Research Article

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Investigating the Influence of Lemon Grass Root on Soil Stability and Slope Erosion: A Case Study in the Nilgiris District

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ABSTRACT

This study investigates the significant impact of lemongrass root on stabilizing the soil in the hilly slopes of Nilgiris. Lemongrass provides hydrological and mechanical support to the soil mass and also helps enhance the shear strength. The crop is grown as a support against sliding since its roots contribute to slope stability. However, the plant's usage in the soil stabilization process is still in early stage. This work was conducted to ascertain the utilization of Indian lemongrass plant, which is capable of enhancing the mechanical strength, which was studied using a pull-out resistance equipment. As a means of reducing the cost of field experiments and labour involved, a simulation study was undertaken with the help of Geostudio to analyse the root topology. Even though it is a preliminary study with numerous boundary conditions, the results are promising. The total shear strength and safety factor of the test soil increased when lemongrass was used.

Keywords: Erosion; Pot culture; Root area ratio; Pull-out resistance; Slope stability.

1. INTRODUCTION

Soil stabilization usually refers to the approach used to enhance the engineering properties of the soil mainly in terms of improvising its load carrying capacity, reducing the permeability and reducing the threat of erosion. Soil reinforcement can be achieved by using mechanical, chemical or even thermal methods of stabilization. These techniques may be used in the fortification of different types of soils using a variety of admixtures (Humeera and Ashish, 2022). Recently, new environmentally sustainable and ecofriendly ways have been investigated as a potential prospect. In this regard, one of the most natural techniques to soil fortification is soil bioengineering, which is a feasible and efficient strategy that uses plant roots to stabilize soil. Plant roots help bind the soil and hold it together, making the soil mass stable in case of a landslide or earthquake. These may become self-sufficient in terms of soil stabilization in places prone to natural calamities. This study was carried out in the Nilgiris district of Tamil Nadu, India, with the goal of ensuring environmental sustainability. The soil in the research area needs to be fortified and stiffened in order to handle the loads and pressures that are applied to it. Natural landslides develop in hilly pavements as a result of soil failure. This issue can be handled by implementing an ecological strategy of implanting roots in the concerned zones. Several studies have been conducted to improve the engineering characteristics of the soil by utilizing the natural plant roots as supporters and strength enhancers against slope failure. Gopinath *et al.* (2021) investigated the effect of available plant roots in soil stabilization and their possible impact on the reduction of slope failure.

The type of plant and root system used for fortification has a direct impact on the success of stabilization. The selection of appropriate plant species is the most significant requirement for a resource-saving and environment-friendly technique. Gopinath *et al.* (2015), used vetiver roots in the soil stabilization and found that the implantation of roots increased the strength and stability of the soil by effectively decreasing the permeability and therefore increasing the density and shear resistance.

A plant that possesses roots which go deep, spread out extensively with many strong bifurcations and which can be planted close enough in lines are the most ideally preferred plant roots for soil bioengineering. Several trials have been done in order to find the most resourceful plant which may be employed in this regard.

Some soil bioengineering methodologies such as cutting, live fascines and brush mattress, in combination with techniques such as vegetated geogrids and geo-gabions have been mostly employed in the river bank construction. Research on roots can be done in a lab setting or on the actual site. The soil-root interactions seen in these experiments led to an increase in shear strength. Traditionally, pull-out experiments have been used to assess in situ root anchoring.

Pot culture is another approach attempted to test the tensile strength of plant root considering the fact that it is planted in the land slide area. It creates an environment for the plant growth and enables routine investigation in the growth period.

Fig. 1: Land slip occurred during the site visit

Elena Vu *et al*. (2022) investigated the effect of moisture dynamics on silty loam soil. The results found that due to higher cohesive and capillary forces and extra pore space cementation, the microstructural stability of the soil was significantly enhanced. This stability was brought about by the irreversible dehydration of those interparticulate microbial structures. The findings contribute to our understanding of the degree to which microbially-induced soil processes and fundamental soil characteristics can influence soil moisture dynamics.

Yujie Wei *et al.* (2022) studied the aggregate structure, stability mechanism and erosion control of granitic soil Rui Xia et al. (2022) suggested that soil aggregate stability has the potential to greatly enhance soil tillage efficiency and promote the development of a loose top and compact lower cultivated layer. Shear strength was more responsive to soil treatment and it responded considerably to the combined impacts of erosion and treatment.

