ha (ranging in between 0.75ha to 1.40ha).(x) the overall fish production per SHG was 16.50 quintals per ha. (xi) cost and net return per ha, per SHG was in the tune of Rs.4033.37 and Rs.26345.65 respectively. (xii) SHGs sold fish @Rs 40 per Kg. (xiii) average lease rent per ha water spread area was RS.2800 (lease rent varies between Rs.1600 to Rs.3000 per ha water spread area. (xiv) there is no restriction on application of fish feed and manure in the leased ponds.(xv) panchayat is the leasing authority (xvi) SHGs got these ponds on lease because FCS, FG, and IF are not existing in the villages where SHGs formed.(xvii)management committee is constituted of president, vice –president ,secretary and treasurer. (xviii) inter -caste conflicts are visible, domination of a few members in decision making and participation in capacity building training. (xix) non payment /timely of loan.(xx) poor monitoring by funding agencies.(xxi) benefit sharing among the members is not equally distributed and in many cases only shared by office bearers. (xxii) continuous watch of ponds by members to restricted poaching.(xxiii) members have to purchase fish at market rates.(xxiv) no conflict with other members of the village.

It is adequately clear from the above analysis that with adequate water availability ,and application of feed, manure and proper and timely use of medicine to prevent fish motility, higher yield, income and employment can be achieved (see yield, income and employment levels of tanks leased by Boriya Khurd common pond). It is also clearly evident in case of the IFs leased in ponds. Further, higher performance can also be achieve even in case of rainfed ponds without imposing restriction to use growth promoting inputs as seen in case of Mandir, Marar, and

Table 7. Performance of Culture Fisheries SHGs

S.No.	Particulars	SHGs
1.	Conditions for formation of SHGs	For composition of SHGs it is mandatory to have representatives members from ST and SC, women's and physically disabled person in proportion of 50%, 40% and 3%, respectively . Minimum 80% beneficiaries must be from below poverty line (BPL).
2.	No. of selected SHGs	6
3.	No. of members per SHG	14
4.	Size and social composition (%)	Large and heterogeneous
	a. OBC	72.62
	b. SC	16.67
	c. ST	10.70
5.	Education	All members have Primary education
6.	Main occupation	Agriculture and fisheries
7.	Average size of land holding of SHG members (ha.)	2.01
8.	Funding agencies	Commercial and Regional Rural Banks
9.	Average Bank loan (Rs.) per SHGs	150000.00
10.	Trained members (%)	41.66
11.	Sources of income (%)	
	a. Farm	73.74
	b. Off-farm(wages)	9.51
	c. Fisheries	16.74
12.	No. of ponds leased in	7
13.	Duration of lease	3 years
14.	Lease rent per ha. WSA* per year	Rs.2800.00
15.	Leasing authority	Village panchayat
16.	Average water spread area of ponds (ha.)	1.08
17.	Type of ponds	Seasonal
18.	Uses	Domestic use, fishing, cattle tending etc.
19.	Restrictions to use fish feed and medicine	Nil.
20.	Management committee	
	a. President	1
	b. Vice-president	1
	c. Secretary	1
	d. Treasurer	1
21.	Cost of fish production per ha(Rs).	23154.00
22.	Fish production (per ha in quintal)	16.50
23.	Net income per ha.(Rs)	42846.00
24.	Input- output Ratio	1:2.85
25.	Employment(man days/ member /year)	
	a. Agriculture (%)	190
	b. Fisheries	66.0
	c. Wages	22.0
26.	Decision making arrangement	Decision making process is by and large confined to executive committee. The main decision making issues include membership fees, purchase of inputs, fish seeds, marketing of fish and benefit sharing arrangements etc.
27.	Per month collection/member	In the range of Rs.50 to Rs.110, average Rs.81.66, penalty on delay payment
28.	Financial Assistance per SHG (Rs.)	
	(a) Revolving fund	
	(b) Cash credit limit	
	(c) Average bank loan	
	i. Total amount	
	ii. Subsidy (50% of total loan amount)	
	iii. Actual loaniv. Upto date balance after 1 year	
	(d) Inter loan(Rs)	
	i. Agriculture (%)	
	ii. Business (%)	
	iii. Home needs (%)	
	iv. Totalv. Recovery of inter loan (%)	
	vi. Over dues (%)	
29.	Conflicts among members and mechanism to resolve	Conflicts among the members breeds just after receiving financial assistance from the banks. Inter -loaning amount was distributed among the executive and other members but not all the members. Similarly profit was not distributed equally among the members. For inter loan the rate of interest is very high. Conflicts remain unresolved.

Mandal. The performance of SHGs is still lower than many IFs who had leased in panchayat owned or privately owned ponds in terms of yield, income and employment generation capability due to inter castes conflict among members and pursuing self motive agenda of non fisheries development.

7. Conclusions and Future Policy Issues

Common pool resources of land, water, forest, wildlife and fisheries constitute an important component of community assets in Chhattisgarh and significantly contribute towards the poor peoples livelihoods despite the decline in their areas and productivity. Community water bodies have been/are the blood vessels of Chhattisgarh rural life. These water bodies in the form of village ponds, irrigation and multipurpose tanks are extensively distributed in all the villages of the state and are multipurpose and multifunctional in nature with inherent interdependencies. Fisheries in inland fresh water (ponds and tanks) dates back to time immemorial in Chhattisgarh and it has been an important source of livelihood for large number of people. Common pool ponds/tanks are being administered and controlled under different institutional hierarchy or property rights regimes (State Department of Water Resource Development, Panchayats, Soil and Water Conservation Wing of State Development of Agriculture, State Department of Fisheries, Panchayat Raj Institutions, and private ownership). Responding to the survival issue of millions of fishermen community, the government of Chhattisgarh has recently designed pro poor policy for freshwater aquaculture development. Under the new freshwater aquaculture policy culture fisheries in common pool water bodies have been managed under cooperative governance structures. In the state of Chhattisgarh freshwater aquaculture has been managed under cooperative governance structure. Lease of ponds/tanks are being assigned on priority basis to registered fish cooperative societies (FCS), fishermen group (FG) and individual fishermen (IF). It is important to mention here that in case if FCSs are not existing in a particular village or do not bid for village ponds/tanks, *only then* these water bodies can be leased out to fishermen groups or individual fisherman or SHGs by respective panchayats. A large number of ponds and tanks are used for fish culture by the fish cooperative societies in the state. All the FCSs listed under general categories have members from fisheries community (locally known as kewat, dhimar, and nishad). Scheduled tribe and castes FCSs are also by and large have members from same caste i.e. in scheduled tribe FCSs all members belong to homogeneous tribal castes. Similarly all members of scheduled caste FCSs are from scheduled castes. This categorization of FCSs clearly indicates that all the three types of FCSs have homogeneous group of fishermen within them selves. There are also socio-political reasons behind adopting homogeneous group/caste based formation of FCSs in the State Fisheries Policy of Chhattisgarh. However, SHGs are in some cases are formed by heterogeneous members belong to different castes. In view of these facts, this study was carried out to understand the performance of fisheries cooperative societies (FCSs), individual fisherman (IF), and self help groups (SHGs) in culture fish farming in village ponds and tanks, which are being administered and controlled by different agencies in the state of Chhattisgarh. The issues related to management of tanks and ponds are complex due to different categories and characteristics of these common water bodies, scale, size, location, and coverage and multiple agencies involved in governing the water resources.

From the point of view of culture fisheries management in common water bodies, this study provides some meaningful findings. Extent of water availability, multiple use (non excluding component) and restriction on application of feed, manure and medicine are the two most important factors which affect the FCSs performance. Further, higher performance can also be achieved even in case of rainfed ponds without imposing restriction to use growth promoting inputs as seen in case of individually leased in ponds. The Performance of SHGs is still lower than many IFs who had leased in panchayat owned or privately owned ponds in terms of yield, income and employment generation capability due to inter castes conflict among members and pursuing self motive agenda of non fisheries development.

In the villages of Chhattisgarh, community ponds and irrigation tanks have traditionally been allotted by local panchayats for different uses like tending cattle, washing cloths and baths, irrigation, fish culture, social rituals (funeral, worship, etc.), These water bodies were managed through collective Labour work. There are invariably one or two temple or sacred ponds in most of the villages. In almost every village ponds were separately allotted for women groups. It can be still seen in many villages. A few ponds are exclusively used for SC community under the social caste hierarchy. Taking a leaf from the traditional allocation arrangements of ponds, a few ponds may be left out for domestic uses and social rituals in a village and rest of the ponds can be exclusively used for culture fisheries without any restrictions on application of growth promoting inputs to achieve potential yield. Fortunately, in every village minimum 7 to 10 community ponds are still existing. Close-in ponds can be reserved for common use and more distant ponds for fish culture. Such simple political and administrative decision can substantially reduce

the inter community conflicts. Similarly irrigation ponds /tanks can be exclusively used for irrigation and fish culture, if some ponds can be kept aside for catering the needs of villagers. Further, a feasible solution can be worked out between FCSs and SDWRD for de- silting the tanks, as one of the major concerns of the SDWRD is increasing silt load and reducing water intake capacity of a tank due to use of fish feed and manure. Such institutional arrangements can increase fish yield and the total productivity of common water bodies by many folds beside minimizing social conflicts. It has been observed in the study area that FCSs have tendency to leased in all the common ponds/irrigation tanks within eight Km periphery(a norm prescribed in Leasing Policy) in a particular village to strategically eliminate FGs and IFs chance to leased in these common water resources. Further, in some case all the leased out ponds/tanks have not been used for fish culture. For example, all the 29 ponds leased in by Kura FCS are not being used for fish culture. In case of village pond leased in by individual fisherman it has been also observed that the lessee is either office bearer of a local FCS or member of any sub-caste of fisherman community. Except in SHGs the lessee has to be from fisherman community to leased in panchayat owned ponds. .In view of these suggestions Fishery Policy of the state need to be change in consultation with SDWRD, State of Department of Agriculture, State Department of Rural Development and Panchayat and Fisheries organizations to enhance the total welfare of poors in India's one of the most unfavourable states.

Acknowledgements

This paper is based on the IWMI – TATA Water Policy Programme Project on Performance Evaluation of Culture Fisheries under Alternative Property Rights Regimes in Chhattisgarh. The author thanks A.K.Gauraha, P.K.Verma, S.B.Kaiwartya, A.K.Verma, Gangadeen Sahu, and Smt.S.V.Nair of DANRE for their assistance. The author is also grateful to President and members of all the five Fisheries Cooperative Societies and P.P.Singh, M.P.Gupta, R.K. Shukla, and N.Verma of State Department of Fisheries, Government of Chhattisgarh (GOC) and other staff for sharing information on various aspects of fisheries governance. The author benefited substantially from the comments and suggestion of Tushaar Shah, Christopher A.Scott, R.Sakthivadivel and K.V.Raju. The valuable comments and suggestions made by R.Sakthivadivel are inclusive in the paper.

Notes

- ¹ It is important to recognize that the governance can be shared among states, communities and private interests groups in various ways. In other words, distributed governance is the extended version of the standard regimes of property rights (state, common and private property, open access). Distributed management system involves a share of authority among different groups/agencies at different decision making levels. (Townsend and Pooley 1995). Distributed governance involves the external institutional arrangements (rights based management, co-management and contracted management) among government and local communities or resource users as well as internal institutional arrangements (self organizing institutions, communal management and cooperative management) within local community institutions or resource users (see also Marothia 2002)
- ² Three alternative internal governance structures are closely associated with concept of fisheries cooperative management, namely, self organizing institution, cooperative management and communal management (see Townsend and Pooley 1995 for details on external and internal distributed governance structures in fisheries management).
- ³ Institutional arrangements or working rules order relationship among resource users with in society or groups and design incentive structures in human exchange, whether social, economic political (North 1990). The institutional arrangement define who can control the resource and how the technologies are applied. Institutional arrangements or working rules define extent of property rights regime over resources, in this case fisheries and related resources (for detail interpretation of institutional perspective on natural resource management see Marothia 1993, 2006,2007).

References

- Arnold, J.E.M. and W.C. Stewart (1991), Common Property Resource Management in India, Tropical Forestry Paper No.24, Department of Plant Sciences, Oxford Forestry Institute, University of Oxford, Oxford, U.K.
- Government of Chhattisgarh (GOC) (2002-03), New Fisheries Policy, State Department of Fisheries, GOC, 2002-03.
- Government of Chhattisgarh (GOC) (2003-04), Annual Technical and Administrative Report of Fisheries, State Department of Fisheries, GOC, 2003-04.

- Marothia, D.K. (1992a), "Village Irrigation Tanks :Institutional Design for Sustainable Resource Use", *Agriculture Situation in India* (47):479-484
- Marothia, D.K. (1992 b), "Village Ponds and Aquaculture Development: Issues of Inequality in common Property Regimes", contributory paper, Third conference of the International Association for the Study of Common Property, Washington, D.C., U.S.A., September 18-20.
- Marothia, D.K. (1993), "Property Regimes and Institutional Arrangements: concepts and their Relevance in Managing the Village Commons", *Indian Journal of Agricultural Economics*, 48(3):557-565.
- Marothia, D.K. (1995), "Village Ponds and Aquaculture Development: Is conflict Inevitable?", Paper presented to the National Workshop on Poultry, Fisheries and Food Processing Organized for the Members of Parliament at the National Academy of Agricultural Research Management, Hyderabad, July 4-7, 1995.
- Marothia, D.K. (1997a), "Institutional Arrangements in common Fish Ponds", in J.M.Kerr, D.K.Marothia, K.Singh, C.Ramasamy and W.R. Bentley (Eds.) *Natural Resource Economics: Theory and Application in India*, Oxford & IBH Pub. Co. New Delhi.pp
- Marothia , D . K..(1997b), "Property Rights, Externalities ,and Pollution" in Agrawal, Anil (Editor) *The Challenge of Balance*, Centre for Science and Environment. New Delhi.pp
- Marothia, D.K. (2002), "Alternative Governance in Common Pool Resource", in D.K.Marothia (Ed.) (2002), *Institutionalizing Common Pool Resources*, Concept Publishing Company, New Delhi.pp
- Marothia, D.K.(2004a) "Restoration of Lake Ecosystem: An Environmental Economics Perspective", *International Journal of Ecology and Environmental Sciences* 30(3) : 197-207.
- Marothia, D.K. (2004b), "Institutional Structures for Governance of Freshwater Aquaculture: Lessons from Chhattisgarh" *Indian Journal of Agricultural Economics*, 59 (3) : 421-434.
- Marothia, D.K. (2004c), "Transforming Institutions for Sustainable Development of Natural Resources Programmes" *Agricultural Economics Research Review*, 17(conference No.):163-190.
- Marothia, D.K.(2006). "Managing Culture Fisheries in Multi-use Water Bodies:A Property Right Paradigm" in K.K.Vass,K.Mitra,V.R.Suresh,P.K.Katiha and N.P.Shrivastava (Editors),*River Fisheries in India-Issues and Current Status*,Inland Fisheries Society of India,Barrackpore,West Bengal.pp.227-240.
- Marothia, D.K.(2007).Fish Farming in Small Multi-use Water Bodies: Water Sharing Mechamism and its Implications, In Vass, K.K. , Sarangi,N. Mitra, K. Jena,J.K. Suresh, V.R. Shrivastava, N.P. and Katiha, P.K. (eds.). *Water Management in Fisheries and Aquaculture*, Inland Fisheries Society of India, Barrackpore, W.B.and Association of Aquaculturists,Bhubaneswar,Orissa. pp.151-159.
- Marothia D.K. and W.E. Phillips(1985) Analysis of Natural Resource Problems Using Synthesis of Neoclassical and Institutional Economics, *Asian Journal of Economics and Social Studies* 4:263-281
- North, D.C. (1990), *Institutions, Institutional Change and Economic Performance*, Cambridge, Cambridge University Press.
- Oakerson, R.J. (1986), "A Model for the Analysis of Common Property Problems", in National Academy of Sciences (1986), Proceedings of the Conference on Common Property Resource Management, Washington, D.C., U.S.A.
- Oakerson, R.J. (1992), "Analyzing the commons: A Framework", in D.W.Bromley (Ed.) (1992), *Making the Commons Work*, ICS Press, San Francisco, U.S.A.pp
- Ostrom, E. (1992), *Crafting Institutions for Self-Governing Irrigation Systems*, ICS Press, San Francisco, U.S.A.
- Tang, Shui Yan (1992), *Institutions and collective Action: Self-Governance in Irrigation*, ICS Press, San Francisco, U.S.A.
- Townsend, R.E. and S.G. Pooley (1995), Distributed Governance in Fisheries in Susan Hanna and Mohan Munasinghe (Eds.) *Property Rights and the Environment-social and Ecological Issues*. The Beijer International Institute of Ecological Economics and the World Bank, Washington, D.C.pp.

Community Management of Common Property Resources in the Agrarian Economy

V.N. Sharda¹ and Swarn Lata Arya²

¹Central Soil and Water Conservation Research and Training Institute, Dehradun 248 195, Uttarakhand, India

²Central Soil and Water Conservation Research and Training Institute, Research Centre, Chandigarh, India

Common property resources (CPRs) constitute a substantial part of the resource base of the rural economy and play a vital role in providing consumer goods, services and employment to vulnerable section of the society. The recent academic and administrative interest in the preservation, development and efficient utilization of CPRs is largely attributed to the increasing concern about environmental security. CPR may be broadly and residually treated as that which is not private property (Karanth, 1992). Jodha's (1986) defines CPRs as the resources accessible to the whole community of a village and to which no individual has exclusive property rights. In the context of Indian villages, the resources falling under the common property category include community pastures, community forests and waste lands, common dumping and threshing grounds, watershed drainages, village ponds, rivers/rivulets as well as their banks and beds. These are resources with varying degrees of access on which multiple and often overlapping property rights and regulatory regimes exist. Such rights of access include those defined on different categories of government forests. Thus CPRs could be simply described as community's natural resources, without anybody having exclusive property rights over them. In most micro-level studies on use and access of CPRs in India, it has been adopted as a broad working definition (Joshi, 2006; Karanth, 1992; Dasgupta, 2005 Gowda and Savadatti, 2004). Table 1 gives the land use classification as per official statistics in India and the assumptions made regarding levels and sanctions for access as common property (Chopra et al., 1988).

There is however, no agreement whether or not to treat government reserved forests as CPRs although such forests are being used by local people for grazing cattle and foraging. In the pre-British India, a very large part of the country's natural resources were freely available to the rural population. These resources were largely under the control of local communities. Gradually, with the extension of state control over these resources and the resultant decay of community management system, CPRs available to the villagers declined substantially over a period of time.

Given the importance of CPRs in the rural economy, it is worthwhile to estimate the extent of CPRs land in India. Chopra *et al* (1990) suggest that other than current fallow, cultivable waste, pastures and protected un-classed forest can be broadly classified as CPRs. Based on this classification, the authors concluded that 21.5 percent of the land in India (1980-81) was CPR with the rider that the estimate be slightly high given the fact that not all protected forests are CPR. In another report "Empowering People for Sustainable Development" issued by MOEF in 2002 by Govt. of India, approximately 77 million ha (23 percent of total geographical area) are designated as common property land resources.

