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Understanding Soil Erosion Protection Capabilities of Four Different Plants on Silty Soil

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Abstract. Soil is a natural wealth to human which need to be preserved, huge amount of soil is normally eroded due to rain and other activities, also anthropogenic occurrences increases the chance of erosion. Multiple methods are being employed to preserve soil erosion along hill slopes but all most of them end up as non-viable or costly. Vegetation plays key role in protecting soil from erosion, presence of vegetation increases the soil burden stability along slopes which increases the shear strength and reduce the soil erosion. In this work we had tried to study the soil binding nature of four different plant roots via soil bioengineering procedures. Primary aim of this paper is to obtain information related to the method of soil binding by the plant roots on silty-clay soil. We had studied the root growth nature and how they really tie up the soil as a monolithic mass to provide soil erosion protection. Plants were grown in pot culture allowing the plants to reach full root growth potential since roots play major role in protection soil from erosion. Triaxial shearing tests were conducted on the soil-root mass obtained using cores from soil. Also pull out tests were done to obtain the load required to pull out a fully grown root which indicates its composite ability. Also, root properties like Root Area Ratio (RAR), Root Biomass (RB), Tensile strength of root, root angle, thickness of root, deep rooting, root length density, root decay rate.

1. Introduction

Hill slopes are primarily important piece of land for any country infrastructure, they need to be maintained in pristine condition for better eco system services [1]. It helps the rural and indigenous people in many ways, protecting them from soil erosion and soil failure is of primary concern to any administrators [2]. Recent few decades had seen degradation in the hill slopes due to anthropogenic activities happening and because of recent developments in transportation growth in those sectors because of which hill slopes are rapidly eroding [3]. Growth should happen without disturbing the natural systems and always should be sustainable [4]. Numerous methods were developed for slope stability by researchers including soil nailing, usage of geosynthetics, retaining walls, compaction, etc but all proved to be either costly or not suitable for all locations. Keeping this in mind many research works being undertaken to analyse the method to make the slopes stable, one such method is to use vegetation for slope protection termed as Soil Bioengineering[5].

It is a method in which specifically selected plants were planted along the slopes in a designed fashion either in tandem with other plants/ trees/ shrubs to protect the slopes against soil erosion and failure[6]. Plant roots work in two different way, mechanical and hydrological performing multiple tasks including support, anchor, drain, reinforce through which the soil will be held as a mass together. This technique is employed for quite long period but not done in a scientific framework, but recently several research works confirmed the support plant roots offer to the slope stability and to protect it from soil erosion[7]. The increase in shear strength due to roots depends on the mechanistic root-soil composite models: the quantity of roots, their diameter distribution and orientation in soil, interface friction between root surfaces and soil, root-soil composite deformation, mobilised tensile stress, tensile strengths, and root moduli [8,9]. Overall research works convey that roots having high tensile strength and good cellulose content acts as a good reinforcing agent concerned with hill slope stability. According to various models developed for the root-soil composite material, increase in the shearing strength of soil is proportional to the amount of roots present in soil, the diameter of plant roots, root distribution inside soil, the friction developed between the root and soil, the mobilized shearing resistance between root and soil during failure and the modules of roots[10]. Also, root growth should be deeper and wider with cluster of roots acting inside the soil to anchor the soil from moving outwards and reduce the possibility of slipping [11]. While the roots are growing they create continuous channels of pores that acts as draining agents which will drain water quickly during continuous rainfall and protect from soil particles being rolled away[12]. Any good root matrix system should act monolithically to the maximum possible extent, absorbing the tensile stresses and thus increasing the shearing resistance of the soil. In nutshell, the root matrix system should have a mixture of roots with length, depth, spread, thickness and also should have good hairs developed in edges[13].Recent studies have shown that even root growth and decay have effects on the hydraulic behaviour of root reinforced soil[14,15]. Such root decay also leads to a decrease in the concentration of roots and root reinforcement. The practical implication is that the bio-engineered slope would become less stable without proper maintenance as plants withered and root decayed, although no explicit method has been proposed to quantify the effect of this phenomenon on slope stability. Most previous research has barely considered the impact of suction and changes in root concentration over time on root reinforcement[16].

Considering this, present research is targeted to obtain the root-soil matrix nature for the selected plant varieties that are grown using pot culture and to understand whether this plants can be used in soil bioengineering for slope stability[17,18].