Waldron (1977) assumed that the roots penetrate to the depth across a horizontal shear zone, and may act as a laterally loaded pile. The tension force is transferred to the roots when the soil is sheared. The developed tension force in each root is resolved into two components such as tangential and normal component. The apparent cohesion is considered as tangential component and the frictional resistance is resolved as a normal component. In reality, the angle of each root in relation to the direction of the applied force is important, as this dictates the distribution of stresses within the root volume and hence the maximum tensile strength reached before root failure.

The tensile resistance of reinforcing roots helps enhance the shear stresses acting on the plane. During the shear failure, roots respond in two different ways (Abernethy and Rutherfurd, 2001):

- While the roots pull out, the capability of root reinforcement, particularly in shallow roots, soil failure occurs after peak tensile strength is reached. Under this phenomenon, the resistance due to the roots is expressed in the form of cohesion of root-soil interface.
- The full reinforcement by the root-wood tensile strength is fully utilized. In the event of shear failure, it is crucial to evaluate the potential reinforcement provided by roots, as there may be residual reinforcement even after root rupture occurs. (Watson and Marden, 2004).

2. MODEL AND MATERIAL

2.1 Research Area

The study was conducted in The Nilgiris situated in Tamil Nadu state, India. The Nilgiris is surrounded by Kerala and Karnataka states on west and northern side and by Coimbatore district on the eastern side. It lies between North Latitudes11° 30' 00".12 and 19° 30' 00".42 and East Longitude between 76° 29' 52".55 and 76°36' 00".21 The district covers an area of 2,543 square kilometers. The gross area under cultivation is nearly 77,520 hectares. Rainfall in the district is bountiful and its effected majorly due to southwest and northeast monsoons. The soil sample for the study has been collected from areas in and around The Nilgiris district especially from areas which were more prone to landslide based on the analysis of the variation soil characteristics on being subjected to landslide.

2.2 Lemongrass Plant

Before starting the research, we had studied different types of plant species cultivated in this district. The physical and chemical properties of those species were obtained from the Tamil Nadu Agricultural University. Lemongrass was cultivated on the soil in pot culture environment under natural climatic conditions using the soil collected from the study site. During the cropping period,the moisture content of the soil was maintained until it is completely saturated. At the end of crop period, an undisturbed root reinforced soil sample was removed from the pot using a small scaled core cutter having a diameter of 38 mm and height of 76 mm. The specimen was prepared to conduct the consolidated drained shear test on a triaxial testing setup. The shear parameters such as cohesion, the angle of repose and shear strength were assessed using Mohr-Coulomb shear failure theory and empirical formulae. The shear strength of the soil was determined by the following relation.

$$\tau = c + \sigma \tan\varphi,$$

where,

c–the cohesion of the soil
σ– Abnormal stress acting on the shear plane
φ–Angle of repose

Then the failure sample was allowed to dry and the root from the soil was segregated. Consequently, the mechanical properties of root such as root biomass, root length, density, root area ratio (RAR), specific root length and root angle were determined.

2.3 Root Area Ratio

Root area ratio is the cross-sectional area of theroot covered on the soil to the cross-sectional catchment of root covered on soil at rooting depth. It is calculated by counting the total roots of various classes in diameter of a particular cross- sectional catchment of the soil, exposed on a vertical. It is an important parameter that defines and controls the shear strength increase due to the presence of roots. The root surface ratio can be obtained by splitting the root biomass by the unit weight of the root fiber.

$$\text{Root area} = \sum di^2$$

$i = 1$

where, d is the average root diameter of class I,
RAR was measured in different soil depth.

$$\text{RAR} = \sum nAri$$

$i = 1A$

where, *Ari* is the root area and A is the soil area occupied by the roots.