A comprehensive survey of 78,990 rural households in 10,978 villages across the country based on approach adopted by NSSO 1999 provides, for the first time in India, State and National level data base on the size, utilization and contribution of CPRs.

The NSSO defines common property resources as resource "*that are accessible to and collectively owned/held/ managed by a identifiable community and in which no individual has exclusive property rights.*"

According to the estimates of NSSO, CPRs constitute 15 percent of the total geographical area of the country (Table 2).

The wide variation in the estimates of NSSO and others is due to the restrictive definition of CPRs in the approach adopted by NSSO that excludes all Government forests and revenue lands which in practice may actually be used as a common property. Still the common property land resource forms a substantial part of the total geographical area.

Table 1. Identification of Common Property Resources

Classification of Land	Included in common property land	Source of Sanction for Access
Net sown area	No	On uncultivated owned land: limited user rights
Current fallow	No	On uncultivated owned land: limited user rights
Fallow other than current	Yes	User rights by convention
Cultivable waste	Yes	Partial user rights by convention
Pastures and other grazing land	Yes	User rights by law
Barren and uncultivable land	May be included	No access
Area put to non-agricultural use	No	No access
Forest area		
1. Reserved	No	No access
2. Protected	Partial	Partial user rights
3. Unclassed	Yes	User rights by law

Source: Chopra, *et al.*, 1988

Table 2. Use of Common Property Land Resources (CPLR)

Item	Estimate
1. Households reporting collection of any material from CPRs	48%
2. Percentage of common property land resources in total geographical area	15%
3. Average CPLR per household	0.31 ha
4. CPLR per capita	0.06 ha
5. Components of Common Property Land Resources	
Community Pastures and Grazing Lands	23%
Village Forest and Woodlots	16%
Others	61%
6. Reduction in CPLR during last five years (per 1000 ha.)	19 ha

CPR Scenario Dynamics

The studies of the CPRs in India can be traced back to early 1980s with evidences from the states of Andhra Pradesh, Gujarat, Karnataka, Maharashtra and Tamil Nadu (Jodha, 1986). He illustrated that the rural poor derived between Rs.445 and Rs.830 annually from CPR compared to Rs. 300 by the rich. The proportion of income among poor families based directly on CPR was in the range of 15 to 25 percent. He also highlighted that between 84-100 percent of rural poor households gathered items such as fuel, fodder, food and fibre from CPRs compared to only 10-28 percent by the rich. Study of 82 villages from seven states in the dry region in India (1997) indicated that between 1950-52 and 1982-84, CPR as a percentage of total village area declined by 31% in some states to as high as 55% in others. Pasha (1992) reported that the area under CPRs declined by about 33 percent over a period of 20 years. Chopra *et al.* (1989) used secondary data on land use and established that the size of CPR reduced by 4% in Maharashtra and by 30% in Haryana during the period from 1970-71 to 1986-87. Following a similar approach, a recent study in A.P. (CWS, 2000) indicated rapid decline in terms of both quantity and quality of village common lands between 1970 and 2000 ranging from 21 to 65%.

A study of 12 villages in West Bengal (Beck *et al.*, 2000) revealed that the contribution of CPRs to the income of rural poor declined from 19 to 12 percent in just a period of 6 years. Iyengar and Shukla (1995) found huge variation of 1 to 22% in the contribution to non-farm households from CPRs in Gujarat.

The main factors responsible for the decline in common land as identified through several studies (Bromley 1992; Ostrom 1992; Tang 1992; and Marothia 1993) are:

- Erosion of Institutions managing CPRs,
- Encroachment by rural households and
- Changing Government policies on redistribution of land among poor households for the purposes of housing and cultivation.

Analysis of CPRs Collection Use Use

The 54th round classifies CPR products as fuel wood, fodder and others which include manure, fruits, roots, tuber, vegetables, gums and resins, honey and wax, medicinal plants, fish and leaves. Fuel wood continues to be the major item collected from CPRs (Table 3). The average value of annual collection per household from CPR works out to Rs. 693/- , which amounts to 3% of the average consumption expenditure of a rural household. About 58 percent of the total CPRs collection is of fuel wood, 25 percent of fodder and 17 percent of others. About one fifth of the households were found to use CPRs for grazing their livestock. The common property water resources (CPWR) were also used by a large section of rural population for various purposes mainly for irrigating the cultivated land. About 23 percent of the households reported use of water resources like tanks, wells and tube wells owned by village Panchayat or a community of the village or those provided by the government canals, rivers and springs, for irrigating their land during 365 days preceding the date of survey. This demonstrates the important resource – supplementing the role of CPRs in private- property based farming, as only 36% of the households were found to have used irrigation during 315 days. Use of CPWR for livestock rearing was also found to be quite common (30%). About 3% households reported use of CPWR for their households' enterprises.

Table 3. Use of Common Property Resources as per NSS Survey (1999)

Particulars	Value	Range (%)
Households collecting CPR products (%)	48	13-73
Average value of annual collections per household (Rs.)	693	230-1989
Ratio of average value of collection to average value of consumption expenditure (%)	3.02	0.91-4.89
Dependence on CPR for fuel wood		
Share of fuel wood in collection of CPRs (%)	58	31-79
Households collecting fuel wood for CPR (%)	45	10.6-70.7
Average quantity of fuel wood collected annually from CPR (Kgs.)	500	219-1203
Dependence on CPR for fodder		
Households reporting grazing of livestock on CPR (%)	20	1-42
Households possessing livestock (%)	56	29-86
Collecting fodder from CPR (%)	13	1-36
Av. quantity of fodder collected from CPR (Kg.)	275	26-1743
Dependence on Common Property Water Resources		
Households (%) reporting use of Common Water Resource		
(i) Irrigation	23%	2-45
(ii) Livestock	30%	6-70
(iii) Household enterprises	2.8%	1-6

Use of CPWR by different categories of households

Table 4 shows the percentage of households reporting use of water resources not owned by them for irrigation and livestock rearing separately for each category of households. It is seen that the landless and smallest of the marginal farmers make least use of CPWRs both for irrigation and livestock rearing. It supports the general finding that the landless rarely has the access to water rights in most parts of the country.

Role of Institutions in Managing CPRs

Understanding of the traditional institutional arrangements may serve as an important step towards rehabilitation of CPRs as well as rebuilding of social capital. Several studies (Agarwal and Narain, 2002; Gupta, 1987; Marothia, 2005; Singh, 1994) have revealed that common property land resources like forests and water were regulated through the traditional institutional set up. Various measures adopted were grazing tax, rotational grazing and penalties for unauthorized use. A land mark change to village forest management came into force from April, 1939 when first Village Forest Cooperative Society, the Kangra Village Forest Society came into existence and subsequently in 51 villages, Forest Cooperative Societies were constituted for managing over 65,000 acres of forests in the outer Himalayas (Harold,1946). These societies were formed as statutory bodies under the Kangra Forest Society Rules, 1941 (Arya and Samra, 2001). Similarly, an act was passed in Punjab known as "The Punjab Minor Canal Act, 1905", to make better provision for the control and management of minor canals. All the Kuhl's operated in Haryana were included in Schedule 7 of the Punjab Minor Canal Act, 1905. This act was designed to

Table 4. Percentage of Households reporting use of CPWRs for different purposes by different categories of Households (all India basis)

Category of Households (ha)	Irrigation	Livestock rearing	Household enterprise	Fishing
Landless	13.7	23.9	2.9	2.7
<0.20	7.9	11.8	2.8	1.5
0.2-0.5	45.7	34.1	2.8	2.7
0.5-1.0	42.6	41.5	2.8	3.4
1.0 or above	32.6	46.5	2.9	2.2
All India	22.8	29.8	2.8	2.5

provide irrigation channels through perennial streams to cover maximum area of villages situated in the foothills of Shiwaliks. From management point of view, the gravity irrigation system of Kangra district of the Himachal Pradesh also needs a special mention (Thakur, 1996 and Thakur et al., 1998). Over a period of time, the '*Kuhl*' system in Haryana Shiwaliks collapsed partly due to drying up of perennial water sources and partly due to changes in Government policies.

Institutional Mechanisms for Rainwater Harvesting and Utilization

It needs no emphasis that rain water harvesting not only meets people's basic water needs for agriculture and livestock but is also instrumental in building monetary and social capital in a society through community management of CPRs.

The Central Soil and Water Conservation Research and Training Institute and its Research Centres established 42 experimental micro-watersheds in the country since 1956 to analyze the impact of conservation measures on biophysical attributes with special emphasis on hydrology. A paradigm shift in participatory watershed management occurred in 1974 with the adoption of 4 pilot operational research projects in the country including the world famous "Sukhomajri" watershed, implemented through Research Centre, Chandigarh. It was the beginning of people's participation in environmental preservation, management of common property resources and above all harnessing the best out of private property resources (Bhumbla, 1976; Bhumbla, 1980; Grewal et al 1997; Mishra et al, 1980, Mittal et al 1986, Arya and Samra, 2001). An example of increase in fodder productivity of common lands through the constitution of local institutions is presented in Table 5.

Table 5. Increase in fodder productivity from common lands in the selected watersheds in the country

Watershed	State	Fodder grass Productivity (t/ha)		Source
		Pre-project	Post-project	
Sukhomajri	Haryana	2.47 (1979-81)	5.05 (1992-93)	Mittal <i>et.al.</i> , 2000
Bunga	Haryana	0.20 (1984-85)	3.20 (1994-95)	Samra & Dhyani (1998)
Bajar-Ganiyar	Haryana	0.10 (1983-84)	0.50 (1988-89)	-do-
Chhajawa	Rajasthan	0.0 (1985-86)	5.42 (1997-98)	Prasad <i>et.al.</i> 1996
Navamota	Gujarat	1.00 (1974-75)	2.00 (1994-95)	Kurothe <i>et.al.</i> , 1997
Chinnatekur	A.P.	0.88 (1984-85)	11.60 (1990-91)	Samra & Dhyani (1998)
G.R.Halli	Karnataka	1.5 (1977-78)	8.19 (1993-94)	Sharda <i>et.al.</i> , 2006
Fakot	Uttrakhand	3.9 (1974-75)	12.0 (1987-94)	Dhyani <i>et.al.</i> , 1997

Apart from the increase in productivity of fodder grasses in the common forest lands, the production of commercial grasses like bhabbar (*Eulaliopsis binata*) also increased in many watersheds due to complete protection of the forest area in Shiwalik foothill villages through "Social Fencing" by the Hill Resource Management Societies (Table 6).

Bhabbar is one of the most important non-timber forest produce in Haryana Shiwaliks. Of the 68,000 ha forest land in Haryana Shiwalik belt, nearly 20,000 ha is under Bhabbar production as it is one of the most important fibre grasses. It meets the long fibre pulp needs for paper manufacturing and is a primary raw material for rope making industry. Similarly, fodder grasses in the Shiwaliks are an important source of subsistence economy in the region. Prior to the formation of HRMS, the Haryana Forest Department used to allot the whole of adjoining area on lease basis for raising bhabbar and fodder grasses. The analysis indicated that yield of bhabbar grass was much higher

Table 6. Productivity of commercial grass (*Eualiospis binata*) from the common lands (t/ha)

Watershed	Pre project	Post project	% age increase	Source
Sukhomajri	1.35	2.67	97.8	Mittal <i>et.al.</i> 2000
Bunga	negligible	0.69		Samra and Singh, 1995
Nada	0.90	4.31	378	Grewal <i>et.al.</i> , 1997

in the forest area being managed by Hill Resource Management Societies (Fig. 1) as compared to the Forest Department, Govt. of Haryana and private contractors (Arya and Samra, 2001). The yields declined after 1998 as HRMS stopped taking the lease of forest areas for raising grasses.

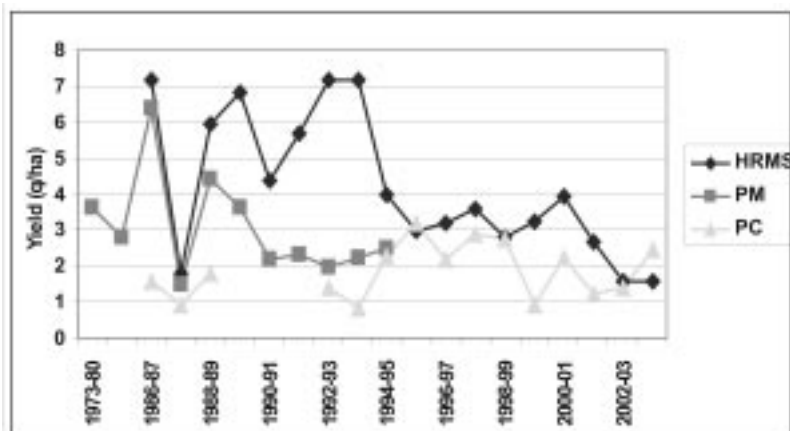


Figure 1. Comparative analysis of Bhabbar yield of forest area allotted to HRMS, Private Contractors and Paper Mills

HRMS working in the area collapsed and stopped functioning after introduction of new sharing system under JFM policy adopted by the Forest Department, Govt. of Haryana as described in a later section. The whole area is now being auctioned to private contractors.

Similarly, the production of Bhabbar in the areas managed by other nine Societies in Raipur Rani range of Panchkula District, Haryana, increased immediately after taking over the management of the area (4850 ha) by the societies from 1990 onwards (Fig. 2).

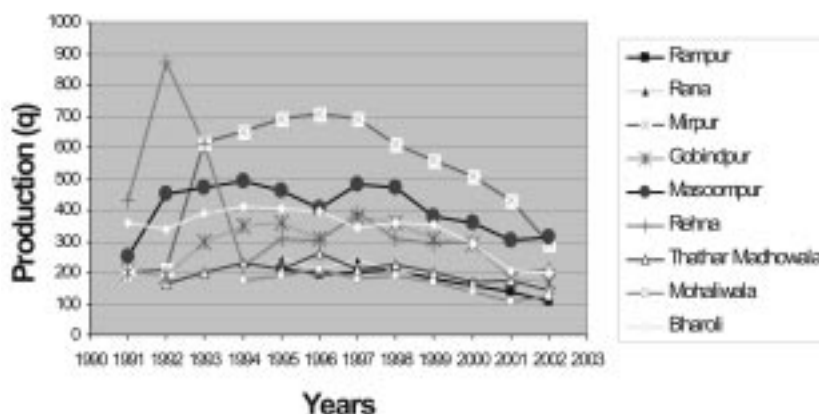


Figure 2. Production of bhabbar grass in Raipur Rani range, Panchkula, Haryana Dependence on Forest for fuel wood

Watershed management projects not only facilitated increase in production of fodder grasses but also helped in lowering the dependence of villagers on forests for fuel wood. Increased fodder production on private lands resulted in substantial increase in dung production which reduced fuel wood extraction from the state forests (Table 7).

Table 7. Dependence on forest for fuel wood extraction

Watershed	Annual fuel wood extraction from forests (tones/household)		Percent reduction
	Pre project (year)	Post project (year)	
Sukhomajri	4.79 (1974)	2.35 (1993)	104
Bunga	4.52 (1984)	2.39 (1995)	89
Fakot	4.71 (1974)	3.90 (1994)	21

Increase in Tree Density in Community Managed Watersheds

Intensive soil and water conservation measures were adopted in the catchment areas before and during the plantation in the watersheds. Due to protection of the catchment area by the local community institutions established for the purpose, the tree density increased manifold as is evident from the data presented in Table 8 for the five selected watersheds. Thus the social fencing helped in significantly improving the ecological security of the area apart from monetary benefits through sale of fuelwood and timber.

Table 8. Increase in tree density in the community managed watersheds

Watershed	Tree density (No./ha)		% increase
	Pre-project	Post-project	
Sukhomajri	58 (1979-80)	308 (1992-93)	431
Bunga	7 (1983-84)	23 (1993-94)	228
Nada	175 (1980-81)	586 (1992-93)	235
Chhajawa	6 (1985-86)	53 (1997-98)	783
Salaiyur	92 (1997-98)	98 (2002-03)	6

Income from Common Pool Resource Management

The two most important common property resources managed by the HRMS constituted on Sukhomajri pattern in Shiwalik foothill villages in Panchkula district of Haryana for maintaining and sustaining the watersheds are forest lands adjacent to the villages and water storage resources. The increase in production of fodder and bhabbar grasses in the catchments areas due to complete protection by the societies by adopting the concept of 'Social Fencing' is directly reflected in terms of revenue generated over a period of time (Arya and Aggarwal, 2004). An account of total income generated by ten HRMS is presented in Table 9.

Table 9. Total income of ten Hill Resource Management Societies operating in Haryana (1983-84 to 2003-04)

Sl.No.	HRMS	Period	Income	Source of income
1.	Sukhomajri	1986-2004	13,75,995	W.H.,B,F,Fh
2.	Dhamala	1989-2002	7,81,277	W.H., B,F,Fh
3.	Bunga	1984-2004	16,62,163	W.H., B,F,Fh
4.	Lohgarh	1990-2002	16,13,682	W.H., B,F,Fh
5.	Gobindpur & Mandappa	1988-2004	2,53,007	W.H., B,F,Fh
6.	Masoompur	1988-2004	6,58,870	B
7.	Raina	1988-2004	7,47,740	B
8.	Khera & Basaula	1995-2002	4,82,275	B
9.	Mirpur	1991-2004	2,19,704	B
10.	Nada	1994-2002	1,38,806	W.H., B,F,Fh
	Total		79,33,519	

B = Bhabbar grass ; F = Fodder grass; W.H. = Water Harvesting; Fh = Fish

Three major sources of income to the societies include i) sale of Bhabbar and fodder grasses; ii) irrigation charges; and iii) leasing out the reservoir for fish raising. Nearly 82 percent of the total income was generated from the sale of Bhabbar grass only followed by 7 percent from fodder grasses, 6 percent from water charges, 4 percent from fish cultivation and the rest from membership fee and imposing fines on individuals for violating the grazing rules.

Impact of CPRs Management on Productivity of Arable Lands, Employment Generation and Economics

Institutional management of common property resources like forest and water has not only resulted in increasing the productivity and income of CPRs but also boosted the economy of the villagers through increase in income, employment opportunities and productivity of private lands (Arya and Samra, 1995, Arya and Samra, 2001, Arya, 2005; Dhyani et al., 1997; Dhyani and Samra, 1998; Sharda et al., 2006, Yadav et al., 2004, Singh et al., 2008). Thus, CPR management essentially has a strong bearing on sustainable development of agriculture land of small and marginal farmers as evident from high benefit cost ratios of successfully managed watersheds (Table 10).

Table 10. Impact of watershed management projects on productivity, employment and economics

Watershed	Agro-climatic zone	State	Percent increase			B.C.R.
			Cropping intensity	Productivity	Employment	
Sukhomajri	Upper Gangatic Plain	Haryana	82	210	38	2.06
Nada	-do-	Haryana	78	165	18.6	1.97
Bunga	-do-	Haryana	110	170	41	1.86
Relmajra	-do-	Punjab	64	111	36	1.58
Behdala	Western Himalayas	H.P.	17	12		-
Bazar- Ganiyar	Upper Gangatic Plain	Haryana	47	115	29	1.90
Chhajjawa	Central Plateau & Hills/ Western Dry Region	Rajasthan	46	229	63	2.05
G.R.Halli	West Coast Plain & Hills	Karnataka	12	42	28	1.4
Joladsari	-do-	Karnataka	18	56	30	1.5
Chinnatekur	East Coast Plains & Hills	A.P	36	18	44	1.8
Rebari	Gujarat Coast Plains & Hills	Gujarat	20	56	3	2.6
Navamota	-do-	Gujarat	19	148	61	1.80
Fakot	Western Himalayas	Uttrakhand	74	297	54	1.93
Narainpur	Upper Gangetic Plain	Haryana	145	185	46	2.65
Johranpur	Western Himalayas	H.P.	29	74	63	1.66
Mandhala	-do-	H.P.	26	172	42	N.A.
Sheetalpur	Central Plateau and Hills	U.P.	73	81	27	N.A.

