Effect of different vegetation roots on mechanical properties of soil stabilization on slope

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Abstract: Soil bioengineering is concerned with the soil stabilisation with the reinforcing agent such as plant roots. This approach is extensively popular in developing countries. Most of the study conducted on soil bioengineering is carried out by ecological researchers, whereas there have been few geotechnical research studies in India that focus on using plant roots for reinforcing purposes. This research aims to investigate the changes in soil strength caused by landslides. The soil will be stabilised using plant roots from regionally common plants in the study region. The lemon roots were collected and planted in the soil, and the alterations in geotechnical properties were investigated. The reinforcing process can result in an increase in the values of MDD, UCS, SS, and OMC due to the improved compaction of soil particles. It was found that as the percentage of plant root added to the soil increases, the MDD, UCS, SS, and OMC also increases until 1% of plant root was added by weight. After that point, these properties decreases. Hence, the most favourable proportion for soil stabilisation is 1% of plant root by weight to the soil. Thus the presence of plant roots in the soil matrix enhanced the soil's stability. Therefore, the plant roots that were examined can serve as cost-effective materials for enhancing slope stability,” particularly in places that are susceptible to landslides.

Keywords: Soil Stabilisation, Vegetation, Slope, Landslides, Compaction Test.

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1 Introduction

Soil stabilization modifying involves the act of altering soils to enhance their physical characteristics. Stabilization enhances the load-bearing ability of soil to support pavements and foundations. This is achieved by augmenting its shear strength and regulating its properties. Stabilization is an effective method for remedying different soil types, such as expanding clays and granular materials. This technique involves the use of a diverse array of additives, including silica, lime, plant roots, fly-ash, and cement. A slope landslide is a significant geological catastrophe, and the primary and immediate trigger for landslides is precipitation [1-2]. Prior research has thoroughly examined the process by which slopes collapse in the presence of rainfall, and several ideas are being put forward. Vegetation materials have the potential to mitigate soil erosion and runoff, while also providing suitable conditions for breeding and habitat [3-5]. Consequently, they are frequently employed in river ecological engineering projects. Hence, it is crucial to choose the soil-bioengineering plant based on its growth characteristics and the strength of its root system in the soil. Numerous investigations are being conducted on vegetation-reinforced soil, including laboratory shear testing on soils containing plant roots [6]. The dynamic interaction of plants, microorganisms, and fundamental soil components such as particle size distribution and organic matter influences the formation of soil structure. This interaction shapes the physical conditions necessary for the growth of crops [7]. The deterioration of soil structure is a significant factor contributing to the worsening risks of erosion and soil fertility loss.

Throughout thousands of years, humans have focused on stabilizing soils to either mitigate erosion or enhance their suitability for construction, such as in earth building and road construction. Efforts are being undertaken to employ various natural, manmade, or discarded materials for the purpose of soil stabilisation [8]. Plants were utilised as a means of soil cover to mitigate erosion and safeguard slopes. Nevertheless, it has to be done to assess the engineering properties of soils that have been strengthened by the presence of plant roots. Therefore, the objective of this study was to examine the impact of reinforcing a soil impacted by landslides by using the roots of a plant that is readily found in the local area, on the soil properties [9].

The occurrence of slope instability poses a significant risk to structures and infrastructure, manifesting as substantial natural landslides and smaller-scale collapses on created by humans slopes [10]. Failure is commonly linked to extended periods of intense precipitation, causes reduction in effective stress in soil and increases water pressure of pores. Previous studies highlighted that vegetation as a reinforcing agent is an effective technique to prevent slope areas and landslides. Planting vegetation on slopes has the potential to boost the soil properties which can mitigate the effect of landslides. The process of reinforcing soil with plant roots increase the pore water pressure which stabilise the soil [11-13].