2.4 Root Morphology

It is the architecture, structure, and shape of the root system that is being used for soil bioengineering purpose, it plays a key role in soil strength enhancement and nutrient acquisition (Noorasyikin and Mohamed, 2015). Presence of plant roots enhances the apparent cohesion of soil through root reinforcement, which in turn increases theslope stability (Schmidt *et al*. 2001). The root soil reinforcement model developed by Wu (1979), and enhanced by Waldron (1977), is widely used to express additional cohesion due to the presence of roots in the soil matrix (Bischetti *et al*. 2005). Some of the main features of root morphology viewed while considering the plant for bioengineering aspects include, root biomass, the spread of root, depth of root and the distribution of root.

2.5 Root Biomass

It is calculated by weighing the total amount of roots per unit volume of soil. Roots were taken from core samples and separated as per their diameter classes before weighing. Each diameter class of root was weighed with a precision balance of accuracy greater than 0.001 mg and the root biomass was obtained according to the volume of auger, it is usually expressed in g/m^3.

2.6 Root Topology

Topology of roots is the organization of the root branching. It influences various parameters such as uptake of resources (soil nutrients), stress distribution within the soil and the pull-out resistance of the roots. For soil bioengineering, dichotomous systems are preferred than herringbone systems owing to their better anchorage capability.

2.7 Root Tensile Strength

The tensile strength of root is defined as the maximum resistance it can offer without disintegrating in tension, to mobilize the fullest strength of root and also to increase the shear strength of the soil. Thus, it is preferred to have finer and smaller roots in soil, rather than few long and thick roots.

2.8 Model Preparation for Pull-out Testing

The pull-out testing machine was designed for the assessment of pull-out resistance of root with the maximum capacity of 100 kg. It consists of a portal frame to distribute the load from pulley to the ground. The tension force is applied to the plant through stayed cable connected between the crank rod and pulley at the top of the frame. The detailed graphical 3D model of the pull-out testing setup is displayed in Fig. 2. The digital load cell was fitted between the stayed cable and the plant, which is used to designate the actual force on the cable. The load can be applied by mechanically rotating handle connected to the crank rod.

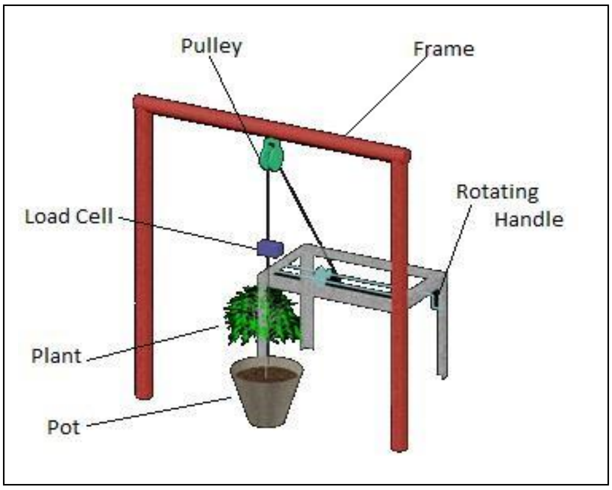

Fig. 2: The systematic diagram for Pull-Out Testing Machine

Table 1. Basic Properties of soil

Properties	Result	IS code referred
Uniformity coefficient(Cu)	4.848	IS1498:1970
Coefficient of curvature(Cc)	1.065	IS1498:1970
Plasticity index(%)	13.37	IS2720(v):1985
Liquidity index(%)	59.83	IS2720(v):1985
Consistency index(%)	159.83	IS2720(v):1985
Bulk density(kg/m^3)	2120	IS2720(vii):1980
Drydensity(kg/m^3)	1930	IS2720(vii):1980
OMC (%)	10	IS2720(vii):1980
Permeability(mm/sec)	0.067	IS2720(17):1986
Cohesion(kN/m^2)	5	IS2720(39):1977
AngleofInternal Friction	33°	IS2720(39):1977
Shear strength(kN/m^2)	135.3	IS2720(39):1977

3. RESULTS AND DISCUSSION

The engineering properties of soil were assessed by using the code for methods of testing of soil (Indian Standards 36). Based on this investigation, the soil is inorganic clay with low plasticity. This is classified from the plasticity chart of IS classification for fine-grained soil. Similarly based on the consistency, it is said to be a very soft clay. The plasticity of the soil varies from 30 to 36 %. It may contain both clay and silt particles moderately. If the soil has high clay particles, the apparent interaction area to the root is considered high.