2. Results and discussion

This research work is done in two stages, first stage involved the field visit to the study area, and collection of soil samples. The second stage involved in growing the plants in the collected soil and performing the experiments related to root reinforcement. The study area here is Nilgiri's which is in the coordinates N11º21'261" and E076º56'686", in Tamilnadu, India. Soil samples were collected by using grab sampling and in disturbed format since large amount of soil is collected for growing plants [19,20,21]. Soil collected is broken properly and stored in clean bags in natural condition without removing the leaves, twigs if any and brought to the laboratory, this is done to manage the natural conditions for growing the plants. Also, indigenous plants from the study area is brought to the site from the field and from nursery in required numbers. The plants were stored for few days before preparation of the pots in necessary conditions. Soil obtained is slightly broken to avoid large lumps since smaller sized pots are used [22,23,24]. Pots were filled with soil from the study area and allowed for settle so that soil is levelled during planting. Temperature in the laboratory varies from 25-40ºC, humidity of 11-23% and wind velocity of 11km/hr. Planting is done in the pot from the plants obtained using utmost care so that the rooting is proper and the plant grows in full. Planted pots were kept in normal sunlight with generic atmospheric conditions which is maintained until the soil-root matrix core is drawn for testing. Plants are kept for growing according to their life span which varies from 4 -7 months for full growth potential after which the experimentation is done. The plant pot with proper growth and ready for experimenting is shown in figure 1.

Figure 1. Soil sampling from the pot

Figure2. An undisturbed soil sample

Once the growth is achieved, soil samples were collected by using specifically designed core of 38 X 76 mm size with a collar to drive the core inside[25].The sample of undisturbed soil is shown in figure 2. The sampling is done at five places inside a pot and the average values of this or repeated values is taken, whichever is better. Soil-root matrix sample collected is directly inserted into the triaxial rubber membrane and testing is done with UU method as per IS 2720-Part-10:1973. The Engineering properties of the soil were collected from the Nilgris district is quantified in the below table. Based on the laboratory investigation the soil is said to be an Silt with Medium Compressibility (MI)[26,27]. And based on the consistency it said to be a very soft. If the soil has high clay particle it can affect growth of root because of poor drainage resulting to hyposia. However from good drainage in silt-soil the apparent interaction area of root is high. The above considered plant root contribution on soil were identified by comparing the investigations conducted for the undisturbed root reinforced soil sample with the normal soil properties.Table 1 presents the soil properties before planting.

Table 1. An Engineering Properties of Soil

S.No.	Properties	Result	IS code referred
1.	Uniformity coefficient (Cu)	4.736	IS 2720(iv):1985
2.	Coefficient of curvature (Cc)	0.844	IS 2720(iv):1985
3.	Liquid limit	36%	IS 2720(v):1985
4.	Plastic limit	30%	IS 2720(v):1985
6.	Plasticity index	6%	IS 2720(v):1985
7.	Liquidity index	59.83%	IS 2720(v):1985
8.	Consistency index	159.83%	IS 2720(v):1985
9.	Bulk density	2.08 g/cm^3	IS 2720(vii):1980
10.	Dry density	1.91g/cm^3	IS 2720(vii):1980

11.	OMC		14%	IS 2720(vii):1980
		1200	0.067 mm/sec	
12.	Permeability test-Falling head (kg/m³)	1450	0.050 mm/sec	IS 2720(17):1986
		1600	0.0192mm/sec	
13.	Cohesion		5.23 KN/m²	IS 2720(10):1973
14.	Φ		33°	IS 2720(10):1973
15.	Total stress		9.03 N/cm²	IS 2720(10):1973
16.	Shear strength		135.3 KN/m²	IS 2720(10):1973

The graph shows very small percentage of silt and clay, and more than 90% percentage of sand presence in soil. The particle size distribution curve of the soil is represented as a graph in below figure 3.

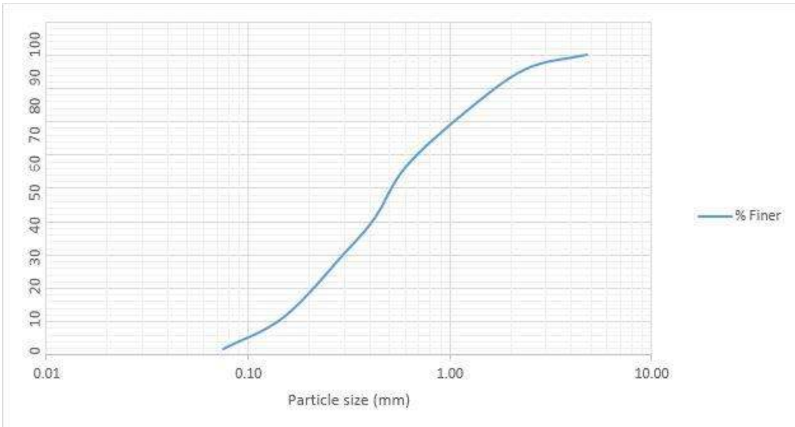

Figure 3. Particle size distribution curve of the soil

3. Root Area Ratio:

Soil shear strength enhancement of any plant is proportion to the amount of root present in the soil-root matrix and the way its oriented. Since this area is still evolving a concept called as Root Area Ratio (RAR) which is defined as the c/s area of root present in the soil to the c/s area of soil is used for measuring the shearing potential of any plant root inside soil.Generally, it is the fraction of total cross-sectional area of a soil to that of the area occupied by the roots, if its more the shear strength will be more (Gary and Sotir, 1996; Ali and Osman ,2008).