The study conducted on soil sample collected from land slides, and use plant of roots would enhance the soil strength [14-16]. Results revealed that addition of plant roots in soil enhance its stability. The experimental study conducted by [17] and visualise the particles of roots and soil in shear zone. The results indicated that with addition of plant root, the properties of soil are improved in the direction of stabilisation [18]. Further the study revealed that for performing sensitivity analysis, it is essential to take mechanical effects and hydrological of roots. Further, this study imparts knowledge to reduce the landslide failures [19]. In bioengineering plant roots are beneficial alternative for soil stabilisation which enhance the stability of soil. Furthermore, previous studies also highlighted the useful role of soil
stabilisation using plant roots on steep slope [20]. These approaches are essential for stabilising the soil and minimisation of waste. Hence, in this context environmental issues are resolved and different waste generated can also be affected. The requirement for engineering building results in the creation of numerous artificial slopes, that have a high potential for causing soil erosion and shallow landslides. The mechanical reinforcing action of plant roots is crucial in strengthening slopes [21-24]. The arrangement of the root system is a crucial determinant of the reinforcement provided by roots for stabilising soil slopes. However, the studies related to lemon plant as a reinforcing agent for soil optimisation is hardly reported [25].

The plant root stabilise the soil by their root arrangements in hilly slopes which improve the soil strength. Prior research has concentrated on examining the role of root reinforcement in situations involving stress or shear [26]. Nevertheless, the literature lacks any comprehensive study exploring the impact of root reinforcement on soils in Indian context in hilly slopes. Roots possess a significant ability to enhance the stability of soils, and current models offer reliable estimates of the enhanced resistance to shear forces. Nevertheless, to get comprehensive knowledge and accurate modeling of the processes at hand, it is imperative to consider the fundamental failure causes [27]. The impact of plant roots on the hydrological and mechanical properties of soil is a crucial issue to be considered when simulating shallow landslides. Root reinforcement is widely acknowledged as a significant factor in slope stability, among the several impacts produced by vegetation [28]. Wood particles of various varieties are now chosen when constructing structures, furniture, walls, and other structures. Rice husk, particularly is obtained as waste generated from rice mills, can be used in the manufacturing of such materials. Increased strength under compression can be seen when using calcined clay to substitute up to 10% of GGBS in [29]. Weight loss evaluation, SEM, and spectroscopic techniques have been used to investigate the effectiveness of Lepidium didymium's aerial component for the prevention of corrosion on mild steel with corrosion in 1 MH2so4. The aviation and automotive sectors are eager to use cutting-edge methods and materials to lower weight, increase component execution, and save costs.

2. Material and methods

The impact of plant roots, specifically those of lemon grass (Cymbopogon citratus), on soil properties are evaluated in this experiment. The experiment began with the collection of soil samples from the immediate vicinity of the study area. These samples were obtained at a depth of two meters below the natural ground surface to ensure they were representative of the subsurface environment. The primary aim was to maintain the soil’s original moisture content for accurate analysis; thus, portions of the soil were sealed in waterproof plastic bags immediately after collection. In this work experimentation was divided into two major steps of operation. The first phase had fundamental tests that were conducted on the collected soil samples which were not subjected to any modification, which was performed in accordance with the guidelines provided by the necessary IS (Indian Standards) Codal regulations of India. They were done as they will be used as control setup that will aid in determining the soil’s qualities in its natural state. The following step of the experiment in the work involved introduction of lime and lemon grass roots which were added in different quantities to soil samples. As inferred the purpose of this modification was found to investigate effect on the parameters of soil after these additions are made which were then compared to the baseline data acquired from the first phase of experiments. The effect of the mixture on the soil parameters were recoded and saved.
Before all the samples were taken for the process of testing, they were first prepared in the laboratory according to standard processes. This included air-drying of each samples to eliminate excess moisture from them, which were then pulverised into finer particles. After this process, the soil was then filtered which was done by making use of a 2.36 mm mesh sieve that resulted in exclusion of bigger gravel fragments, which guaranteed consistency in sample size thereby allowing for more accurate testing process. Before any laboratory tests were conducted, the soil samples were thoroughly mixed to ensure a homogenous composition, representing the overall sample accurately. The choice of lemon grass (Cymbopogon citratus) as the study's plant was strategic. Lemon grass is not only widely available and easy to procure but also recognized for its medicinal properties. Importantly, its root system is known to be robust and expansive, making it an ideal candidate for studying the effects of plant roots on soil characteristics. This aspect of the experiment aimed to explore how the physical and possibly chemical interactions between the soil and the roots affect soil stability and structure.