CPR-PPR-Income Linkages

Common pool resources can either complement private property resources or substitute them for production to provide direct income/consumption benefits. An economic plodding can be pushed to a new growth path by efficient management of CPRs and making them available to non-PPR owners. But, if CPRs are neglected, their productivity may decline with no linkage between CPRs and village incomes. Arya and Samra (1995) analyzed the inter-villages variations at different levels of CPR, PPR and overall development activities in four community based watershed development projects in the foothills of Northern Shiwalik region in Haryana. The analysis revealed that CPR management provided essential input to the privately organized production activities in the highly successful watershed development projects like Sukhomajri and Bunga (Table 11).

Table 11. Participation Indices and CPR-PPR-Income linkages

Village	Indices of participation	CPR-PPR	PPR-Income	CPR-Income
Sukhomajri	1.00	Dependent	Marginally dependent	Marginally dependent
Bunga	1.00	Dependent	Marginally dependent	Dependent
Tibbi	0.05	Independent	Dependent	Independent
Chowki	0.44	Independent	Dependent	Independent

Impact of Watershed Development on Cattle Migration

Seasonal migration of pastoral nomads i.e. *Gujjars*, which constitute 48 percent of human population in Shiwalik foothills, is being practiced since long in the region. To a large extent, these movements are necessitated due to non-availability of water and fodder resources in the water scarce region. This kind of migration is fairly close to involuntary migration (Shah, 2001). A study in the three most successful watersheds in Panchkula district of

Table 12. Percent decline in cattle migrating households after the watershed development projects

Village	% households migrating	
	Pre-project	Post-project
Bunga	79	20
Sambhalwa	86	Nil
Sher Gujjaran	81	46

Haryana State revealed that number of households migrating their cattle to other states like Punjab and Uttar Pradesh in search of water and fodder reduced significantly after development of water resources (Table 12).

A major inference from the study was that significant decline in cattle migration could be achieved only when there was substantial increase in irrigation intensity as evident in the case of Sambhalwa watershed.

Experiences of Integrated Wasteland Development Projects

The six watersheds located in diverse agro-ecological regions of the country, namely Eastern Ghats, Western Ghats (Nilgiris), Shiwalik (Himalyan foothills), Bundelkhand region, Western Coast Gujarat Plains and Chambal ravines were developed by the Institute as per 1995 guidelines of MoRD (Sharda et al., 2006). Empowerment of community, gender neutrality, equity, transparency and management of common property resources by village level Institutions were the paradigms enshrined in the new guidelines. The elevation of the watersheds ranged from 35 m to 1329 m indicating diverse agro-climatic settings of the watersheds (Table 13). Agriculture and labour accounted for 70 to 100 percent of the stake holder's occupation indicating high dependence of the watershed community on natural resources for their livelihood. Of the six watersheds, four watersheds had an average size of land holding less than or equal size to 2 ha signifying that majority of the farmers fall in small and marginal category with average family income varying from Rs. 1000 to Rs. 2500 per month.

The interventions on arable lands included construction of contour and graded bunds, water disposal structures, land leveling and terracing and packages of practices for crop improvement. On non-arable lands, grassed waterways and diversion channels were constructed for safe disposal of inevitable runoff. Drainage line treatment, including construction of check dams and gully plugs, was also undertaken for regulating the flow and reducing sedimentation. Afforestation works were carried out on wastelands and community lands in conjunction with other agro-forestry measures. Besides implementing various interventions in the watersheds, Watershed Committees, Self-help groups, Users groups and WDTs were constituted to ensure maximum participation of the community.

Various indicators employed to assess the impact of different interventions showed significant improvement in bio physical, participatory and socio economic attributes. Community organization had a catalytic effect on management of wastelands and private lands and contributions varied from 27 to 62% in the six IWDPs.

Water resource development was undertaken in five watersheds through renovation/rejuvenation of existing ponds and construction of water harvesting structures like small tanks and percolation ponds (Table 14). As a result of various water resource development activities, additional water storage capacity ranging from 121 to 1584 ha-cm with an average of 474 ha-cum was created resulting in increase in irrigated area by 65 to 585 percent.

The runoff reduced by 9 to 24 percent while the soil loss was brought down within the permissible limits in all the six watersheds (Table 15).

Water resource development in conjunction with introduction of high yielding varieties and other packages of practices helped in improving the Crop Productivity Index (CPI) from 0.5 in the pre-project period to 0.64 after the implementation phase. Crop Diversification Index (CDI) also increased by 6 to 79% as the farmers switched over to high yielding and remunerative cash crops (Table 16). The cultivated Land Utilization Index (CLUI) which is an indicator of how long the cultivated area is under crops in the year, also increased from 0.26 in the pre-project to 0.33 in the post-project period.

Vegetation Cover: Vegetative measures implemented in the arable and non-arable lands in conjunction with the mechanical measures helped in soil moisture conservation, which resulted in establishment and regeneration of vegetation and provided additional green biomass cover to the soil in all the watersheds. The Induced Watershed Eco Index (IWEI) was worked out indicating the additional area brought under vegetation including pasture lands,

Table 13. General features of IWDP watersheds implemented by Research Centres of CSWCRTI, Dehradun

Watershed	District & State	Agro-Ecological Region	Area (ha)	Elevation range (m) amsl	No. of families	Population	Major occupation (%)		Average holding size (ha)	Average annual income (Rs./ family)	Average milk production (lt./ family)
							Agri.	Landless labour			
Aganpur Bhagwasi	Patiala (Punjab)	9	550	80-286	166	1150	37	33	1.72	30,523	745
Antisar	Kheda (Gujarat)	5	812	25-35	500	2104	88	12	3.12	16,247	677
Badakhhera	Bundi (Rajasthan)	5	683	150-173	117	1117	78	22	3.23	25,811	613
Bajni	Datia (M.P.)	4	532	263-284	176	993	52	48	1.10	18,597	653
Kokriguda	Koraput (Orissa)	12	318	880-1329	78	249	93	7	2.15	12,155	12
Salaiyur	Coimbatore (Tamil Nadu)	19	513	370-472	314	1314	56	38	1.98	19,837	1146

Table 14. Water resource development in the IWDP watersheds

Watershed	Water storage capacity created (ha-cm)	Wells influenced (%)	Increase in well recharge rate (%)	Irrigated area increase (%)
Aganpur Bhagwasi	N.A.	N.A.	N.A.	N.A.
Antisar	1584	73	23	90
Bada khera	256	20	6	65
Bajni	144	50	50	585
Kokriguda	121	N.A.	N.A.	583
Salaiyur	266	46	10-50	84

Table 15. Impact of interventions on surface runoff and soil loss in the IWDP watersheds

Watershed	Surface runoff (%)		Soil loss (t/ha/yr)	
	Beforeproject	After project	Beforeproject	Afterproject
Aganpur Bhagwasi	48.5	24.0	12.6	2.8
Antisar	33.0	16.0	0.405	0.042
Bada khera	30.0	10.0	40.0	1.0
Bajni	25.4	16.3	12.1	8.3
Kokriguda	36.8	12.4	38.2	6.6
Salaiyur	45-72	1.3	1.7-8.9	0.5-1.6

Table 16. Crop productivity, crop diversification and cultivated land utilization indices of IWDP watersheds

Watershed	Crop productivityindex		Crop diversificationindex		Cultivated land utilization index	
	Pre-project	Post-project	Pre-project	Post-project	Pre-project	Post-project
Aganpur Bhagwasi	0.49	0.68	0.55	0.76	0.16	0.29
Antisar	0.29	0.42	0.50	0.90	0.25	0.37
Bada khera	0.83	0.99	0.79	0.54	0.26	0.27
Bajni	0.33	0.48	0.68	0.98	0.14	0.21
Kokriguda	0.55	0.61	0.53	0.74	0.59	0.67
Salaiyur	NA	NA	0.94	0.99	0.18	0.19

Table 17. People's participation (%) in the IWDP watersheds

Watershed	Planning	Implementation	Maintenance	Monitoring & Evaluation	Overall
Aganpur Bhagwasi	81	89	NA	69	79.5
Antisar	72	71	74	NA	72.1
Bada khera	64	38	NA	NA	51.4
Bajni	34	62	78	56	57.5
Kokriguda	48	51	37	NA	45.3
Salaiyur	75	63	54	NA	63.9

horticulture and forestry plantation in the six watersheds. The IWEI varied from 0.05 to 0.42 with an average of 0.12 among the six watersheds thereby indicating that 12% watershed areas were rehabilitated through green biomass cover.

The people willingly participated in the planning, implementation and maintenance phases as is evident from the overall participation index which ranged from 45.3% to 79.5% with an average of 61.6% (Table 17).

Interventions like land improvement, water resource development and afforestation generated maximum additional casual employment varying from 7 to 78 mandays in Kokriguda watershed to 51461 mandays in Antisar watershed with an average of 17,004 mandays. As a result of various interventions, the overall average income per family in the six watershed increased by 8 to 106 percent with an average increase of 49%. Even a remotely located watersheds at Kokriguda registered a quantum jump in annual family income from Rs. 12115/- to 24981/- within a period of five years.

The experiences of the six watersheds have amply proved that holistic development of wastelands/community lands in rainfed areas by involving the local community has tremendous potential of achieving sustainable productivity in agriculture lands and ensure environmental security through efficient use of common property resources.

Joint Forest Management (JFM) and Management of Water Bodies

JFM has tremendous possibilities for changing the face of rural areas by poverty eradication. About 147 millions people living in 1,70,000 villages of the country are completely or substantially dependent on nearby forests to meet their livelihood requirements. The watershed development programmers would have sustained benefits only when the forest areas remain green and covered with adequate vegetative cover. All the states at present have started JFM covering an area of about 11,629 million ha managed by 44943 committees. As per the NSS survey of 1999, it was found that 96 percent of the villages do not have local bodies for managing forest resources. The data also revealed that more than 88 and 80% of the villages do not have any local bodies for managing the common water resources either for irrigation or for other uses, respectively.

A detailed study was undertaken by the Institute's Research Center, Chandigarh (Arya, 2005) to analyze the impact of JFM on-sharing and management of common property resources in Shiwalik foothill villages of Haryana state.

Haryana has been a pioneering state in the implementation of JFM resolution way back in June, 1990. Subsequently, Govt of Haryana issued a revised notification in 1998 covering all government owned forests in the state, in which the benefit sharing system was changed drastically in favour of forest department (Fig. 3). About 4500 families in 58 Hill Resource Management Societies are involved in the protection and management of approximately 19,840 ha of forest areas in Shiwalik foothill villages in two forest divisions Morni-Pinjore and Yamunanagar.

The detailed information was collected from 10 successfully working societies which indicated that after the introduction of new JFM notification in 1998 involving new benefit-sharing system, the income of all the societies reduced by 45 percent in the first year (1997-98) and in certain cases by more than 75 percent in the subsequent year (1998-99). From 1999-2000 onwards, the income has gone down drastically. For example, in case of Masoompur society, the income has gone down from Rs.93,063/- in 1997-98 to just Rs.5,392 in the year 2002-03 over a period of five years (Table 18). The Societies working in Pinjore range have altogether collapsed for want of funds. The two main reasons for loss of income to HRMS were recorded as (i) introduction of new sharing system and (ii) reduction in demand and market value of Bhabbar (*Eulaliopsis binata*) which was the major source of income to Societies.

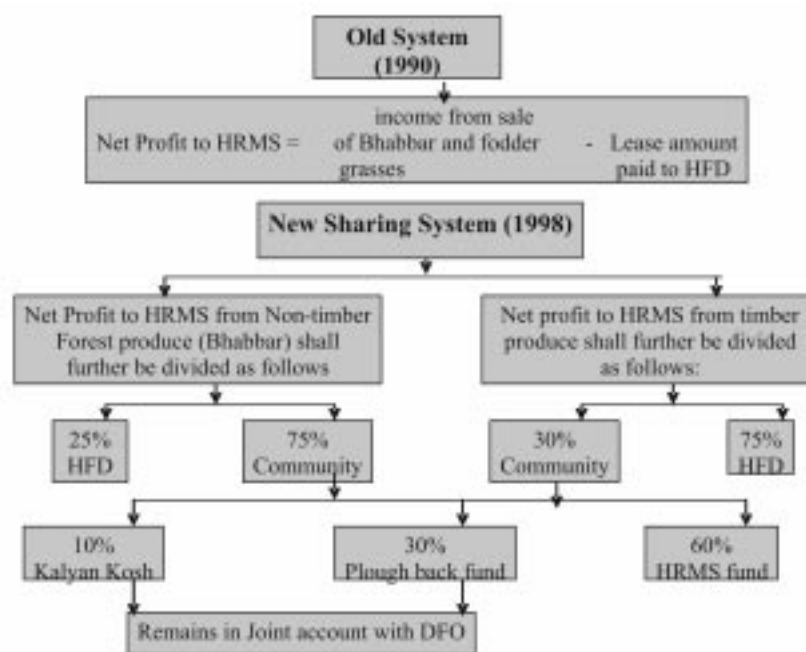


Figure 3. Benefit Sharing System under JFM between HRMS and HFD

The much publicized and frequently quoted self sustaining SUKHOMAJRI MODEL has lost its relevance as far as functioning of HRMS is concerned in the context of JFM policy. The HRMS Sukhomajri which earned more than Rs.14 lakhs in the last 20 years is now virtually bankrupt.

In the past, low cost lease rates provided the required support to the community for sustaining the benefits which were mainly limited to Bhabbar and forage grasses. Very little effort was made to define the sharing rights for long maturing shrubs and trees planted in the watershed. However, as per the new JFM Policy, various other items like timber, Katha, Bamboo etc. have been included in the list for which sharing will be done in the ratio of 30:70 between the communities and the department. It is stated that communities will have the obligation to protect the grasses and trees but the major part of the benefits would be shared by the department as per the Joint Management Agreement (JMA) (issued by Government of Haryana, Forest Department, dated 29.6.1998).

In new sharing system (both in case of Bhabbar and fodder grasses as well as timber), the forest department has been made a co-signatory for operating the bank accounts of the HRMS, whether it is 'Kalyan Kosh' or 'Plough Back' account. Though monitoring and control of funds is vested with the state, it remains unaccountable to the users. Thus, the important issue/question is of the distribution of income/profits from CPRs between the community which protects, manages and maintains the watershed and the department which invests in its management with overall control over use of funds.

Conclusions and Policy Implications

From the study, it is amply clear that the role of institutional arrangements is extremely important in natural resource management in general and common pool resources in particular under any resource governance structure (state control, private property, common or communities control, open access, and distributed or shared governance) (Marothia, 2002). The most challenging issue in managing common pool resources is that of designing institutions or the process of working rules for collective action in the implementation of watershed development projects. Some very successful case studies in rehabilitation of CPRs following watershed approach, using collective management systems have been demonstrated effectively in different agro-climatic regions of the country by CSWCRTI, Dehradun and its Research Centres. Rehabilitation/restoration of wastelands through implementation of IWDP projects were aimed at upgrading the productive capacity of land with sufficient conservation value.

Table 18. Comparison of new benefit sharing system under JFM with old system in terms of net income to HRMS from sale of Bhabbar grass

Village	Gross income from resale of Bhabbar (1997-98) (Rs.)	Share of HRMS in 1997-98		% reduction in profit in new system vs old system	Share of HRMS in 1998-99 (New System)	Percentage reduction in profits in 1998-99 over 1997-98	Share of HRMS in the year				
		Old* System	New system				1999-2000	2000-2001	2001-2002	2002-2003	2003-2004
Sukhomajri	95,000	68140	30663	45	7784	75	Nil	Nil	Nil	Nil	Nil
Dhamala	135000	106458	47906	45	23534	51	Nil	Nil	Nil	Nil	Nil
Lohgarh	303000	266852	120083	45	47183	61	10733	12983	Nil	Nil	Nil
Jatanmajri	40000	25881	11646	45	8947	23	2124	Nil	-	Nil	Nil
Khera	40000	32305	14537	45	9376	36	8237	Nil	-	Nil	Nil
Basawal	20000	12121	5955	45	2755	54	Nil	Nil	-	Nil	Nil
Gobindpur & Mandappa	28500	27159	12222	45	6597	46	8398	7590	3000	2323	2323
Masoompur	100000	93963	42283	45	27883	34	15431	8478	5528	5392	5498
Raina	120050	112009	50405	45	16632	67	16642	14618	17319	6292	11018
Mirpur	31000	28312	12741	45	7341	42	2844	1928	1853	594	144

*In case of old sharing system, the profit of HRMS is estimated while actual profits are given for the new system.

The five decades experience of the Institute and other similar studies (Sethi and Singh, 2001; Gupta, 2001; Arya 2003; D'Silva and Nagnath, 2002) have shown that the outcome of the institutional arrangements in the management of CPRs is possible if:

- the institutions are noted in the society's value system and developed with long term objectives in view,
- common resources are left to the community, while simultaneously strengthening the institutions of local self government,
- keeping the distributive end effects in view, the less well off sections of society are cushioned from the operation of market forces,
- the technology, the institutions and the environment are mutually harmonized, and
- the local community made partner not only in protection but also in sharing the benefits of it.

References

- Aggarwal, A. and Narain, S. 2002. Community and Household Water Management: The Key to Environmental Regeneration and poverty Alleviation. .In. "*Institutionalizing Common Pool resources*", Edited by Dinesh, K. Marothia, Concept Publishing Company, New Delhi.
- Arya, Swarn Lata and Aggarwal, R.K. 2004. Organisational Structure, Membership Pattern and Status of Hill Resource Management Societies in Haryana Shiwaliks. *Journal of Social and Economic Development*, Volume VI , No. 1, pp. 91-112.
- Arya, Swarn Lata and Samra, J.S. 1995. Participatory Process and Watershed Management:A Study of theShiwalik Foothill villages in Northern India. *Asia-Pacific Journal of Rural Development*, Vol. V, No. 2, pp 35-57.
- Arya, Swarn Lata and Samra, J.S. 2001. Revisiting Watershed Management Institutions in Haryana Shivaliks, India. *Published by Central Soil and Water Conservation Research and Training Institute, Research Centre, Chandigarh*, pp. 328.
- Arya, Swarn Lata. 2005. A Study of Joint Forest Management Programme and New Benefit Sharing Systems in Shivalik Foothill Villages in Haryana. *Van Sahyog*, Vol.6, Issue 4, p. 14-17.
- Beck, T. 1994. Common Proper Resource Access by poor and class conflict in West Bengal. *Economic and Political weekly* 29:187-196.
- Beck, Tony and Madan G. Ghosh. 2000. Common Property Resources and the Poor: Findings from West Bengal. *Economic and Political Weekly*, January 15, Pp 147-53.
- Bromley, D.W. (ed.). 1992. Making the Commons Work., *San Francisco: ICS Press*.