3.1 Root Reinforced Soil

Generally, the apparent cohesion of soil may decrease with an increasing pore water pressure. When this pore pressure reduces, automatically soil gets stable with an increase in cohesion. In bio- engineering technique, the stability factor of slope can increase through increasing the apparent cohesion of soil by introducing the root reinforcement. In this technique, the soil is mobilized from the shear by reinforcing the root as a reinforcement material because the plant root acts as a fibre roll. So that the amount of mobilization is based on the root traits and morphology, particularly tensile value, root area ratio and root biomass, etc.

Fig. 3: Plants cultivated in pot culture

Fig. 4: An undisturbed soil sample taken from the pot

Fig. 5: The Pull-Out resistance test for the lemon grass plant

The root reinforced soil was sampled from the pot using a small scaled core cutter. An undisturbed soil sample was extracted from the core cutter without any distraction using a sample remover. Then, the samples underwent a consolidated drained shear test in a triaxial shear setup.

3.2 Pull-Out Resistance Test

The pull-out resistance test was conducted for the purpose of understanding the behavior of root when it is kept-out from the soil mass. This resistance depends on the tensile strength of the individual roots. During this test, the moisture content of the soil was maintained at 20-30%, because this resistance value varies with an increase in the moisture content of the soil.

By knowing these displacement values, we can calculate the ultimate load capacity of the roots. The behavior of root in pull-out is clearly visible along with ultimate load carrying capacity of plant root.

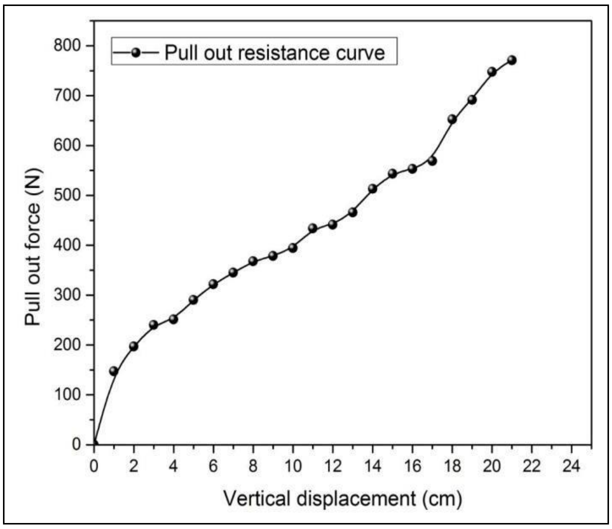

Fig. 6: Pull out resistance curve

Table 2. Variations in shear parameters of root reinforced soil

Plant	Cohesion (KN/m^2)	Angle of Friction	Normal Stress (KN/m^2)	Shear strength (KN/m^2)	Pore Water Pressure (KN/m^2)
Plant-1	3.1	53º	102.0	138.45	111.18
Plant-2	2.2	46º	128.0	134.75	71.94
Plant-3	40.6	36º	180.0	171.37	52.32
Plant-4	18.5	37º	134.5	119.85	73.575

Table 3. Root morphology of the lemongrass

Plant	Average Diameter (mm)	Root Length Density (cm/cm^3)	RootBiomass (g/cm^3)	Root Area Ratio	Tensile Strength (Mpa)	Specific Root Length (cm/g)	Average Length of Root (cm)	Root Angle	
								Mother	Daughter
Plant-1	0.74	0.0496	32.9864	0.786	1950	18.8929	31	20	40
Plant-2	0.6	0.0414	34.0066	0.652	1350	15.9554	37.5	40	40
Plant-3	0.44	0.0435	24.4847	0.75	890	19.3725	47	30	40
Plant-4	0.75	0.0404	23.1245	0.674	1220	17.5845	36	90	60