3. Test conducted

a. Laboratory Tests: This study conducted many laboratory experiments to assess the stability of soils. The tests performed included the MDD, OMC, UCS, CBR, Swell test, and Plasticity Index. By using the standards of ASTM these tests were conducted. In all studies, the selected PE content was initially blended with the air-dried soil manually, adding little amounts at a time. Significant attention was given to ensure a uniform blend during the mixing procedure. In this context the necessary amount of water was added.

b. Compaction Test: This test was conducted in accordance with ASTM D698 protocol. Further, by using this test, one can examine the effect of plant root on MDD and OMC for stabilised soils are show in Fig. 1.

![Compaction test](image.jpg)

Fig. 1. Compaction test

c. Unconfined Compressive Strength Test: This test was conducted to analyse the impact of plant roots on UCS. The test was conducted following the guidelines specified in ASTM D2166. Basically, this test will determine the OMC and MDD. Beside this, the samples were left for cooling in natural environment and cured for 7 days by show in Fig. 2.
**Unconfined compressive strength test**

**d. California Bearing Ratio Test:** This test involved creating cylindrical specimens by utilising their MDD at OMC. The specimens used in this investigation were soaked after being prepared at the OMC, as determined by the standard compaction test by show in Fig. 3.

**Free Swell Index Test:** Fig. 4 presented test deals with soil expansion with definite volume, when it is submerged in water without any external restrictions. An examination should be conducted to identify soils that are likely to have undesired expansive qualities, since they have the potential to cause damage to structures. This test will determine the capacity of soil to expand.
Fig. 4. Free swell index test

To determine the free swell index in percent for the given clay, the author use the following method:

Free swell index (%) = \( \frac{(V_d - V_k) + 100}{V_k} \)

Where, 
- \( V_d \) = The soil specimen's volume was measured using a graduated cylinder filled with distilled water, in ml.
- \( V_k \) = The soil specimen's volume was measured by reading the graduated cylinder that contained kerosene, ml.

f. Plasticity Index: The Plastic Limit (PL) quantifies the demarcation between semi-solid and plastic states, whereas the LL quantifies the demarcation between plastic and liquid states. The Plasticity Index (PI) quantifies the degree of flexibility exhibited by a soil. The plasticity index is calculated by below equation.

\[ PI = LL - PL. \]

4. Results and discussion

The outcomes of the experimental study on how different soil qualities are affected by plant root integration. It was mainly concerned with how different plant root percentages affect the soil's Maximum Dry Density (MDD), Optimal Moisture Content (OMC), Shear Strength, and Unconfined Compressive Strength (UCS). The application of soil in civil engineering requires greater understanding of consolidation, compaction along with overall strength qualities of soil.

4.1 Effect of root percentage on MDD

Fig. 5 shows the maximum dry density of soil had been modified by the introduction of roots. This measure is crucial for assessing the consolidation and compaction properties of soil. The roots of plants can physically modify the composition of soil by penetrating and consolidating soil particles. As the proportion of plant roots introduced into the soil rises, there frequently occurs a commensurate elevation in soil compaction and density because of the reinforcement supplied by the roots. It was found that if the soil particles are strengthened through this process it might lead to an increase in MDD which is a result of improved compaction.
The terrestrial ecosystems and environment have a complex link between plant roots and soil structure, which is a representation of intriguing interactions between them. As the plants are physically penetrating and consolidating soil particles, they have transformative effects on their immediate environment. As the roots expand and the soil, they exert a reinforcing force, increasing the density and stiffness of the soil in line with root penetration. This phenomenon results from the mechanical strengthening of the root systems that bind soil particles together more efficiently. As a consequence, as the fraction of plant roots penetrating the soil increases, the degree of leakage increases, with an increase in maximum dry density (MDD) – a parameter that determines the density of the soil at maximum compacted state. 1% of timul reaches a critical threshold, but beyond this, an opposite trend emerges, and further increases in muscle mass decrease MDD. It was found that as the proportion of plant root added to the soil increased, the MDD also increased until 1% of plant root was added by weight. After that point, the MDD decreased.