- Bhumbla, D.R. 1976. Soil Conservation in Shiwaliks. *Indian Farming*, 25(12):3-5.
- Bhumbla, D.R., Mishra, P.R., Grewal, S.S. and Mittal, S.P. 1980. Soil Conservation in Sukhomajri-A New Direction. Proceedings of the National Symposium on Soil and Water Management in 1980's held at Dehradun in February, 1980. India.
- Chopra, K. and Gulati, S.C. 2001. Migration, Common Property Resources and Environmental Degradation: Inter Linkages in India's Arid and Semi-arid Regions. *Sage Publications India Pvt. Ltd.*, New Delhi.
- Chopra, K., Kadekodi, G.K. and Murthy, M.N. 1990. Participatory Development: People and Common Property Resources. *Sage Publications India Private Limited.*, New Delhi.
- CWS, 2001. Common Pool Resources in Semi-Arid India: Dynamics, Management and Livelihood Contributions. *A.P. Regional Report-Centre for World Solidarity*.
- D'Silva, Emmanuel and Nagnath, B. 2002. 'Behroonguda: A Rare Success Story in Joint Forest Management', *Economic and Political Weekly*, Vol. 37, No 6, pp 551-557.
- Das Gupta, P, 2005. Common Property Resources: Economic Analytics, *Economic and Political weekly*, April 16, pp1610-1622.
- Dhayni, B.L., Sasmra, J.S., Juyal, G.P., Rambabu, Katiyar, V.S. 1997. Socioeconomic analysis of a participatory integrated watershed management in Garhwal Himalaya-Fakot Watershed. *Technical Bulletin No. T-35/D-24, CSWCRTI*, Dehradun (Uttarakhand). 113p.
- Dhyani, B.L., Samra, J.S., Juyal, G.P., Ram Babu and Katiyar, V.S. 1997. Socio-economic Analysis of a Participatory Integrated Watershed Management in Garhwal Himalayas – Fakot Watershed. *Bulletin No. T-35/D-24, CSWCRTI*, Dehradun, 113 p.
- GOI, Ministry of Environment & Forest. 2002. Report on Empowering People for Sustainable Development, New Delhi.
- Gowda, M.N. and Savadati, P.M. 2004. CPRs and Rural Poor: Study in North Karnataka. *Economic and Political Weekly*, August, 14, pp. 3752-3757.
- Grewal, S.S., Samra, J.S., Mittal, S.P. and Agnihotri, Y. 1997. Sukhomajri Concept of Integrated Watershed Management. *Technical Bulletin No. T-26/C-5, CSWCRTI*, Research Centre, Chandigarh, 157p.
- Gupta, A.K. 1987. Why Poor People do not Co-operate? A Study of Traditional Forms of Co-operation with Implications for Modern Organisations, in *Politics and Practices of Social Research (ed)*, Wanger, G.C. George Allen and Unwin, London.
- Gupta, H.S. 2001. Effect of JFM Practices on Nutrient Status of Soil- A Case Study". *Van Sahyog*, Vol. III, No 2, p.7.
- Harold Glover. 1944. Erosion in the Punjab: its Causes and Cure- A survey of Soil Conservation, *Feroz Printing Works, Lahore*, 143 p..
- Iyengar, S and Shukla, N. (1999). Regeneration and Management of Common Property Land Resources in India: A Review, *Working Paper No. 110. Gujarat Institute of Development Research: Gota, Ahmedabad*.
- Iyengar, S. 1988. Common Property Land Resources in Gujarat: Some Findings about their size, status and use. Working Paper No. 18, *Gujarat Institute of Area Planning: Gota, Ahmedabad*.
- Jodha, N.S. 1986. Common Property Resources and Rural Poor in Dry Regions of India. *Economic and Political weekly*, 21(27). 1169-81.
- Jodha, N.S. 2000. Wastelands Management in India: Myths, Motives and Mechanisms. *Economic and Political weekly*. Feb. 5, pp 466-473.
- Karanth, G.K. 1992: Privatization of Common Property Resources: Lessons from Rural Karnataka. *Economic and Political Weekly*, August 1-8, Vol.31&32, pp1680-1688.
- Kurothe, R.S., Singh, H.B., Nambiar, K.T.N., Pandey, V.C., Samarth, R.M. and Kumar, V. 1997. Watershed management for sustained production in Aravali hills of North Gujarat-Navamota Watershed. *Technical Bulletin No. T-36/V-1, CSWCRTI*, R.C. Vasad (Gujarat). 63pp.
- M.S. Rama Mohan Rao, R.N. Adhikari, S.K.N. Mah, M.P. Admaiah, M, Chandrappa and K.K. Reddy 2000, Resource Conservation through Watershed Management for Economic and Financial Sustainability of Dryland Agriculture in the Semi Arid Region of Deccan Plateau. Lead paper presented in International Conference on " Land Suhas P. Wani November 9-13, 2000, New Delhi, India.
- Marothia, D.K. 2005. Common Property Resources: Managing the Unmanaged. In *Watershed Management Challenges-Improving Productivity, Resources and Livelihoods*. Edited by Bharat R. Sharma, J.S. Samra, C.A. Scott and Suhas P. Wani published by International Water Management Institute in association with the Indian Council of Agricultural Research and the International Crops Research Institute for Semi-Arid Tropics . 327 p.
- Marothia, D.K. 2003. Institutions for Common Pool Resources. In "Institutional Change in Indian Agriculture", Edited by Suresh Pal, Mruthyunjaya, P.K. Joshi and R. Sexana. *National Centre for Economic and Policy Research, New Delhi*.

- Mittal, S.P., Mishra, P.R. Grewal, S.S and Agnihotri, Y. 1986. Success Story of Sukhomajri Watershed Management Project. *Indian Journal of Soil Conservation*. 14 (3): 1-8.
- Mittal, S.P., Agnihotri, Y., Samra, J.S. and Aggarwal, R.K. 2000. Development of Sukhomajri model of integrated watershed management in Shivalik foothills. *In 50 years of research on sustainable resource management in Shivaliks*. Eds. S.P. Mittal, R. K. Aggarwal and J.S. Samra. CSWCRTI. R.C. Chandigarh. 506p.
- Mishra, P.R., Grewal, S.S., Mittal, S.P., and Agnihotri, Y. 1980. Operational Research Project on Watershed Development for Sediment, Drought and Flood Control- *Sukhomajri-Bulletin-CSWCRTI, Research Centre*, Chandigarh, pp 1-57.
- NSSO, 1999. Common Property Resources in India, *NSS 54th Round* (Jan-1998 – June 1998), Government of India.
- Ostram, E. 1992. Crafting Institutions for Self Governing Irrigation Systems, *San Francisco: ICS Press*.
- Pasha, S.A. 1992: CPRs and Rural Poor: A Micro Level Analysis. *Economic and Political Weekly*, November 14, pp 2499-2503.
- Prasad, S.N., Singh, Ratan, Prakash, C., Katiyar, V.S., Samra, J.S. and Singh, K.D. 1996. Watershed management for sustainable production in south-eastern Rajasthan (Chhajawa Watershed) CSWCRTI, R.C. Kota (Rajasthan) *Technical Bulletin No. T-32/K-3*. 51p.
- Samra, J.S. and Dhyani, B.L. 1998. Elements of Participatory Watershed Management in India. In National Workshop on “*Watershed Approach for Managing Degraded Lands in India, Challenges for 21st Century*”, sponsored by Ministry of Rural Areas and Employment, New Delhi.
- Samra, J.S. and Singh, S.C. 1995. Comparison of Soil Properties, Tree Base Area and Aboveground Biomass of Grasses and Shrubs at three Topographic Positions of a Restored Watershed. *Indian Journal of Soil Conservation*. 23 (3): 175-184.
- Sethi, P. and Singh, T.P. 2001. Village Resource Development as an Incentive to Sustain the Joint Forest Management Programme. *Indian Forester*, 127(11): 1215-1222.
- Shah, Amita 2001. Water Scarcity Induced Migration : How Far Watershed Projects can Help?. *Economic and Political Weekly*, Vol. XXXVI, No. 35..
- Sharda, V.N.; J.S.Samra.; and Pradeep Dogra 2005. Participatory Watershed Management Programmes for Sustainable Development: Experiences from IWDP. *Indian Journal of Soil Conservation*. Vol.33, No. 2, pp 93-103.
- Sharda, V.N; Juyal, G.P and Sikka, A.K. 2006. Participatory Integrated Watershed Management – A field manual, Published by CSWCRTI, Dehradun, p. 363.
- Singh, K. 1994. Managing Common Pool Resources: Principles and Case Studies. *Oxford University Press*. New Delhi.
- Tang, S.Y.1992. Institutions and Collective actions: Self-Governance in Irrigation, *San Francisco: ICS Press*.
- Thakur, R.K., S.C.Tiwari and Y.S.Negi. 1998. Community Participation in the Management of Gravity Irrigation System in Himachal System. *Journal of Agricultural Development and Policy*. Vol X, No 1.
- Thakur, R.K.,1996. Economics of Hill Farming Systems and their Linkages with Common Property Resources” *Ph.D dissertation*. Nauni-Solan: Dr. Y.S.Parmar University of Horticulture and Forestry.
- Yadav, R.P; Aggarwal, R.K; Arya, S.L; Partap Singh; Ram Prasad; Bhattacharyya, P., Tiwari, A.K and Yadav, M.K. 2005. “Rainwater Harvesting and Recycling Technology for Sustainable Production in Small Agricultural Watershed- Johranpur” *Bulletin No. T-50/C-11, Central Soil and Water Conservation Research and Training Institute, Research Centre, Chandigarh*. pp 163.

Irrigation Tanks: A New Way Forward? (focus on tanks in South India)

K. Palanisami

*IWMI-Tata Water Policy Programme, International Water Management Institute,
South Asia Regional Office, ICRISAT campus, Hyderabad, India
(Email: K.Palanisami@cgiar.org)*

Irrigation tanks in India are century old water harvesting structures. There are about 208,000 tanks in the country irrigating about 2.3 m.ha in 2000-01 and about 64% is concentrated in southern states. Net area irrigated by tanks in India has declined by 29 % between 1990-91 and 2000-01. Among the tank intensive states, Tamilnadu has the highest decline of 34.2% and Maharashtra the lowest (6%). Other tank non-intensive states put together experienced a decline of about 47%. Encroachment, poor management, privatization and government appropriation of the tanks have been the main outcomes of the failure of local authority system to enforce the institutional arrangements under common property resources management regime. Poor management of the tanks had also resulted in lower land productivity compared to canals and wells. In addition to the existing constraints, the emerging threats may also affect the stability of tank irrigation. However, due to constraints in the future expansion of the canal and well irrigated areas, tank irrigation still offers more scope for revival. Several interventions such as revenue mobilization, augmenting groundwater resources in the tanks, strengthening the multiple uses, tank sluice management, integrating social forestry and desilting, and tank modernization are suggested. Hence a new way forward incorporating the needed interventions is warranted to make the tank irrigation a sustainable livelihood option for the future.

Tank Irrigation Systems in India

Tank irrigation contributes significantly to agricultural production in parts of South and Southeast Asia. Especially in South India and Sri Lanka, tank irrigation has a long history and many currently used tanks were constructed in the past centuries. The tanks have existed in India from time immemorial, and have been an important source of irrigation especially in southern India. They account for more than one-third of the total irrigated area in Andhra Pradesh, Karnataka and Tamil Nadu states. The tank irrigation system has a special significance to the marginal and small scale farmers. They make a very large number, and essentially depend on tank irrigation, as these systems are less capital-intensive and have wider geographical distribution than large projects (Palanisami 2000).

An irrigation tank is a small reservoir constructed across the gentle slope of a valley to catch and store water during rainy season and use it for irrigation during dry season. Tank irrigation systems also act as an alternative to pump projects, where energy availability, energy cost or ground-water supplies are constraints for pumping. The distribution of tanks was quite dense in some areas. However, over the years the performance of the tanks has been in decline.

The share of tank irrigated area in India has declined from 16.51 percent in 1952-53 to 5.18 percent in 1999-2000, whereas the share of groundwater irrigation has increased from 30.17 percent to 55.36 percent during this period. The share of the tank irrigated area to net irrigated area (NIA) had been declining continuously over the years (Fig. 1). The net area irrigated by tanks at all India level between 1990-91 and 2000-01 has declined by 29.4% and among the states, highest decline was observed for Tamilnadu (34%) and the lowest for Maharashtra (6%) (Table 1). Among the three major sources of irrigation, tank is the only source, where the irrigated area has been declining continuously since early seventies and many argue that the area under tank irrigation started declining only after the introduction of the green revolution. Further, among the states in India, the area under tank irrigation has declined more drastically in those states where tank irrigated area accounts for relatively a larger share in the net irrigated area and it has increased marginally in certain states where it accounts for very low share in the net irrigated area.

Data from the Agricultural Census of India for five time points namely 1970-71, 1976-77, 1980-81, 1985-86 and 1990-91 indicated that the resource poor farmers (owning less than 2 hectares) still account for major share of tank-irrigated area in India. Marginal (less than 1 ha) and small farmers (1-2 ha) together accounted for about 40 percent of tank-irrigated area in 1970-71, which further increased to nearly 55 percent in 1990-91 thus accounting for nearly two third of tank irrigated area. On the other hand, the share of tank irrigated area used by large farmers declined from 13.59 percent to 6.02 percent during this period. Since the farmers belonging to marginal and small size group

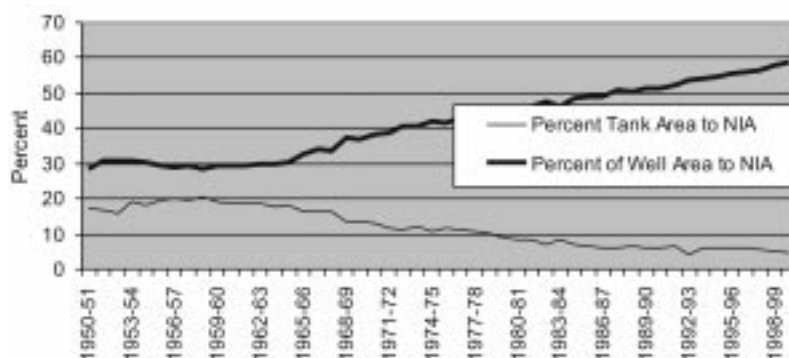


Figure 1. Share of tank and well-irrigated area to net irrigated area (NIA), India

Table 1. Net Area Irrigated under Tanks in India

No	States	No. of tanks#	% to total tanks	1990-91*		2000-01**		% area decline in 10 years
				Area irrigated (ha)	% to total area	Area irrigated (ha)	% to total area	
1	Andhra Pradesh	60745	29.15	969319	29.88	822306	35.90	15.17
2	Karnataka	20152	9.67	238560	7.35	192469	8.40	19.32
3	Maharashtra	12539	6.02	310692	9.58	292155	12.75	5.97
4	Tamil Nadu	39366	18.89	530406	16.35	348888	15.23	34.22
5	Sub total for 4 states	132802	63.73	2048977	63.16	1655818	72.29	19.19
6	Sub total for other states	75579	36.27	1195235	36.84	634711	27.71	46.90
7	All India total	208381	100.00	3244212	100.00	2290529	100.00	29.40

Source: # Vaidyanathan, (2001). For Tamilnadu state, the data is from Tamilnadu – An Economic Appraisal, 2002.

* Directorate of Economics and Statistics, Ministry of Agriculture, as quoted in World Bank, 1998:128.

** Minor Irrigation Census (2000-01), Ministry of Water Resources, Govt. of India

are mostly poor, they couldn't afford for cost-intensive irrigation sources like groundwater as in the case of medium and large farmers and tank irrigation continues to play a crucial role among small and marginal farmers even today. This is also true across different states where tank irrigation has considerable presence even today (Narayanamoorthy 2004). As a consequence of the decline in tank irrigation, the land productivity is also observed to be low under tanks compared to other sources of irrigation. Among the southern states, for example, in Tamilnadu state, compared to tanks, land productivity per ha. is higher under canals (13%) and wells (183%) (Table 2).

This warrants the revival of the tank irrigation as a viable irrigation source.

Table 2. Land Productivity by Sources of Irrigation (tons/ha in food grains energy equivalent units)

States	Land productivity (t/ha)*			% productivity higher in wells over tanks	% productivity higher in canals over tanks
	Wells	Canals	Tanks		
Andhra Pradesh	5.7	3.4	2.00	185.00	70.00
Tamilnadu	6.5	2.6	2.30	182.61	13.04
Karnataka	4.2	3.5	2.30	82.61	52.17

* Data quoted in Thakkar, 1999, P.23. Others were calculated by the author

Tank Systems of South India

Southern parts of India are noted for the intensity of tanks. Unlike the northern region, the rivers in the south are mostly seasonal and the plains are not much extensive. Further, the geology is not favourable for groundwater storage. The local topographic variations have been effectively exploited to impound rainfall in tanks which are used to raise irrigated rice crop and simultaneously serve as means of improving groundwater recharge in their command areas. There are about 120,000 tanks in the southern region consisting of Andhra Pradesh, Tamil Nadu and Karnataka states (Agarwal and Narain 1997).

This tradition of tanks as the largest source of irrigation continued until mid 1960s. The decline of tank irrigation was due to the constitution of policy which had its origins in the very early phase of British rule in India. An impression was created that the smaller irrigation works were uneconomical and unnecessary burden on revenue officials because of changes in the tenurial system towards Raiyatwari or Zamindari.

Among the southern state, Tamil Nadu state alone has about 39,366 tanks with varying sizes and types. The tanks are classified into system tanks (which receive supplemental water from major streams or reservoirs in addition to the yield of their own catchment area) and non-system / rainfed tanks which depend on the rainfall in their own catchment area and are not connected to major streams / reservoirs. The tanks are also classified into Panchayat Union, Public Works Department (PWD) and *Ex-zamin* tanks based upon the management authority. Panchayat Union tanks have a command area less than 40 ha, and under the control of village communities (Panchayat union). Those tanks having a command area more than 40 ha as well as all the system tanks are maintained by PWD. *Ex-zamin* tanks were constructed by *zamindars* (landlords) during the British administration. After abolishment of *zamindari* system by the State government in 1957, they were transferred to Panchayat Union and PWD based upon the sizes of command areas. Out of the total number of tanks in the State, 53 per cent are PU tanks, 22 per cent are PWD tanks and 25 per cent are *ex-zamin* tanks. There are about 9,800 *ex-zamin tanks*, of which more than 60 per cent are concentrated in the undivided Ramanathapuram district (Palanisami, et al. 1997).