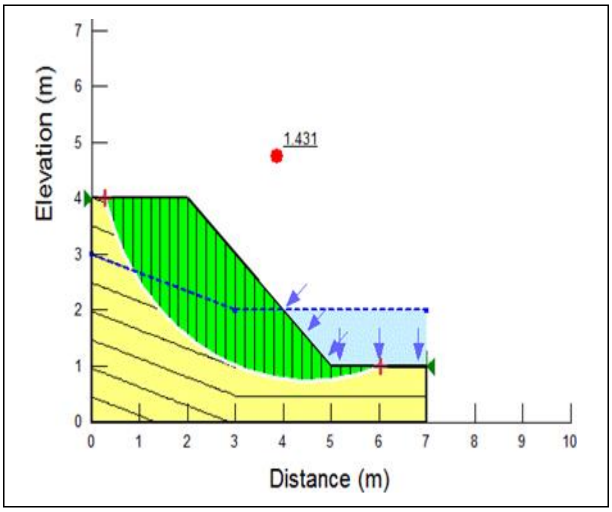

Fig. 7: Slope stability analysis for un-reinforced soil by using Geostudio

Fig. 6 shows the displacement of single lemongrass plant in the vertical direction with consecutive pull-out force applied over it. From this graph it is clear that the displacement of lemongrass root is increased with the increase in pull-out force. The variations in the shear properties of soil for various root reinforced soil is represented in Table2. Generally, the soil has a high resistance capacity against shear with its cohesion value varying between 12 to 25 kN/m^2. From this work, it is clear that the soil gets high shearing resistance by introducing the roots naturally as a reinforcing element.

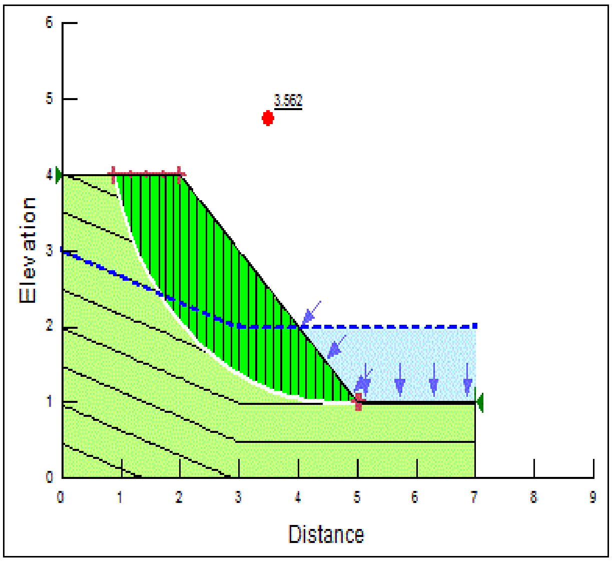

Fig. 8: Slope stability for root reinforced soil by using Geostudio

Table 2 shows the improvement in the burden stability of soil against the shear failure. In fact, that the higher stability results from finer roots the rather than the thicker roots. Similarly, Fig.7 represents the topology of the lemongrass root. The roots are branched to a width of 60 – 70 cm and a depth of 50-70 cm within six months after cultivation.

Table 3 shows the root angle of lemongrass plant for both mother and daughter roots. The angle of mother root and daughter root varies for different plants based on the density of soil. The mother root angle varies from 20 to 90°, so that it can grow either in the horizontal direction or with some deviation from the horizontal plane. Likewise, it can't cover a large area in both horizontal and vertical directions.

3.3 Analytical Solution

The stability of unreinforced and root reinforced soil slope was formulated using a software tool called Geostudio. The slope model was created in the software with dimensions manipulated during the field visit. The safety factor of slope for both conditions is computed in the software by importing the mechanical properties of soil formulated in the laboratory.

Fig. 7 shows the critical failure pattern of slip surface on the slope for an unreinforced condition. Similarly, Fig.8 shows the failure pattern for root reinforced condition. The red dot signifies the factor of safety of slope.

4. CONCLUSION

As per the results obtained from laboratory tests, the soil gets high shearing resistance by growing lemongrass plant. It gives stability on the hill slope and increases the drainage properties. However, the stability was found to increase further with the usage of plant with extensively spread finer roots (smaller diameter roots) in the soil as they provide a high tensile strength than thick roots. Similarly, the stability of slope is directly proportional to the rooting depth of plant on a slope surface. By introducing a root to the soil mass, it gets stability with decrease in pore water pressure. The shear stress at failure plane depends upon the normal stress acting on the potential failure plane. The roots enhance the normal stress at failure plane, automatically increasing shear strength of the soil. Thus, lemongrass has a potential in soil bioengineering process.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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