4.2 Effect of root percentage on OMC

Fig. 5. Effect of percentage addition of plant root with respect to MDD

Fig. 6. Effect of percentage addition of plant root with respect to OMC
The addition of roots had an impact on the optimal moisture content of the soil, as observed from Fig. 6. This measure is crucial for assessing the consolidation and compaction properties of soil. It has been found that the OMC of the soil improves as the proportion of plant root addition increases, up to a 1% addition by weight. However, beyond this point, the OMC declines. This represents a significant rise in the amount of water needed to compress the soil. The increased water absorption throughout the mixing and maturation process is mostly due to the roots' enlarged surface area. Roots have a lower degree of influence on water absorption compared to natural fibres or ash, as seen in many investigations. The optimal moisture content (OMC) of soils is an important factor in determining its mechanical properties, especially in compaction design processes. Notably, research has found a remarkable correlation with plant root bite and land OMC between. Initially, as the number of plant roots incorporated into the soil increases, OMC improves remarkably, increasing within a 1% change in weight. This increase indicates that water is required to enable has increased the quality of compaction, and shows the influence of roots on soil structure and water distribution, reflecting changes in the dynamics of land-water interactions. This phenomenon indicates that an increase in plant root fraction decreases the water requirement to achieve optimal pressure, which may be due to changes in soil vascular structure or water retention mediated by roots. However, this study observed a rise in OMC, whose might be attributed to several factors, such as the channels formed by the roots within the soil.

4.3 Effect of root percentage on shear strength

![Shear strength, N/cm²](image)

**Fig. 7.** Effect of percentage addition of plant root with respect to shear strength

The primary cause of soil failure is often shear failure, making it essential to activate the shear strength, as observed from Fig. 7. The investigation revealed a significant enhancement in shear strength as the proportion of root mass in the soil increased, up to 1% plant root refer to Fig. 7. The shear strength of the undisturbed soil samples was investigated, revealing that
the increase in shear strength was solely due to the tensile strength of the roots and the biomass of the roots. Further analysis of the undisturbed soil samples provided important insights into the mechanisms that gave rise to the observed high shear strength. High shear forces were attributed to only two factors: muscle tensile strength and absolute muscle biomass.

4.4 Effect of root percentage on UCS

Unconfined compressive strength (UCS) The soil has been modified by the introduction of roots. strength and the share of root mass inside the soil, as much as a maximum of 1% plant root as per the Fig. 8. As the proportion of plant roots within the soil rises, there is often a commensurate rise in the UCS. The roots correctly unite particles of soil, therefore growing shear strength along with the cohesion properties, ensuing in extended UCS values. Further analysis of the undisturbed soil samples provided important insights into the mechanisms that gave rise to the observed high shear strength. High shear forces were attributed to only two factors: muscle tensile strength and absolute muscle biomass. The tensile strength of a root system, which refers to its ability to withstand compressive or stretching forces, is an important determinant of soil stability. As the roots expand and penetrate the soil, they form reinforcing fibers that better connect the soil particles, thereby increasing its resistance to deformation In addition, the absolute ecology of the roots injects new material into the soil, raising the whole again vitality and harmony.

5. Conclusion

The addition of roots had an impact on the MDD, UCS, SS, and OMC of the soil. These measurements are crucial for assessing the consolidation and compaction properties of soil. The roots of plants can physically modify the composition of soil by penetrating and consolidating soil particles.

Soil Consolidation and Compaction Properties.

a. The influence of plant roots on various soil material qualities is presented in this study.

b. With the addition of plant root in soil, MDD increases till 1% after it is decreases. It is due to fact that As the proportion of plant roots introduced into the soil rises, there
frequently occurs a commensurate elevation in soil compaction and density because of the reinforcement supplied by the roots. The strengthening of soil particles through this process might result in an increased MDD due to enhanced compaction.

c. It has been found that the OMC of the soil improves as the proportion of plant root addition increases, up to a 1% addition by weight, after that MDD decreases. However, beyond this point, the OMC declines. This represents a significant rise in the amount of water needed to compress the soil. The increased water absorption throughout the mixing and maturation process is mostly due to the roots’ enlarged surface area.

d. The investigation revealed a significant enhancement in shear strength as the proportion of root mass in the soil increased, up to 1% plant root. Because, the shear strength of the undisturbed soil samples was investigated, revealing that the increase in shear strength was solely due to the tensile strength of the roots and the biomass of the roots.

e. The investigation revealed a significant correlation between the UCS and the proportion of root mass in the soil, up to a maximum of 1% plant root refer to Fig. 8. Plant roots enhance soil stabilisation through the physical reinforcement of the soil matrix. As the proportion of plant roots in the soil rises, there is often a commensurate rise in the UCS.

f. Overall, 1% plant root is suitable for the modification of soil properties.

References