Management of Tanks

In ancient days, tanks were considered to be the property of rulers. The farmers paid a portion of the produce to the ruler. Farmers also were in charge of the maintenance of the tanks, and supply channels. Zamindars ensured the proper maintenance of the tanks, and channels, since they reaped the benefits of farming in large areas. However, when the British introduced the Raiyatwari system in 1886, tanks with an ayacut of 40 ha and above were brought under the control of PWD and smaller tanks were under the administrative control of local bodies, or vested with the villagers themselves. Since the local bodies did not have qualified engineers, and the duties of the ayacutdars were not clearly mentioned, the system of the farmers themselves taking up maintenance work known as *kudimaramath* works slowly declined. Tanks were silted up, and supply and distribution channels choked. The deterioration of the tank irrigation system has been a subject of considerable discussion, at least since the middle of the 19th century. The Report of the Public Works Commission of 1852 stated that there was not much of voluntary community labour involved in tank maintenance, and it reported that in all districts labour was more or less forced to work. In fact an act was passed, namely the Madras Compulsory Labour Act of 1858 (or what is known as the *Kudimaramath* Act), with a view to legalising compulsory labour for certain aspects of maintenance, and also to penalize the non-performance of *kudimaramath* labour. The entire administration of the act of levying and collection of fines was left with the irrigation panchayats. The Famine Commission of 1878 brought to light quite forcefully the deteriorating conditions of tanks and advocated a systematic policy of maintenance. One of the most important recommendations of the commission was the creation of tank restoration parties (Palanisami, et.al, 1997).

However, at present the responsibilities are shared between different institutions which also vary among the different states (Table 3). In all the states, the local village is responsible for water distribution and management of the tanks with a command area of below 40 ha. In spite of these institutions on tank management, the performance of the tanks has been reduced over the years.

Performance of Tanks over the Years

Compared to all India level, in Tamil Nadu state, the share of tank irrigated area to net irrigated area has declined (Table 4). Among the farmer categories, area irrigated by marginal farmers has decreased from 39.53 per cent in 1970-71 to 35.17 per cent in 1990-91, area by small farmers had decreased from 32.02 to 0.23 per cent, medium farmers (2-4 ha) has decreased from 30.03 per cent to 21.47 per cent and large farmers (more than 4 ha) has decreased from 28.46 per cent to 19.40 per cent during the above periods respectively, indicating the poor performance of the tank irrigation systems in the state (Palanisami, 2005).

In a 10-year period, the tank usually gets normal supply for three years and gets deficit supply for five years, and the water supply fail completely for two years (Table 5). Given the rainfall uncertainties, the tank performance is seen as declining over the years. There are above-outlet problems such as poorly maintained structures (bunds,

Table 3. Tank Management Responsibilities in Three Indian States

State	Tank Command Area (ha)	Public works Department	Revenue Department	Village
Andhra Pradesh	<40 ha	—	Revenue collection	Maintenance & repairs; Water regulation
	40-400 ha	Maintenance & repair	Revenue collection; Water regulation	—
	> 400 ha	Maintenance & repair; Water regulation	Revenue collection	—
Karnataka	< 40 ha	—	Revenue collection	Maintenance & repairs; Water regulation
	40-80 ha	Maintenance & repair	Revenue collection	Water regulation & supervision
	> 80 ha	Maintenance & repair; Water regulation	Revenue collection	—
Tamil Nadu	< 40 ha	—	Revenue collection; Water regulation	Maintenance & repairs
	> 40 ha	Maintenance & repairs	Revenue collection; Water regulation	—

Source: Palanisami and Easter, 2000.

Table 4. Share of Different Sources of Irrigation in India and Tamilnadu (per cent)

	Source	1960-61	1970-71	1980-81	1990-91	1999-2000	2005-2006*
India	Canals	42.05	41.28	39.40	35.63	31.29	29.25
	Tanks	18.5	13.22	8.24	6.84	5.18	4.57
	Wells	29.56	38.22	45.70	51.04	57.81	60.88
	Others	9.89	7.28	6.66	6.49	5.73	5.30
	All	100	100	100	100	100	100
Tamil Nadu	Canals	35.80	33.90	32.70	32.40	27.58	27.40
	Tanks	38.00	34.50	32.10	22.38	19.47	19.69
	Wells	24.20	29.80	33.80	44.61	52.88	52.64
	Others	2.00	1.80	1.40	0.61	0.37	0.27
	All	100	100	100	100	100	100

Source: Tamil Nadu - An Economic Appraisal (Various issues).

For India, this relates to 2001-02

Table 5. Rainfall and Tank Irrigation Probabilities, Tamilnadu

Average wet-season rainfall (mm)	State of tank storage	Probability of occurrence
> 500	Surplus or normal	0.10
450 – 500	Full or normal	0.20
300 – 450	Deficit	0.50
< 300	Failure	0.20

Note: Based on 46 years rainfall data.

surplus weirs). Catchment is mismanaged and forest land adjacent to the catchment is already converted for human settlement by the Government. There is severe encroachment in the tank foreshores. Siltation of the tankbed has reduced the water storage capacity, ranging from 20 to 30 per cent. In the case of below-outlet problems, channels are not maintained and broken, resulting in heavy water losses. Well irrigation has dominated the tank irrigation in several cases where the increase in the number of wells in the tank command had been signaling the inactiveness of the tank systems for providing reliable water supply. In fact it had been found that a large number of tanks have become defunct in less tank intensive districts (i.e. 76 per cent of Panchayat Union tanks and 64 per cent of Public Works Department tanks have become defunct) compared to tank intensive regions, where the percentage of defunct tanks is less¹ (Table 6) (Palanisami, 2000).

¹Less tank intensive regions refer to the regions where tank irrigation is not the major source of irrigation compared to tank intensive regions, where the tanks are the major source of irrigation.

Table 6. Defunct or Inactive Tanks Across Regions, Tamilnadu

Region / Tank type	Number of tanks		Mean command area (ha)	
	PU	PWD	PU	PWD
<i>I. Tank intensive districts</i>				
a) Total tanks counted	2064	487	-	-
b) Functioning tanks	2039	474	12.67	105.2
c) Defunct tanks	25(1.21)	13(2.62)	15.81	74.81
<i>II. Less-tank-intensive districts</i>				
a) Total tanks counted	67	90	-	-
b) Functioning tanks	16(23.9)	32(35.6)	22.48	79.75
c) Defunct tanks	51(76.1)	58(64.4)	18.16	99.46

Source: Palanisami, et al., 1997.

Figures in parentheses represent the percentage of tanks to the total number of tanks in each category.

PU = Panchayat Union

PWD = Public Works Department

The credit facilities through loans provided under agricultural cooperative credit societies and banks further facilitated the intensification of the well investment. Hence, tanks were no longer an asset that needed to be maintained, but at the same time, the prolonged deterioration has resulted in the acquisition of the tankbed by the influencing villagers for their private cultivation. The village level irrigation institutions like *kudimaramath* had also slowly become inactive and their roles insignificant. Government allotment of funds has also been insufficient for the operation and maintenance (O & M) of the tanks (Palanisami & Easter, 2000).

The neglect of tanks has meant that most farmers receive inadequate quantities of water from tanks. To offset the decline in tank water supplies, farmers have resorted to supplemental well irrigation to avoid crop losses (Palanisami & Easter 1987, 1991). Since only about 15 per cent of the farmers in the tank command area own wells, and there is a growing demand for well water, the well owners in most cases act like local monopolists and are able to charge high prices for well water. However, profit-making through privately owned water source (i.e. wells) within the hydrological boundary of the common property resource (tanks) poses serious threat to the very survival of the tanks, because of the declining interest among well-owners in proper upkeep of tank structures. The level of well interference on tank performance is also different between PU and PWD tanks.

The analysis of the well distribution in the tanks has shown that the well density (number of wells per ha of command area) was higher in PU tanks (0.42) than in PWD tanks (0.35), but the difference is not significant. The reason for higher number of wells in PU tanks is that the duration of water supply is comparatively lesser in PU tanks (2-3 months) than in PWD tanks (3-5 months) (Palanisami et al. 1997).

Even though several factors have influenced the tank performance, the level of their influences has varied across locations (Table 7). The well density had negative influence on the tank performance. It was observed that the higher the well density, the less the tank performance. Tanks without the well supplementation in the tank season had performed well and this clearly indicated the availability of adequate tank water supplies.

Concerning the O & M expenditure on tanks at state-level, the results of the study had indicated that though outlay per hectare of command area at current prices increased from Rs.26 to Rs. 161 per ha, the outlay at constant (1980-81) prices has increased only marginally from Rs. 33 to Rs.43 per ha. However, the level of O & M amount spent on the sample tanks revealed that the average amount spent was high for PU tanks (Rs. 154 per ha) compared to PWD tanks (Rs. 74 per ha). Since the O&M amount was spent, mainly in accordance with the urgency of the tank repair and the local political pressure, the level of tank performance and the amount of O&M spent could not be directly related (Palanisami et al. 1997).

In view of the inadequate financial support from the state for tank maintenance, farmers mobilize financial resources for tank maintenance from tank usufructs. The major sources of income are : a) sale of fishes raised in tank water, b) sale of trees grown on the tank bunds and the water spread area, c) sale of silt, and d) collection of fees / rents from duck-growers and cattle growers for allowing the ducks and cattle in the tank command area after harvesting of rice crop, etc. Classification of parameters influencing tank performance under different levels of tank performance revealed that there is a negative relationship between resource mobilized and the tank performance.

Table 7. Parameters Influencing Tank Performance under Different Levels of Adjusted Tank Performance, Tamilnadu

Tank Type	Adjusted Tank Performance (per cent)	Well Density (No. per ha)	O & M Expenditure (Rs. per ha per year)	Resource Mobilised (Rs. per ha per year)	Encroachment (per cent of waterspread area)	Farmers' Participation (man days per ha per year)
PU	<25	1.30	73.80	28.00	34.44	0.28
	25-50	1.00	12.07	0.60	20.26	0.20
	50-100	0.30	154.00	8.25	12.24	0.56
	>100	0.00	24.00	0.00	8.22	0.72
Mean	75.70	0.42	154.00	9.00	16.23	0.54
PWD	<25	1.25	28.50	68.80	19.76	0.09
	25-50	1.00	108.00	61.30	11.66	0.35
	50-100	0.30	73.20	9.45	6.99	0.49
	>100	0.00			No tanks under this category	
Mean	83.30	0.35	74.00	14.00	10.23	0.30

Adjusted tank performance uses the actual tank irrigated area after adjusting for the area irrigated by wells in the tank command area. For details, see, Palanisami & Easter, 2000

The resource mobilized per ha of command area was found to be higher in tanks with poor performance. The average resource mobilization was Rs. 28 per ha in PU tanks and Rs. 68.80 per ha in PWD tanks with performance less than 25 per cent. The resource mobilization was about Rs. 8.25 to Rs. 9.50 per ha in tanks (both PU and PWD) with performance between 50-100 per cent. The reason for this might be that farmers used to mobilize the resources (mostly labour) expecting that the tanks will be filling in the coming seasons, but, due to erratic rainfall pattern, the tanks will not be filling up, resulting in poor tank performance.

Further, the percentage of PU tanks having water users' organisation was lower when compared to the PWD tanks. As much as 31 per cent of the PWD tanks had informal Water Users' Organization (WUO), whereas only 14 per cent of the PU tanks had informal WUO. The functions of these organizations include the appointment of 'neerkattis' (common waterman), organizing and coordinating tank maintenance works (mainly cleaning supply channels and main canals), resource mobilization for tank maintenance, lobbying with government departments for better maintenance of tank structures, etc. The farmers' participation in tank maintenance was also comparatively higher in PU tanks (0.54 man days per year per ha of command area) than in PWD tanks (0.30 man days per year per ha of command area). It is observed that the performance of tanks and farmers' participation were directly related. In the case of encroachment in the catchment, supply channel and water spread area, it was higher (16.23 per cent) in PU tanks as compared to only 10.23 per cent in PWD tanks. The results had indicated that the level of encroachment directly influenced the performance of tanks. Because of lesser catchment, foreshore and water spread area in the case of PU tanks the encroachment is relatively high. Further, since the PU tanks are smaller in size with less number of farmers, the aggression of the encroachment is also comparatively higher.

Possible Interventions – A New way forward?

Resource Mobilization and Use

The major source of tank operation and maintenance expenses (O & M) is from funds allotted by the Government. However, in real terms it has been almost constant over the years. There are also funds mobilized from forestry, fishery resources besides farmers own contribution. More commonly, the resources mobilized in recent years can be grouped under forestry and fishery resources. The individual contributions are restricted to periods when water scarcity is acute. Farmers' contribution to water users' association (subscription fees), direct labour contribution for tank maintenance works, getting commission from the social forestry contractors, and other minor sources such as grazing lease, duck and goat rearing in the command areas (after harvest), sale of trees in tank bunds and village common lands are considered important in quantifying the resource mobilization by the farmers and authorities.

The social forestry project was launched in 1981 with Swedish International Development Authority's (SIDA) assistance in Tamilnadu. The project contemplated a massive afforestation programme to ensure sustained supply of fuel wood, bamboo, small timber, fodder, grass, fruit, oil seeds and other minor forest produce to rural population

to satisfy the local needs. More than 80 per cent of the social forestry has been established in tank foreshores and bunds and became integral part of tank systems in recent years. Consequently a new set of rules and regulations were framed by the government for selection, planting, maintenance, harvest and sharing of income thereof.

Fishery is an important water based resource of the tank system. The rights of the people to the tanks are usually customary usufruct rights if the tank is on public land. Rights of the tank are vested in the panchayat or municipality. But if the tanks are on private land the state or the people have no rights. If the lakes and tanks are natural, then the people have the customary rights and the state has the absolute rights.

Historically, the rights to benefits were vested with the respective local village panchayats as regards the fishery and forestry in the tank systems. There were no organized set up to culture fish or plant trees and enjoy the benefits. But the village panchayats enjoyed the benefits of whatever was available. Only after launching of social forestry project in 1981 and establishment of Fish Farmers Development Agency (FFDA) in 1982 there has been an organized way of promotion, maintenance and harvesting and sharing the benefits of fishery in the tank system.

The revenue mobilized per ha of command area was less in the case of PU tanks (Rs. 9.00 per year) than PWD tanks (Rs. 14.00 per year) . This might probably be due to the higher expenditure on operation and maintenance by the PU, which in turn reduces the necessity for resource mobilization by the farmers. The extent of revenue mobilization was found to be positively correlated with the presence of water users' organization and the correlation coefficient was significant at one per cent level in PU tanks and at 5 per cent level in PWD tanks. This clearly indicates that the presence of water users' associations will help to capture the resources in a better way through collective efforts and decision making.

Multi-uses from Tanks

Even though tank were originally serving irrigation and other village needs such as domestic, livestock, besides fish production, due to change in the village profile over the years, tanks are mostly saving the irrigation needs only. However, judging the tank performance using the irrigation component may be inadequate, as it will not reflect the true performance of the tank benefiting the village in several ways. Hence, multi-uses of the tank should be considered in arriving at the tank performance. If such uses are in reasonable proportion, then rethinking tank management in terms of multi-use performance may be warranted. Also using the multiple benefits approach will indicate the magnitude of the receipts from all the uses which can be effectively used for tank maintenance.

In absolute terms, as given in Table 8, social forestry raises the most revenue (averaging Rs. 170 per ha), followed by irrigation (Rs. 88 per ha) and fisheries (Rs. 15 per ha). Social forestry collects the highest revenue (100 per cent) as a proportion of total value of output, but irrigation pays a relatively small proportion of the value of output (3.2 per cent) in various fees. Social forestry appears to perform well in absolute, as well as relative, revenue realisation at the tank level. The State Revenue Department, Social Forestry Department, Mines Department, Panchayats, and informal organizations in the village community are all involved in collecting revenue from the tank users. The agency-wise income realised is presented in Table 9. Among the various agencies, Panchayat Unions receive the maximum realised revenue (64.96 per cent), followed by the Social Forestry Department (24.84 per cent), village community (5.18 per cent), and the Revenue Department (4.67 per cent). But if the panchayats generate so much income from the tank uses, why are they not investing more in attending to the maintenance of the tanks? The panchayats feel that it was the responsibility of the state government to pay for the maintenance, and therefore did not put their own resources into tank maintenance. It is not clear what effect the Panchayati Raj Amendment has had on this situation, but it is essential to explore what will happen if the responsibility for tank maintenance as well as the entire revenue collection authority is given to a single institution such as local panchayats or water users association.

It is important to see that the total revenue realized in terms of taxes, fee etc., ranges from Rs. 337.12 per ha in PU tanks to Rs. 270.29 per ha in PWD tanks, with an average realization at the tanks as Rs. 275.40 per ha (Palanisami & Dick, 2001). This is higher than the government allotment of Rs. 140 per ha for tank O & M. Hence, instead of receiving heavy small allotments from the government, in fact tanks themselves can generate more resources for maintenance. Present practices do not seem to be even exploiting the full potential of tapping all the uses of tanks for revenue to support them and hence tanks suffer from lack of maintenance funds which is one of the major reasons for poor condition of the tanks. However, further analysis is needed to determine whether the revenue generation will be uniform across tanks, and how different combinations of uses may be competitive and or complimentary in nature.

Table 8. Revenue Realization at Tank Level from Multiple Tank Uses, Tamilnadu

(Rs. per ha)

Tank Type	Irrigation	Fishing	Ducks	Bricks	Social Forestry	Trees	Silt	Total
PU, Head	80.38	6.67	0.24	0.47	228.09	2.55	0.00	318.40
PU, Tail	51.66	17.00	0.41	0.08	284.01	2.70	0.00	355.85
PJ	66.02	11.83	0.32	0.28	256.05	2.62	0.00	337.12
PWD, Head	101.04	3.36	0.07	0.21	242.22	0.41	0.00	347.31
PWD, Tail	88.21	20.83	1.42	0.10	49.27	1.07	0.00	160.88
PWD	94.05	14.62	0.60	0.14	160.10	0.77	0.00	270.29
Average	88.00	14.87	0.48	0.15	170.85	1.05	0.00	275.40

Table 9. Average Revenue Realized by Different Agencies, Tamilnadu (Rs. per ha)

Tank type	Revenue Department	Panchayat Union	Village societies	Fishery Cooperative Department	Forestry	Total
PU, Head	12.96	206.96	6.37	0.00	91.24	317.53
PU, Tail	8.74	215.85	16.75	0.00	113.60	354.94
PJ	10.85	211.40	11.56	0.00	102.42	336.24
PWD, Head	14.63	232.62	3.02	0.04	96.89	347.20
PWD, Tail	12.63	105.95	20.82	1.61	19.71	160.72
PWD	13.52	177.43	14.10	1.05	64.04	270.15
Average	12.84	178.75	14.27	0.96	68.34	275.16
Percent to total	4.67	64.96	5.18	0.35	24.84	100.00

Conversion of Tanks into Percolation Ponds

As the rainfall is highly varying over year, several tanks are functioning as percolation ponds recharging the wells in the tank command. Partial budget was worked out with the aim of comparing the financial gains and losses by cultivating paddy and sugarcane crop. In normal practice, a farmer under tank with well condition having 2 ha land prefers to cultivate 1 ha paddy and 1ha sugarcane. The same farmer in the tank only situation cultivated only paddy for 2 ha. Farmers with wells could be able to get a net income of about Rs 49000/ha compared to other categories (Table.10) (Palanisami & Upali, 2008b). As such the PU tanks provide more scope for such conversions, as they have less inter village variability and the number of farmers covered under such tanks is also comparatively less. Hence depending upon the tank performance and the location of the tanks, possibilities for converting tanks into percolation ponds can be examined.