This ratio plays an important role in the soil strength enhancement and its measured by measuring the root c/s area that are present in a particular volume of soil by direct measurement, the novelty of this work is we had measured the RAR directly for the plants and its calculated. It is well established that the RAR should be on higher end for more shear strength enhancement. roots hold in core sample and topology is shown in Figure 4, 5.

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Figure 4. Roots holds in core sample

Figure 5. Root topology

4. Root Biomass and root length density

Root Biomass is the weight of root quantifying from the unit volume of soil. Roots from each core samples are to be air dried and taking the mass of dry root. For every plant the total number of roots present in each core is carefully counted manually since mechanized procedure does not exists, the obtained roots are carefully weighed in a balance with precision 0.001mg. To obtain root biomass the volume of core is taken as total volume (g/m^{3}since we are unable to measure the volume of individual core of soil, this will have a mis accuracy of 10% which is correlated with the results. Root bio mass is calculated with the volume of roots to the volume of soil in the core, if the volume of root is more the soil will have more shear strength due to the mechanical action of the roots (Marie Genet et al 2006).Root Length Density is the Average length of root per unit volume of soil. It is normally expressed in cm/cm^3, which can be measured when the shear test was conducted. Those root diameter and length were determined by using Digital Vernier Caliper with accuracy of 0.01mm and its mentioned in mm. In this study itis found that the plant roots that are thin and the core which have more root biomass produced more shear strength that other cores. This is in correlation with other research works results which says about the enhancement of cohesion (added cohesion) through the presence of plant roots in the soil. Also, the main parameter to be looked upon while analysing a landslide prone soil is the pore water pressure generated in the soil due to the continuous rainfall, more roots present in the soil will not only reinforce but also helps in draining the additional water present in the soil, thereby reducing the generated pore water pressure. Every plant will have its own capability of root presence and the pore water pressure dissipation in the soil. Table 2 provides the information about the nature and capacity of various plants to support soil bioengineering practice.

Table 2. Shear Parameters of soil for undisturbed sample from the pot

Sl.No	Plant	Cohesion (KN/m^2)	Angle of Friction	Normal Stress (KN/m^2)	Shear strength (KN/m^2)	Pore Water Pressure (KN/m^2)
1	Co-5	16.2	52	45	73.8	112.815
2	Co-4	5.7	36	129	99.42	65.4
3	Lemon grass	3.1	53	102	138.45	111.18
4	Vetiver	126	19	240	208.6	19.62

Figure 6 shows the variation in root biomass of studied plants. Table 3 clearly shows the difference of root morphology and mechanical properties of root reinforced soil. The soil reinforced by vetiver roots are to be resulting a high shearing resistance and low pore water pressure. The vetiver roots are absorbing high water content from the soil and holds a soil particle on the root hairs. Hence, it will end up in enhanced mechanical and hydraulic properties of the plants in tandem with the soil.

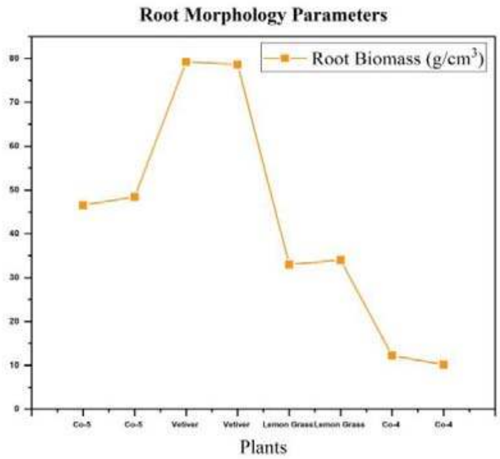

Figure 6. Root Morphology (Root Biomass)

Table 3. Root Morphology

Sl.No	Plant	Average Diameter (mm)	Root Length Density (cm/cm^3)	Root Area Ratio
1	Co-5	0.72	0.0467	0.67
2	Co-5	0.8	0.0401	0.71
3	Vetiver	0.34	0.0436	0.634
4	Vetiver	0.45	0.0407	0.475
5	Lemon Grass	0.74	0.0496	0.786
6	Lemon Grass	0.6	0.0414	0.652
7	Co-4	1.19	0.0387	0.31
8	Co-4	1.2	0.0595	0.42

5. Conclusion

Soil bioengineering is a concept of utilizing the vegetation for the slope protection, in this work we had studied the soil erosion protection potential of four plants which are indigenous to India hills and can grow in any altitude. It is found that the CO-5 grass and vetiver gives more shear strength to the soil, also CO-5 is a fodder grass and can be used effectively in top area of slopes where the cattle grazing is possible or near edges, in between this layers we suggest planting lemon grass or vetiver but second is creating few issues in certain slopes including more water absorption. Considering the shear strength enhancement Lemon grass and vetiver performed well and they are recommended for the usage along stiff slopes and to protect slopes with more height and unstable soil. Also, care should be taken while planting these plants since they can grow in certain season rapidly and that period should be capitalized for the establishment of the plants along slopes. This study, being a preliminary study can be taken as a framework but we strongly suggest planting these plants along natural slopes and conduct the same experiments via on field data to have better results.

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