Table 10. Value of Production in Tanks under Different Typologies, Tamilnadu

Typology	Total income (Rs/ha)	Additional income (Rs/ha)	Cost of cultivation (Rs/ha)	Net income (Rs/ha)	Net income over tanks alone (Rs/ha)
Tank alone	28343	0	17589	10754	0
Tank+well	71406	43063	38719	32687	21933
Wells alone	106582	78238	57505	49076	38322

Note: Wells alone typology indicates the conversion of tanks into percolation ponds.

Social Forestry and Tank Desilting

Since 1984, social forestry plantations mainly *Acacia nilotica* occupied the tank water spread area prohibiting the desilting process by the farmers. Also there is increasing pressure from the farmers that the plantations should be removed as they consume more tank water. A recent study on the water consumption by the tree has shown a linear increase in uptake and utilization with the age of the trees with a correspondingly increase in the biomass production. But there is no significant loss in tank water compared to tanks without the social forestry plantations as the tree cover prevented the evaporation of water from the tank. The efficiency in utilization of water by the tree also improved, and the young trees utilized more water, but could yield only little biomass (131.16 kg/ha/cm). because of more water might have been spent for maintaining the plants and fresh growth rather than developing

building blocks. However, a maximum water use efficiency of 150.93 kg/ha/cm was registered by the 25 years old trees and this spurt in the efficiency might have occurred due to more photosynthesis and conservation of biomass (Palanisami, et.al, 2006).

While analysing the economics of water consumption and profit, the cost of water** consumed by trees increased from Rs. 825 to 6099/ ha but simultaneously the value of biomass also increased to Rs. 13,603/ha where maximum profit of Rs 1,16,639/ha attained with 25 year old trees (Table 11).

Table 11. Water Consumption, Biomass production and Economics of *Acacia nilotica* under Tank Irrigation systems, Tamil Nadu

Age (Year)	Water Consumption (cm / ha)	Biomass (kg / ha)	WUE (Kg / ha cm)	Economics (Rs / ha)		
				Cost of biomass	Cost of Water	Profit
5	275	36071	131.16	14,428	825	13,603
10	477	66303	139.00	26,521	1,431	25,090
15	566	79806	141.00	31,922	1,698	30,224
20	1326	1,90,577	143.72	76,230	3,978	72,252
25	2033	3,06,847	150.93	1,22,738	6,099	1,16,639

Cost of Biomass : Rs. 1.00 to 1.20/ kg; WUE=Water use efficiency.

Cost of Water : Re. 0.10 per litre

Siltation is a major problem affecting the tank storage. Silt is impounded in tanks due to sedimentation and the storage capacity of all the tanks has been reduced by half or more. Tank desiltation is also looking viable due to use of silt as manure besides increased groundwater recharge. The cost of desilting in these tanks could vary from Rs.33 to Rs.76/m³ where about 70% of it is accounted by the transportation cost. Given the high cost of desilting as well as the problems in disposal of the huge volume of silt, partial desiltation is recommended.

In this context, it is possible to combine the desilting and social forestry cycles so that the benefits of both activities could coexist and reinforce the benefits from tanks (Table 12). Even though, both social forestry and desilting involve certain costs, the benefits are higher with a rate of return of about 8%. This way, the storage capacity of the tank could be maintained, at the same time realizing the benefits of social forestry in tank beds also. In the absence of social forestry, the prosopis trees will occupy the tank water spread area which has comparatively less economic value.

Tank Sluice Management

Currently the tank sluices are continuously open and the tank water is exhausted within 6-8 weeks of tank water release for crop cultivation. Hence in order to keep the tank water available for a longer period as well as to recharge the wells, the tank sluices can be rotated alternatively. By doing so, the tank water can sustain for 10-12 weeks and groundwater supplementation can also be assured to all the farmers.

Sluice rotation involves the impact of opening and closing sluices on alternate weeks. The main purpose of this management strategy is to extend the period of tank water supply. It would increase the supply of tank water later in the season and also would increase groundwater recharge. Although non-well owning farmers would have to pay for groundwater from the well owners in the alternate weeks when the sluices were closed, the reduction in yield loss due to water stress will compensate this additional cost. Thus there is a trade-off between continually leaving the sluices open and opening the sluices at alternate weeks (i.e., rotation management).

Further, due to sluice rotation, well owners can also maximize the profits from water sales where about 6 hours of pumping per day will be possible. Currently they can pump only 2-3 hours per day due to poor recharge in the wells particularly during the later part of the tank season. Also, well water output at tank level can best be increased by having farmers install more wells with increased competition for water. With more wells, the demand for water from each individual well will fall, resulting in a lower well water price. According to a detailed survey about 25% wells can be increased in many tank command areas over the existing wells (Palanisami and Upali, 2008b).

**Cost of water in tank system reflects the water charges, local loss and local loss surcharge. Accordingly, per unit of water varied from Rs. 100 to 120 per 1000m³. The biomass (timber) value also varied from Rs.1.00 to 1.20/kg.

Table 12. Economics of Social Forestry and Desilting of Tanks, Tamilnadu

No.	Social forestry	Amount (Rs.)	Desilting	Amount (Rs.)
1.	Cost of seedlings @ Rs.2/seedlings for 1100 nos.	2,200	Desilting cost @ Rs. 33/m ³ for 77,000m ³	25,41,000
2.	Digging of pits (@ Rs.2/pit)	2,200		
3.	Watering & maintenance (@ Rs.3/tree for 5 years)	16,500		
4.	Cutting expenses @ Rs.10/tree	11,000		
5.	Total cost	31,900	Total cost	25,41,000
6.	Income from tree (fuel wood)	18,14,000	Value of silt as manure (25% of 77,000m ³ @ Rs.10/m ³)	7,70,000
7.	Fodder value @ Rs.10/tree	11,000	Additional water storage & irrigation benefits (@ Rs.5000/ha for 20 ha)	1,00,000
8.	Total benefit	19,26,000	Total benefit	8,70,000
9.	Net Benefit	18,94,100	Net benefit	16,71,000
10.	Net income from both	Rs 2,23,100		
11.	Rate of return	8.67%		

Stabilization Value of Groundwater

Given the water level in the tank and wells, the pumping hours vary across tanks. It is important to keep the well pumping at an optimum level so that maximum number of farmers could be benefited.² Well owners maximize profits from water sales when the water level is at about 5 meters and this correspond to about 5 to 6 hours of pumping per day from the well. This is further supported by the stabilization value of ground (well) water.

As such, groundwater supplementation reduces the variability associated with tank water, since in most of the years' tank storage is below normal. In the below normal tank supply periods, if groundwater is not supplemented then crop yield will be drastically reduced or crop will fail completely. The variable reducing value of the groundwater carries an economic value, which is designated as the stabilisation value of groundwater. The stabilization value as such helps for the better investment in wells in different tank command areas as this will clearly justify how many times the value of groundwater is higher than the value of groundwater just estimated from additional crop yield details. Normally the stabilization value is expected to be higher than the average value of ground (well) water under different tank water supply situations. Cross section data related to the selected tanks irrigating both from tanks and wells in Sivagangai and Madurai districts of Tamilnadu state were used to estimate the stabilization value of ground water in the tanks³. The average value of the groundwater equals to Rs 4527267 The profit assuming that the

² Using the fitted inverse demand, and output and average cost (AC) functions, and solving the equations for well yield (WY), Inverse demand function: $Pp = 36.47 - 2.77 Qp^{**}$
(1.622) (0.27)

Output function: $Qp = -0.237 + 1.19 WY^{**}$
(.784) (.177)

Cost function: $AC = 11.001^* - 0.491 Qp^{**}$
(0.49) (0.063)

** , * significant at 1 percent and 5 percent level respectively. Figures in brackets are standard errors; the profit maximizing levels of WY and Qp are 5meters and 5.59 hours respectively.

³ Using the following equations, the stabilization value of groundwater was estimated:

$$\pi(s) = \int_0^s \gamma dw - p_s s$$

$$= \int_0^s a e^{-kw} dw - p_s s$$

$$= (a/k) (1 - e^{-ks}) - p_s s$$

Similarly

$$\pi(s + g) = (a/k) (1 - e^{-k(s+g)}) - p_s s - p_g g$$

where,

π = Profit in Rs; s = surface water quantity in ha.cm; g = ground water quantity in ha.cm; p_s = price of surface water in Rs/ha.cm; p_g = price of ground water in Rs/ha.cm; a, k are coefficients estimated from the model.

surface water supply was stable at mean level (7733 ha cm) equals to Rs 4344587. The difference between these two is Rs 182680 which is the stabilization value of groundwater (Table 13). This was the value of ground water due to its role in stabilizing the supply of irrigation water which is above the average value of ground(well) water used for supplementation in the tank systems.

Table 13. Stabilization Value of Ground Water in Tank Systems, Tamilnadu

Tanks	Surface water (S) (ha cm)	Ground water (G) (ha cm)	Profit (S) (Rs)	Profit (S+G) (Rs)	Profit ((S+G)-S) (Rs)
1	24314.85	10922.00	24312839	32884588	8571749
2	14496.84	11626.40	14991739	24821396	9829657
3	12828.35	3582.20	13342897	16508258	3165361
4	7131.24	7400.80	7565185	14301039	6735854
5	8018.46	9812.00	8480203	17267300	8787097
6	14973.93	10922.00	15459675	24684432	9224757
7	4342.36	4038.82	4651560	8456842	3805282
8	1439.64	774.34	1557875	2313442	755567
9	799.17	981.20	866744	1828132	961388
10	1562.01	835.90	1689571	2504242	814671
11	1487.75	1333.90	1609667	2907942	1298275
12	1406.16	386.25	1521824	1899369	377545
Average	7733.40	5217.98	8004148	12531415	4527267
Profit at average S	7733.40	5217.98	8186828	12531415	4344587
Stabilization value of ground water (Rs)					182680
Proportion of stabilization value to total value of ground water					4.04 %

Tank Modernization

Tank modernization is one of the key strategies being recommended in all the policy documents. Even though, tank modernization has been done through different programs in a small scale, a major program was implemented during 1984-85 to 1994 - 95, with financial aid from European Economic Community (EEC). In the first phase (1984-91), a total of 150 non-system tanks with a command area of 100-200 ha were selected for modernization with a financial outlay of Rs.4,500 lakhs. In the second phase (1989-1995), an additional 230 tanks were included and in the same period, considered as phase II extension 269 tanks were also included at a financial outlay of Rs. 5,000 lakhs. The approximate cost per hectare was Rs. 21,000. The project was expected to save about 20 per cent of water over the present use, thus permitting the expansion of cultivation by about 9,000 ha (PWD, 1986).

However, no significant difference in performance between the modernized and non-modernized tanks in the region except marginal improvements in terms of water availability in the tanks, reduction in encroachment, siltation, presence of water users association and area covered by well (Palanisami, et.al 2008a)(Table 14).

Table 14. EEC Tank Modernization: Performance of EEC vs. non-EEC tanks, Tamilnadu

Parameters	EEC Tanks	Non-EEC Tanks
Tank Performance (%)	81.72	77.63
Filling pattern (no. of times)	1.36	1.28
Water availability (no. of days)	56.52	52.20
Siltation (%)	36.2	46.8
Presence of WUA (%)	36.0	28.0
Farmers participation (%)	40.0	42.0
Presence of Neerkatti (%)	68.0	64.0
Maintenance of tanks (%)	44	36
Farm income (Rs/acre)	6240	5975
Water management (%)	12	12
Equal water distribution (%)	40.0	38.0
Employment opportunity (mandays)	40.0	40.0
Cooperation among farmers (%)	44.0	40.0
Encroachment %)	36.2	44.50
Area covered per well (ha.)	9	11

Since the EEC program adopted the *package* modernization where the modernization strategies are same for all the tanks irrespective of their physical conditions, it is important to identify *selective* modernization strategies. Different tank modernization strategies have been examined which include sluice modification, provision of additional wells, sluice management and sluice rotation. Among these options examined, sluice modification did not improve system performance (Table 15). Sluice management (closing for 2 days after heavy rain) could increase total rice production by 14 per cent. The options of canal lining, providing additional wells and sluice rotation increased total rice production by between 30 per cent and 36 per cent. The greatest saving due to lower losses in rice yield and production occurred when management and physical investment strategies were used in combination.

Table 15. Evaluation of Different Tank Improvement Strategies, Tamil Nadu

Strategies	Production ratio	Equity ratio	B/C ratio	IRR (%)
Sluice modification	1.0	-	0.5	0
Sluice management	1.1	2.6	10.0	142
Canal lining	1.3	1.6	1.8	24.4
Additional wells	1.3	1.5	1.7	23.5
Rotation management	1.4	1.5	10.8	159
Canal lining + additional wells	1.4	1.0	1.5	23.2
Sluice management + additional wells + canal lining	1.5	1.2	1.7	23.7
Rotation management additional wells + canal lining	1.5	1.2	1.4	32.5

Productivity ratio: It is the ratio of increased production with the modernization strategies to the production at base level. Equity ratio: It is the ratio of net income per ha in the head region to the net income per ha, in the tail region. For more details, see, Palanisami, 2008a. Discount rate=10%, life period is varying from 6 to 15 years for different options.

Justifying the Future Investment Priorities in Tank Irrigation

The present cost of development of tank irrigation projects is Rs. 98,000 per ha for new projects (around 40 ha command area) and Rs 60,000 per ha for rehabilitation project and for major and medium (M&M) projects, it will be about Rs. 3,32,000 per ha in 2007 prices. Also, if the hidden costs behind M & M projects are included, the M & M projects would prove even more costly.

The latest review of India's irrigation sector (the World Bank,1998) begins with this observation, "— There is need for a major shift in India's irrigation strategy. There is a need for shift from the past near exclusive reliance on irrigation expansion to a strategy emphasizing improving the performance of irrigation and irrigated agriculture".

As a result of intense budgetary constrains from other sectors, the share of irrigation investment in total plan expenditure declined from 22% in the first plan to 11% in the sixth plan and to 7% (5% in real terms as per Gulati (1999) in the Eighth plan. Out of total Ninth Plan (1997-2002) of Rs. 581.64 billion for irrigation sector, Rs. 458.61 billion (78.85%) is allocated for M & M projects (GOI, 1999). The average annual net irrigation potential created through M & M schemes slowed down during the 1990s, falling from almost 0.225 M Ha per annum (average) till early seventies to about 0.13 M. ha per annum (average) during the 1990s.

There are compelling reasons for giving much greater attention and resources to small scale surface irrigation schemes, notes Vaidyanathan (1999). The reported decline in area under this category of works is a reflection of past neglect. These works have not received much attention under the Plans, and investments in this category have been meagre in relation to the magnitude of the problem. Substantial investments in system improvement are necessary for improving the quality of surface irrigation, and this must be given priority over the construction of new systems (Vaidyanathan, 1999).

Warning Signals

There are as many obstacles to tank irrigation as there are benefits, due to their large number and the differences in water demand, managerial experiences, and investment needs for maintenance. In addition to the already well documented problems in tank irrigation, the following warning signals may add to the existing problems if not attended to.

- Many farmers have started abandoning tank agriculture due to its continuous uncertainties in water supplies and moving to the nearby towns for other jobs and only the elderly people are staying back in the tank villages.

The *prosopis juliflora* are growing freely in the cultivated lands, thus making the land preparation difficult and costlier during years when the tank has adequate water.

- The livestock support activities are also completely gone out of the village eco-system thus eroding the livelihood options in the village. Farmers used to take the silt using bullock carts and after the introduction of the social forestry scheme in the 1980s in the water spread area, silt removal from the tanks was prevented which made the bullock maintenance uneconomical for the small and marginal farmers particularly in the off-season.
- It is seen in several locations, due to intensification of watershed development programs by the Government, several structures such as small check dams and percolation ponds are developed in the upstream of the tanks thus affecting the inflows into the tanks. Hence a clear demarcation should be done between the watershed programs and tank improvement programs.
- House construction works due to population increases and village development activities such as roads, schools, buildings are concentrated in the government poramboke (common) lands which are the main sources of inflow to the tanks as well as interlinking the tanks in the chain. This is one of the reasons why tanks are not getting adequate storages even though the rainfall is normal in several years.
- The traditional village institutions like needkatti or madayan thotti who looked after the tank catchment and tank structures and facilitated the inflows into the tanks regularly during rainy seasons also disappeared, as they could not be paid by the farmers due to frequent tank failures.
- The growing nexus between castes and politics among the younger generation in the village made the traditional leaders in the village (who looked after the tank management) inactive. Several regional political parties are coming up and the village households are divided among the political and caste related groups which affect the collective action in tank maintenance.
- The growing self-interest and non-cooperation by the well owners in the routine tank maintenance also made the tank management a difficult task. This is because in several villages, well owners feel that the tanks will not be much useful, as tanks are dry in most of the periods.
- The rice supplies at subsidized rates in the village ration shops to some extent make the poor households survive without tank irrigation which in turn put less emphasis on tank maintenance as well as tank irrigation itself even during years of normal tank storage.
- Many people now raise the question: Do we really need the tank bund which makes 1:2 or 1: 4 water spread : command area? The 1:2 ratio (i.e. for every one hectare of water spread, only 2 hectares of command area is available) is very attractive for making the rainfed tanks into rainfed land as there is not much difference between the tank irrigation and rainfed agriculture when the tanks are often dry. Also the growing tank foreshore encroachment gives more scope for such conversion particularly where the tanks are shallow. But the question is how the risks in rainfed agriculture will be much different from the rainfed tanks?

Questions for Future

The following are some of the important questions that will help the policy makers, national and international funding agencies and researchers to find a new way forward.

- What is the tank irrigation potential in the country?
- What is the total investment requirement for rehabilitation of the tanks?
- What portion of the tanks could be converted into percolation ponds?
- How to prevent the tanks from Government encroachment?
- What proportion of tanks conflict with watershed development programs?
- How the tanks could cope up with the advanced irrigation technologies such as drip and sprinkler?
- What is the magnitude of realization of equity and poverty reduction aspects due to tanks in the future?

In spite of these issues and the overall declining tank performance, tank irrigation still offers vast scope for future expansion in irrigation, as the constraints in large scale projects and groundwater development are increasing

due to competition from non-agricultural uses, pollution, over-exploitation etc. Further, any investment made on tanks will be justifiable and equitable given the vast majority of small and marginal farmers benefited from tank irrigation. However, the major questions are: What policies are appropriate and what will be their likely implications on the society? Some of them are discussed below.

Policies for Improving Tank Systems

Investment

Tank rehabilitation options that restore the original standards should be given priority. Desilting is an important option. However, it was observed, that in a ten year cycle, only in three years, the tanks get full storage, five years deficit storage and in two years the tanks fail. Hence, desilting the tank fully will not be economical, as the benefits due to desilting will be in three years only, in which the tanks get full supply. Also disposal of the entire desilted material is difficult, as the fertile silt is found only in the top (0.4 metre) layer. Therefore, full scale desilting may not be warranted. Considering the high cost of Rs. 33-76 per m³ of silt, partial desilting that helps to restore original (10 per cent) dead storage could be attempted as part of tank rehabilitation options as this will help increase non-irrigation benefits of tank water particularly in the non-tank-irrigation season. Also recharging of wells will be improved. Partial desilting can be done nearer to the lower sluice as well as around the periphery of the tank water spread area.

Most of the tanks are not getting adequate water supply and the chain system of tanks has almost broken. Hence, there is an urgent need to revive the tank-chains through appropriate modernization strategies for improving the supply channels connecting different tanks. This highlights the need for taking up modernization works at chain-level i.e. by considering the entire hydrological boundary as a single unit rather than viewing individual tanks as separate entities for new investment.

Wherever, the tanks are receiving less than 40% storages even in normal rainfall periods, they can be converted into percolation ponds and groundwater development should be encouraged. In other tanks with 40-70 % storages, crop diversification should be encouraged with adequate market facilities and crop insurance programs. To start with the PU tanks could be taken up for such conversion given the existing number of wells and the long-term tank storage details. The interest of the non-well owners should however be protected by providing the necessary supplemental irrigations for non-rice crops in the tank season through community wells. The district level data base should be generated for such tank – pond conversion.

Since the stabilization value of groundwater in tank systems is higher, it is always recommended to have optimum number of wells in the tank commands, viz., one well per 2 ha in well only situation, one well per 4 ha in tank cum well situation and one well per 10 ha in pure tank situation. In general, total number of wells in the tanks can be increased by 25%

Community wells should be installed in the tank water spread area to provide few supplementary irrigations to the non-well farmers during critical periods.

Management

Farmers in few water scarcity tanks have already been adopting crop diversification strategy involving groundnut, pulses, cotton and other crops and this practice should be extended to tanks whose water storage is 50-60 percent. The water required to produce one kilogram of rice ranges from 4,500 – 5,000 litres compared to 1,500 – 2,000 litres in the case of non-rice crops such as groundnut. Hence, using the 50 per cent tank storage, the entire command area can be covered with non-rice crops. Extension efforts and marketing support to farmers should be strengthened to introduce crop diversification particularly in the wet season. Crop demonstrations by the Department of Agriculture should help speed up the process. To complement the above options, tank territory structures should be repaired for effective water control.

Water losses in the canals are about 30 per cent besides creating inequity in distribution between head and tail farms. Lining the main canals can be followed without disturbing the field boundaries. Tank management strategies such as sluice rotation will help save the tank water by 20 per cent. Instead of continuous water withdrawal from tanks, sluices can be opened and closed on alternate weeks (rotation of sluices). The main purpose of this management strategy is to extend the period of tank water supply. Earlier studies (Palanisami and Flinn 1988)

indicated that closing and opening the alternate sluices in alternate weeks had saved the tank water by about 20 per cent besides extending the tank irrigation supplies to 2.5 months instead of the present supply of 1.5 months with continuous opening of the sluices. It would also increase ground water recharge.

Though most of the tanks have informal WUO, only about 30 percent of them in PWD tanks and 10 per cent of them in PU tanks are found to be active. The existing informal WUO should be given incentives by the Government in such a way that they will become formal and could generate more resources for tank management. This will also give scope for the revival of *Kudimaramath*. The magnitude of poverty can also be reduced if collective action in tank management is ensured (Kajisa, et.al., 2007.)

Currently the rain-gauges are available in the block offices only and periodical measurement of the intensity of the rains is not followed. Rain-gauge stations should be established at different locations of the tank-chains, so that the exact relationship between tank storage and rainfall can be captured. Also rainfall intensity in various locations should be measured.

The women self-help groups in the villages should be encouraged to go for intensifying the livestock activities so that some employment opportunities to the households will be ensured and also it will help maintain their links with the tanks.

Adequate attention should be given for development of charcoal making local units in the tank regions, as this will help cut down the prosopis tress in the tank water spread area. Local people should also get adequate employment opportunities within the village.

Since the water spread area is very poorly managed and it is important that local people should be encouraged to use the tank water spread area for cultivation of seasonal crops like water melon, vegetables soon after the tank water is exhausted. This will facilitate the cleaning up of the water spread area by themselves. The water users organizations should be empowered to implement this option without affecting the normal functioning of the tank systems during the rainy season.

Legal

More tanks have become defunct in recent years due to encroachment, siltation, choking of supply channels and pollution from industries. Tanks close to the cities should be protected from environmental pollution and further be made as groundwater recharges structures for domestic purposes. Strict regulations and penalty mechanisms should be imposed on the encroachers of catchment, supply channel, and foreshore area. Panchayats should be given powers to evict the encroachers as well as to prevent further encroachment even by the Government departments.

Necessary legal support be given to tank water users association for the collection of fees from tank multiple uses and maintenance of the tanks. Also convention of tanks into percolation ponds should be given legal backups.

References

- Agarwal, A. and Narain, S. 1997. *Dying Wisdom: Rise, Fall and Potential of India's Traditional Water Harvesting Systems*. State of India's Environment, A Citizen's Report, Centre for Science and Environment, New Delhi.
- Centre for Water Resources (CWR) 1998. *Participatory Tank Management*, various reports. Anna University, Chennai.
- Government of India, 1999. Ninth Five Year Plan 1997-2002 Vol. I and II, New Delhi: Planning Commission, GOI.
- Government of Tamilnadu. 2002. Tamilnadu – An Economic Appraisal, Applied and Evaluation Department, Chennai.
- Government of Tamilnadu. 1986. EEC Tank Modernization, Unpublished papers. Public Works Department (PWD), Chennai.
- Gulati, Ashok, Ruth, Meinzen - Dick, Raju, K.V. 1999. *From Top Down to Bottoms Up: Institutional Reforms in Indian Canal Irrigation*, Delhi: Institute of Economic Growth.
- Narayanamoorthy, A. 2004. "Tank Irrigation in India: Can the Oasis be Rejuvenated?", Unpublished paper, Gohale Institute of Politics and Economics, Pune.
- Palanisami, K.,G. Velu, K. Appavu, D. Tamilmani & P. Paramasivam. 2006. Sustainable Management of Common Property Resources under Agro-forestry Situations with Special Reference to Tank Irrigation System in Tamilnadu. Research Bulletin. Water Technology Centre, Tamil Nadu Agricultural University, Coimbatore

- Palanisami, K., M. Jegadeesan, Koichi Fujita and Yasuyuki Kono. 2008a. Impacts of Tank Modernization Programme on Tank Performance in Tamilnadu State, India, Kyoto Working Papers on Area Studies No.5.(G-COE Series 3), Centre for Southeast Asian Studies, Kyoto University, Kyoto, Japan
- Palanisami, K., and Upali Amarasinghe. 2008b. Tank Irrigation Management with Focus on Groundwater Management and Conversion of Tanks into Percolation Ponds. Research Report, CARDS, Tamilnadu Agricultural University, Coimbatore.
- Palanisami, K., Balasubramanian, R., & Ali, A. M. 1997. *Present Status and Future Strategies of Tank Irrigation in Tamil Nadu*. Bulletin 97, Water Technology Centre, Tamil Nadu Agricultural University Press, Coimbatore.
- Palanisami, K., & Flinn, J. C. 1988. "Evaluating the performance of tank irrigation systems", *Agricultural Systems* 28:161-177.
- Palanisami, K., 2000. *Tank Irrigation - Revival for Prosperity*, New Delhi: Asian Publication Services.
- Palanisami, K. & Easter, K. W. 2000. *Tank Irrigation in the 21st Century - What next?*, New Delhi: Discovery Publishing House.
- Palanisami, K. & Easter, K. William 1987. "Small Scale Surface (Tank) Irrigation in Asia", *Water Resources Research*, Vol. 23, No.5, pp.774-780.
- Palanisami, K., "Sustainable Management of Tank Irrigation Systems in South India". 2005. Working Paper Series No.2. Afrasian Centre for Peace and Development Studies. Kyoto, Rukoku University, Japan.
- Kajisa, Kai., K. Palanisami and Takeshi Sakurai. 2007. "Effects on Poverty and Equity of the decline in Collective Tank Irrigation Management in Tamil Nadu, India". *Agricultural Economics*, 36(2007) 347-362.
- Palanisami, K. & Easter, K. William 1991. "Hydro-economic Interaction in Tank Irrigation Systems", *Indian Journal of Agril. Economics*, Vol. XLVI, No.2, April-June, 1991.
- Palanisami, K., & Ruth Meinzen-Dick, Tank Performance and Multiple Uses in Tamil Nadu, South India, *Irrigation and Drainage Systems* 15: 173-195, 2001
- Thakkar, Himanshu., Assessment of Irrigation in India, Paper prepared for Thematic Review IV.2 Assessment of Irrigation Options. Draft # 1, 1999.
- Vaidyanathan, A. 2001. Tanks of South India. New Delhi, Centre for Science and Environment.
- Vaidyanathan, A. 1999. *Water Resources Management: Institutions and Irrigation Development in India*, New Delhi: Oxford University Press.
- World Bank. 1998. *India-Water Resources Management Sector Review: Groundwater Regulation and Management*, New Delhi: the World Bank.

Improving Efficiency and Sustainability of India's Agriculture through Judicious Management of Common Property Resources : A Perspective

Katar Singh

Honorary Chairman, India Natural Resource Economics and Management Foundation, Anand, 388 001, India

Of late, there has been a growing public awareness about the adverse environmental impacts of increasing chemicalisation of India's agriculture and the consequent loss of its sustainability. This has come from increasing air and water pollution, soil erosion, depletion of groundwater aquifers, denudation and degradation of forests, increasing water-logging and soil salinity in canal command areas, growing desertification, and extinction or threat of extinction to many valuable plant and animal species. In response to this, a new paradigm of sustainable or conservation agriculture is fast emerging which does not favour the blind pursuit of the goal of maximizing agricultural production at the cost of environmental degradation. Given this emerging scenario, a major challenge confronting agricultural scientists, economists and environmentalists is how to reconcile the (conflicting) goals of efficiency defined in terms of maximization of net present value of agricultural production in the long run and conservation or sustainable agriculture. The former is necessary for meeting the growing requirement of food and other agricultural produce of the rapidly increasing world population, particularly in developing countries and the latter for ecological and food security.

In India, common property resources (CPRs)¹ constitute an important part of its natural resources endowment and occupy an important place in agriculture. A characteristic feature of the CPRs is that they are more prone to degradation and depletion than the private property resources (PPRs); they suffer from what Hardin (1968) called "the tragedy of the commons"². This poses a serious threat to the livelihoods of millions of rural poor in India, who mostly depend on CPRs for their sustenance. Besides, it also increases the biotic pressure on agriculture, leading to the loss of its efficiency and sustainability. It is in this context that there is need to judiciously manage the CPRs so as to conserve agriculture and sustain agricultural production. This raises another related issue and that is how to integrate CPR management and programmes of agricultural development such that the goals of conservation / sustainable agriculture and efficiency are properly balanced.

In this paper, we first present a conceptual framework to examine the relationship between economic efficiency and sustainability in agriculture. This is followed by a brief account of the role of CPRs in India's agriculture and alternative CPR management regimes. Thereafter, we illustrate the effects of two of the CPR management regimes which are now in vogue in India on efficiency and sustainability in agriculture, and finally we outline the main elements of an institutional mechanism for integrating CPR management and agricultural development programmes.

A Conceptual Framework

The nature of relation between degradation of CPRs (a proxy for loss of sustainability of agriculture and per capita income (a proxy for economic efficiency) could be explained in terms of several paradigms. But we consider the Environmental Kuznets Curve (EKC) hypothesis and the Hardin's thesis of "the tragedy of the commons" as most plausible of them all. We now briefly describe both the hypotheses.

The EKC Hypothesis

The EKC hypothesis proposes that there is an inverted U-shape relation between environmental degradation (a proxy for loss of sustainability) and per capita income (a proxy for economic efficiency) ((Figure 1). This means that environmental degradation is low initially when the per capita income is low, then it increases with increase in per capita income, and eventually it declines with further increase in per capita income. The EKC is named after Simon

¹By a CPR, we mean a natural resource or an environmental amenity that is used in common by an identifiable group of people irrespective of who owns the resource. I prefer to call such resources as common pool resources as property rights in those resources are not clearly specified and hence nobody in the group can be debarred from accessing the resources.

²See for details Singh and Shishodia (2007: 98-100).

Kuznets (1955) who proposed a hypothesis that the relationship between a measure of inequality in the distribution of income and the level of income is depicted by an inverted U-shape curve. The EKC hypothesis has been interpreted by many scholars to imply that economic growth will eventually redress the adverse environmental impacts of early stages of economic growth and that continued growth will lead to further improvements in the quality of environment. The hypothesis has been criticised by many scholars on both the theoretical and empirical grounds (Stern, 1998: 173-196). But overall, the general consensus is that it holds for some, but not all environmental indicators and that economic growth alone cannot solve all environmental problems. The best fit is for air pollution and a few indicators of water pollution (Barbier, 1997: 357-58).

In the Indian context, we could say that the EKC hypothesis holds partially in the sense that degradation of land and water resources has been increasing with moderate increase in per capita income in conjunction with growing commercialization of agriculture, urbanization, and industrialization. We have not yet reached a stage of economic growth when per capita income is high enough for people to adopt eco-friendly livelihood strategies. The environmental degradation in India is due partly to the abject poverty and partly to wasteful use of natural resources, particularly the CPRs by the rich³.

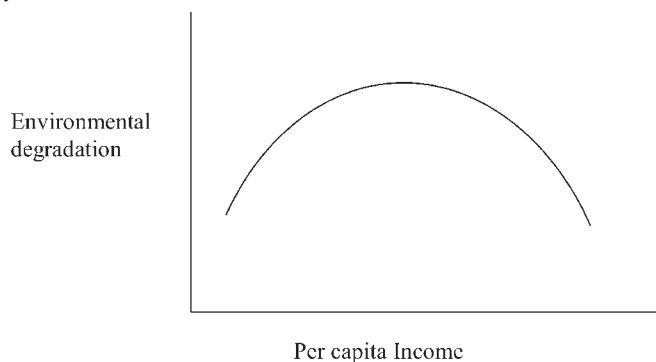


Figure 1. A typical environmental Kuznets curve

Hardin's "Tragedy of the Commons" Thesis

As we stated in the preceding section of this paper, all CPRs suffer from what Hardin (1968) called, "the tragedy of the commons". The logic of the 'tragedy' is purely economic and can be stated as: unregulated access to a CPR creates a decision-making environment in which incremental private benefits to an individual from the increased use of the resource markedly exceed the incremental private costs associated with the increased use. Under these circumstances, each rational consumer or user of the resource is motivated to consume or use more and more of the resource till the resource is completely destroyed or degraded as a result of collective and uncoordinated use by all the individuals in the community. Thus, individual rationality leads to collective ir-rationality. The calculus of incremental or marginal private benefits markedly exceeding the incremental private costs follows from the fact that, in the case of a CPR whereas an individual can appropriate all the benefits resulting from his increased use of the resource, he bears only a small fraction of the incremental costs associated with his increased use; the incremental costs are shared by all the members of the community (Singh, 1994:12-14). This means that there exists an externality⁴ in the use of the CPR in question as evident from the difference between the incremental private cost and the incremental social cost; the former being less than the latter. Thus, the common pool problem is basically one of the existence of externality - a divergence between private cost and social cost of exploitation which eventually leads to either depletion or over-crowding or congestion (Friedman, 1971: 855). The problem is a manifestation of either the absence of exclusive private property rights or the breakdown of the structure of property rights (Randall, 1975: 734).

When an externality is present, the competitive equilibrium use of the resource (CPR) is socially inefficient (Dasgupta, 1982:19-23 and Singh, 1994: 26-31). This is illustrated in Figure 2. As shown in the figure, the competitive equilibrium level of grazing (X) in a community pasture is attained when the level of grazing is X_2 where the private marginal cost is equal to the marginal revenue whereas the socially optimum level of grazing is X_1 , where the social

³See for details Singh and Shishodia (2007: 48-50)

⁴By externality, we mean unintended side effects of actions of an individual or a group of individuals on others which could be useful or harmful to others. Externalities are not taken into account by their causal agents while estimating costs and benefits of their decisions / actions.

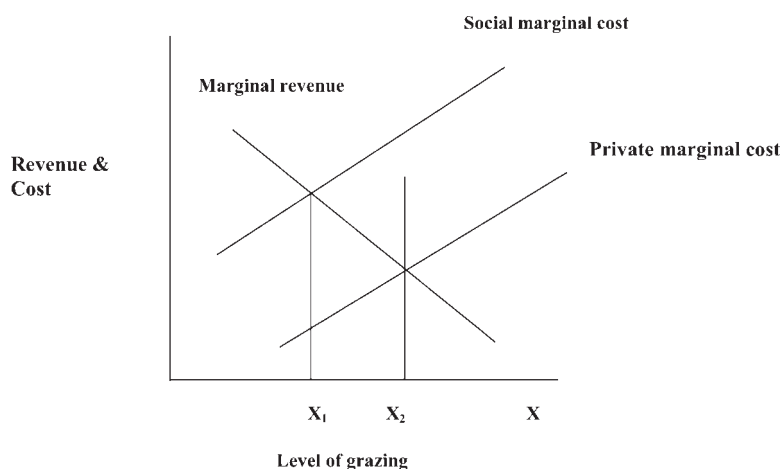


Figure 2. Competitive (open access) equilibrium level and socially optimal level of grazing in a village pasture

marginal cost is equal to the marginal revenue. Thus, the open access equilibrium is attained at a higher level of grazing and hence a higher level of exploitation than the socially optimum level of exploitation, i.e., $X_2 > X_1$.

To sum up, we could say that the EKC hypothesis gives us a clue that both the goals of economic efficiency and sustainability in agriculture could be achieved simultaneously in the long run at a stage when per capita income is high enough for people to choose eco-friendly production technologies. In the initial stage of agricultural development, however, these goals conflict with each, i.e. higher efficiency can be achieved only at the cost of loss of sustainability and vice versa. The Hardin's thesis points to a possible solution of the problem of degradation of CPRs in the initial stages of agricultural development.

Role of CPRs in India's Agriculture

The CPRs in India include such diverse things as village panchayat grazing lands, privately-owned fallow lands, privately-owned cultivated lands lying vacant in between two crop seasons, community threshing floors, degraded revenue lands, degraded forest lands, protected and unclassed forests, village forests and woodlots, lands lying alongside railway tracks, roads, water reservoirs, tanks, ponds, lakes, rivers, streams, *nalas*, groundwater basins, marine fisheries, public (state) and community inland fisheries, wildlife and so on.

In the Indian context, it is important to note that public land such as the degraded revenue lands owned by the State Revenue Departments and degraded forest lands owned by the State Forest Departments are also *de facto* CPRs in the sense that they are accessible to and used in common by the villagers in whose (village) jurisdiction they lie. The rights and practices that determine who has access to and can use such public land are generally a matter of convention.

There are no reliable estimates of the extent of CPRs available in India. But roughly speaking, all protected, unclassed, and degraded forest lands, all degraded revenue lands, all surface water resources and most of the groundwater aquifers, and all marine and riverine fishes are *de facto* CPRs. It is estimated that more than 100 million hectares of non-forest land and some 28 million hectares of forest land are CPRs (Singh, 1994 : 9-11). Given their fairly large extent, CPRs play an important role in India's rural economy as a source of sustenance and income to millions of the rural poor. According to Jodha (2002:36-37), the CPRs contributed Rs. 534 to Rs. 774 to the annual income of the sample households, who were all poor, in the dry regions of India⁵. This accounted for 19 to 23 percent of the total annual income of the sample households and that the proportion of the poor households who mainly depended on the CPRs for meeting their requirements of food, fuel, fodder, and fibre ranged from 84 percent to 100 percent in contrast to 10 percent to 20 percent of the rich farmers. As a consequence of the income derived from the CPRs by the poor households, income inequality also declined significantly.

⁵ The study covered more than 80 villages in 21 districts in seven major dry land states of India and was conducted over a period of four years.

India's natural resources and biodiversity are economically important both nationally and globally. As one of the world's oldest and largest agricultural countries, India has an impressive diversity of crop species and varieties. At least 166 species of crop plants and 320 species of wild relatives of cultivated crops originate in the subcontinent. About 90 percent of all medicines in India come from plant species, many of which are harvested in the wild. Medicinal plants and other non-timber forest products are particularly important as a source of income and sustenance for poor tribal population. Natural ecosystems strongly influence natural resources development and management which is important not only for agriculture but also for industrial and municipal development⁶.

The availability of CPRs, and hence their role, varies widely from region to region in India, depending mainly on the ecological conditions and agricultural systems prevailing there and partly on the present and past land settlement and land tenure systems. These factors affect not only the nature and extent of CPRs but also the broader institutional framework that governs their management and their integration with the PPRs. Arnold and Stewart (1991: 8-11) identify three regions in India which exhibit markedly different patterns of endowment, use, and management of common property land and related resources. The regions are: (1) semi-arid and arid regions; (2) hill regions; and (3) forested tribal regions. In the semi-arid and arid regions, CPRs are less in extent than those in wet mountainous areas but are more fully integrated into the agricultural production systems and local institutional frameworks than is the case in other regions. In the hill regions, local people heavily depend for fuel wood, fodder, grazing of animals, green manure, small wood and timber on the CPRs of forests that comprise 60 to 80 per cent of the wet forest areas in the Himalaya, Shivaliks, and parts of the Western Ghats. The Forested tribal region stretching from West Bengal to Gujarat is characterized by a great variety of forest and land resource use and management systems, and forest communities. Compared to the hilly and the semi-arid and arid regions, CPRs are relatively less important as a source of inputs for agriculture in this region but are very important as a source of minor forest produce for sale, and sites for shifting cultivation. Irrespective of their actual use and management, many areas in this region are classified as forest or revenue lands with very limited private or village rights. Therefore, it is necessary to take into account regional variations in the endowment and use of CPRs while planning for their development/restoration, use, and management.

Natural resources, particularly the CPRs, in India have been under great biotic pressure for decades now. India's high levels of human and domestic animal populations, their high density and rapid growth, high incidence of poverty and high level of illiteracy have all contributed to degradation of natural resources and hence loss of sustainability of agriculture. Many plant and animal species are on the brink of extinction. It is high time that India adopted a responsible national policy of CPR management, which is in tandem with its economic and social development policies.

CPR Management Regimes

A pragmatic CPR management policy should specify a particular management system or a combination of management systems appropriate for fulfilling its goals. *A priori*, any one or a combination of privatisation, nationalisation, and collective management (by CPR users) could be used to achieve the goals of a CPR management policy and, theoretically speaking, any one of these three alternative systems could be as good or as bad as any other. In practice, all the three systems co-exist in most situations and there is no single best system of management that will work successfully in all situations and at all times. The choice of a system will depend on the particular resource and setting in question and often requires an interdisciplinary approach, use of traditional knowledge and modern scientific knowledge and consultation with local people and government functionaries. It is not always easy to determine whether a resource would be better managed as a private property, public property, or common property; there are many 'grey' areas when it comes to choosing a particular management system. Based on a survey of literature, the following general guidelines/principles could be laid down to help determine an appropriate management system. The guidelines are organised under three heads, namely, privatisation, centralised public management, and decentralised collective management (Singh, 1994 : 314-18)

Privatisation

Privatisation means creating private property rights in CPRs and enforcing them. Privatisation can be accomplished in many different ways such as by enacting laws, issuing government decrees / resolutions, signing voluntary

⁶ See for details Singh and Shishodia (2007: 306-7)

contracts, and so on. The property rights created for the purpose could be conferred on an individual, a group of individuals, a private firm, a cooperative society, or a voluntary agency. Privatisation of CPRs may prove to be an appropriate system if the assignees of property rights are poor, are organised into some formal or non-formal associations, are willing to use the CPR in a socially desirable manner and if the government is willing and able to help the assignees with technical information, training and funds.

Centralised Public Management

Under centralised public management or nationalisation, the central government fully owns and manages the CPRs directly through one of its departments/agencies. Nationalisation of CPRs has been a policy pursued by numerous developed and developing countries of the world, particularly the socialist countries. The underlying rationale of nationalisation is that a national government can better serve the interest of its people at large, can raise investment funds more easily and has a longer planning horizon and hence, a lower discount rate than individuals. The experience with nationalisation of CPRs has not been generally good; there have been more failures than successes. However, nationalisation may be an appropriate system if the CPR in question is of strategic importance to the nation, is bound to be overexploited and depleted under the existing system, and if the investment required for its restoration is beyond the capacity of CPR users.

Decentralised Collective Management

An increasing number of scholars now advocate that decentralised collective management of CPRs by their co-users is most appropriate of all the three systems. Cases of success in collective management of CPRs by their co-users abound in the literature on CPR management. Collective management is likely to succeed under the following conditions:

- (i) If the community of CPR users is small, well-defined, homogeneous, self-conscious, self-governing with political and economic independence to manage the CPR as it sees fit, and organised formally into some association which is headed by a good leader;
- (ii) Access to and use of CPRs are both regulated by a set of rules that are compatible with the technical and physical characteristics of the resource and the local setting and that are mutually accepted, enforced, and monitored by the CPR users themselves rather than an external super ordinate authority;
- (iii) Rules for equitable sharing of benefits and costs are incorporated in the bye-laws of the CPR users' association, have a legal back up, are easy to understand and enforce, and are enforced and monitored by the CPR users themselves;
- (iv) There exists a system of sanctions against violation of rules and free-riding or shirking that is mutually accepted by all the CPR users and is enforced by them voluntarily;
- (v) CPR users have high stakes in the CPR and there is an immediate threat to their survival if the CPR is degraded or depleted;
- (vi) There exists good local leadership and political support to CPR users and their organisation at all levels;
- (vii) The government is willing and able to help the CPR users with needed funds, technical information, training, provision of basic infrastructure including marketing and processing facilities and facilitating legal and political environment; and
- (viii) Last but not the least, expected private benefits to each individual CPR user from collective management not only markedly exceed the expected private costs of his participation in the collective management but also are assured by an honest and benevolent local leader or an external authority having high credibility among the CPR users.

Efficiency and Sustainability Effects of CPR Management Regimes

In this section, we illustrate through case studies the possible effects on efficiency and sustainability of agriculture of two of the three CPR management regimes that are now in vogue in India.

Collective Management through the Watershed Approach

In the watershed approach, a watershed is used as the basic unit for planning and management of land, water, and other resources of the watershed. The approach is holistic and multidisciplinary and is a practicable approximation of the systems approach. It enables the planners and managers to consider together various physical, biological, socio-cultural, economic and institutional factors operating within a watershed and its surrounding environment, internalize the externalities and formulate a comprehensive and integrated watershed development plan to achieve specific social objectives. It requires a formal organisation of watershed users' to make it effective and hence it is an example of collective management.

In India, the watershed approach was first adopted on a significant scale in 1974 when the Government of India (GOI) implemented it under the Centrally-sponsored Scheme of Soil Conservation in the Catchments of River Valley Projects (Bali, 1988). In 1982, the GOI, under the auspices of the Indian Council of Agricultural Research (ICAR) sanctioned 46 model watershed projects for implementation in the dry land areas of the country. In July 1986, the Union Ministry of Agriculture and Rural Development launched the National Watershed Development Project for Rainfed Areas (NWDPPRA) as a Centrally-sponsored scheme. The Government of Karnataka (GOK) has taken quite a few pioneering steps in the development and management of dry land watersheds. A project in Integrated Watershed Development was launched in a selected watershed, Kabbalnala, in Bangalore district in 1983 with financial aid from the World Bank. It became widely popular in India for its innovative approach. Consequently, in 1984, the GOK decided to replicate the Kabbalnala model of watershed development in all the 19 districts of the state (Singh, 1994: 165-183).

There are many success stories of watershed development projects in India, confirming the suitability of watershed approach to conservation and development of dry land agriculture. For example, in 1999, an ex-post evaluation study of Mendhwan Watershed in Sangamner taluk of Ahmednagar district in Maharashtra was conducted by the National Bank for Agriculture and Rural Development

(NABARD). The study revealed that, among other things, the adoption of watershed approach resulted in increased crop yields and income (efficiency), increased employment and income from dairying and other activities allied to farming and reduced distress migration (equity) and increased recharge of groundwater basins (sustainability) (Singh and Shishodia, 2007:209-213). To sum up, the watershed approach, besides resulting in increased crop yields, incomes and employment, also creates positive environmental impacts such as reduced soil erosion and consequent reduction in siltation of river beds and reservoirs and increased recharge of groundwater (Singh, 1995). By facilitating the restoration of degraded CPRs and ensuring their productive use, it helps achieve the goals of both efficiency and sustainability.

Another example of successful management of common CPRs is furnished by cooperative tree growers' cooperatives (TGCS) (Balooni and Singh, 2001). The main objective of the TGCS is to improve the socio-economic condition of the members, who comprise mostly poor landless households, and marginal and small farmers (equity) and restoration and productive use of the degraded private and common property lands. The National Tree Growers' Cooperative Federation (NTGCF) and the Foundation for Ecological Security (FES) are promoting the establishment of TCCF in India. By the end of March 2005, NTGCF/ FES had organised 973 village institutions⁷ including 540 TGCS in 21 districts spread across seven states (FES, 2005: 9 and Singh and Shishodia, 2007: 216-220).

Privatisation of CPRs

According to Hardin (1968), and many other scholars, one of the ways of averting the 'tragedy of the commons' is their privatisation, i.e., creating and enforcing private property rights in the commons. In India, there are many success stories of privatisation of common lands. One of them is the privatisation of degraded public lands (state property) and village common (waste) lands in West Bengal under the Land Patta Scheme launched in 1977. The basic objective of this scheme was to improve the socio-economic status of the poor landless households and marginal farmers through provision of common property land on lease and other basic necessities such as fuel wood, fodder, timber, and minor forest produce. Under the scheme common pool wastelands were allotted to the target group on long term lease by the Land Settlement Department. However, the productivity of land so allotted was very low as those lands were degraded and the poor lessees did not have access to the resources required for

⁷ The village institutions comprise TGCS (540), Van Panchayats (64), Village Committees on Gramya Jungle Lands (40), Grazing Land Development Committees (41), Village Forest Committees (167), Panchayat Raj Institutions (49), and Village Committees (72).

their restoration and more productive use. However, this situation was ameliorated in 1979 when the State government launched a special programme called 'Operation Barga'. The main objective of this programme was to confer to the lessees legal rights in the land that they had been cultivating for many years. The distribution of *patta* lands got an impetus in 1984 when the Government of West Bengal integrated the Land Patta scheme with its social forestry scheme. The patta holders (lessees) planted trees, mainly eucalyptus, on the patta lands. They were given saplings and fertilizers at subsidized rates by the State Forest Department, besides provision of technical information and training in planting trees. This resulted in not only best possible use of these wastelands (efficiency) but also improved the equity through the increased incomes of the poor lessees and sustainability through averting the tragedy of those lands (Singh, 1994:149-163). To conclude, we could say that privatization of common wastelands in India following the West Bengal model could become an important instrument of restoring them, making them more productive, improving equity and environment.

Integration of CPR Management and Agricultural Development Programmes

Institutional arrangements play an important role in managing the CPRs through creating a common forum for the CPR users to come together, discuss common issues in CPR management, identify alternative strategies for their resolution and coordinate their actions (Marothia, 2002: 1-22). Given the evidence cited in the preceding section of this paper that judicious management of CPRs could help achieve the goals of both efficiency and sustainability, we need to raise and answer this question: what kind of institutional arrangements are required to integrate CPR management and agricultural development programmes. This is done in the following paragraphs (Singh, 2002 : 104-107).

Integration at the National Level

Environment and forestry are in the Concurrent List and agricultural and rural development in the State List of the Constitution of India. This means that policies for the former are made by both the Central and State governments and for the latter by State Governments. Even in the case of agricultural development and environment, the Central government plays an important role by way of providing policy guidelines and sponsoring and funding programmes of national importance. So, to be meaningful, the process of integration should start at the Central government level. At the national level, the Ministry of Environment and Forests (MoEF), and the Ministry of Agriculture (MoA) are primarily responsible for policy, planning and programming in the fields of natural resources (including CPRs) management and agricultural development. Planning Commission also plays an advisory and coordinating role in those spheres. So, the first step in the process of integration is to make a clear policy statement that every agricultural development programme will have an Environmental Impact Statement (EIS) built into it and that no programme will be approved for funding until and unless such a statement is incorporated in it. For overall coordination, guidance and monitoring of the compliance with this requirement, a small Standing Committee of Secretaries representing the Union Ministries concerned and Members in charge of the relevant portfolios in the Planning Commission may be constituted. The Committee may be co-chaired by the Union Ministers concerned. The Committee may meet at least once every three months to review the progress of integration and coordination of various programmes and resolve the problems encountered.

A multidisciplinary cell comprising specialists in ecology, agriculture, animal husbandry, natural resource economics, and development planning may be set up within the MoEF to assist the Committee and provide technical guidance to the State Departments concerned on a regular basis. Such an administrative arrangement will need to be backed up by an appropriate legislative measure as has been done in USA under their National Environmental Policy Act of 1969. In India, the Environment (Protection) Act of 1986 provides such a back up. Many other countries also have formalised incorporation of EIS in their development programmes.

Care should be taken that compliance with EIS requirement should not result in unnecessary delays, rigidity and increase in the cost as has been the case in USA and other developed countries. Preparation of EIS is a technical job which should be done by well trained ecologists/environmental scientists with the help and close cooperation of the project personnel.

Integration at the State Level

A mechanism similar to the one proposed at the national level will need to be established at the State level. The Standing Committee of Secretaries of the Ministries of Agriculture and Forests and Members, State Planning

Commission concerned may be headed by the Minister in-charge Agriculture. The Secretary, Department of Agriculture may convene the meetings of the Committee and secure a commitment of all the officers concerned to implement the programme.

Integration at the District Level

At the district level, a Coordination and Monitoring Committee representing the following departments/disciplines may be constituted:

1. President of the Zila Parishad
2. District Collector
3. District Head of Department of Agriculture
4. District Head of Forest Department
5. District Head of Rural Development Agency
6. District Head of Animal husbandry Department
7. A natural resource economist / ecologist

The Committee may be headed by the President, Zila Parishad or the District Collector and the District Head of Agriculture Department may be its Member-Secretary. The Committee should be responsible for integrating agricultural/rural development programmes with the CPR management programmes in the district. Ideally, there should be only one comprehensive integrated plan for overall development of the district. A format and guidelines for preparing such a plan will need to be developed by the Coordinating and Monitoring Committee with the help of an expert. All the funds earmarked for agricultural/rural development, animal husbandry and dairy development, forestry, irrigation, watershed development and infra-structure development in the district should be placed at the disposal of this Committee.

7. Concluding Remarks

Increasing chemicalisation of India's agriculture poses a threat to its economic efficiency and sustainability, besides adversely affecting the quality of environment. In response to this threat, a new paradigm of sustainable or conservation agriculture is fast emerging which does not favour the blind pursuit of the goal of maximizing agricultural production at the cost of environmental degradation and the consequent loss of sustainability. Conceptually, it is possible to achieve the (conflicting) goals of efficiency and sustainability simultaneously in the long run.

In India, common property resources (CPRs) occupy an important place in its agriculture. A characteristic feature of the CPRs is that they are more prone to degradation and depletion than the private property resources (PPRs). This poses a serious threat to the livelihoods of millions of rural poor in the country, who mostly depend on CPRs for their sustenance. Besides, it also increases the biotic pressure on agriculture, leading to the loss of its efficiency and sustainability.

What we need to mitigate this threat is a comprehensive strategy of CPR management which is in tandem with the objectives of agricultural development programmes. Such a strategy would help achieve the goals of efficiency defined in terms of maximization of net present value of agricultural production in the long run and conservation or sustainable agriculture. There are many success stories of use of this kind of strategy in India including the watershed development programmes.

References

- Arnold, JEM and WC Stewart (1991), *Common Property Resource Management in India*, Tropical Forestry Paper No. 24, Oxford Forestry Institute, Oxford University, Oxford.
- Bali, J.S. (1988), *A Critical Appraisal of the Past and Present Policies and Strategies of Watershed Development and Management in India and the Role of Governmental and Non-governmental Organisations in Small Scale Watershed Development*, Monograph, Society for Promotion of Wastelands Development, New Delhi.
- Balooni, K. and Katar Singh (2001), "Tree Plantations for Restoration of Degraded Lands and Greening of India: A Case Study of Tree Growers' Cooperatives", *Natural Resources Forum: A United Nations Journal*, Vol. 25, No. 1, February.
- Barbier, Edward.B. (1997), "Introduction to the Environmental Kuznets Curve", Special Issue, Summaries, *Environment and Development Economics*, Vol. 2.

- Dasgupta, Partha (1982) *The Control of Resources*, Cambridge, Massachusetts: Harvard University Press.
- FES (2005), Annual Report 2004-2005, Foundation for Ecological Security, NDDDB Campus, Anand.
- Friedman, Alan E. (1971), "The Economics of the Common Pool: Property Rights in Exhaustible Resources", *UCLA Law Review*, Vol. 18, May, Pp.855-887.
- Hardin, G. (1968), 'The Tragedy of the Commons', *Science*, 162, 1143-1248.
- Jodha, N.S. (2002), "Decline of Rural Commons : Role of Population Growth and Public Policies" Chapter 2 in Dinesh K. Marothia (ed.), *Institutionalising Common Pool Resources*, Concept Publishing Co., New Delhi
- Kuznets, Simon (1955), "Economic Growth and Income Inequality", *American Economic Review*, Vol. 49, Pp. 1-28.
- Marothia, Dinesh K. (ed.) (2002), Introduction and Overview, Chapter 1 in Dinesh K. Marothia (ed.) *Institutionalising Common Pool Resources*, Concept Publishing Co., New Delhi
- Randall, Allan (1975), "Property Rights and Social Microeconomics", *Natural Resources Journal*, 15:729-40.
- Singh, Katar (1994), *Managing Common Pool Resources: Principles and Case Studies*, Delhi: Oxford University Press.
- Singh, Katar (1995), The Watershed Management Approach to Sustainability of Renewable Common Pool Natural Resources: Lessons of India's Experience. Research Paper 14, Institute of Rural Management, Anand.
- Singh, Katar (2002), Integrating Common Pool Resources Management with Rural Development Programmes, Chapter 5 in Dinesh K. Marothia (ed.), *Institutionalising Common Pool Resources*, Concept Publishing Co., New Delhi
- Singh, Katar and Anil Shishodia (2007) *Environmental Economics: Theory and Applications*, New Delhi: Sage Publications.
- Stern, David I. (1998), "Progress on the Environmental Kuznets Curve?" *Environment and Development Economics*, Vol.3.