Hydrological modification of laterite soil considering root soil interaction

Safa T.T.[1] Mahima D.[2] Jayasree P.K.[3] Balan K. [4]

[1] P.G Student, Department of Civil Engineering, College of Engineering Trivandrum, APJ Abdul Kalam Technological University, Thiruvananthapuram-695016.
safattppm@gmail.com

[2] Research Scholar, Department of Civil Engineering, College of Engineering Trivandrum, APJ Abdul Kalam Technological University, Thiruvananthapuram-695016.
mahimadethan@gmail.com

[3] Professor, Department of Civil Engineering, College of Engineering Trivandrum, APJ Abdul Kalam Technological University, Thiruvananthapuram-695016. jayasreepk@cet.ac.in

[4] Vice principal, Rajadhani Institute of Engineering and Technology, Thiruvananthapuram,-695102.

Abstract. Slope bioengineering has been practised worldwide as an environmental friendly way of stabilizing shallow slopes. The contribution of the two plant aspects namely hydrological and mechanical effects in slope stabilization can be understood by analyzing root-soil interaction. Plant roots act as a structural element to provide mechanical reinforcement. With the growth of roots day by day, transpiration becomes significant, which induces soil suction. The induced suction is the governing factor that determines the suitability of roots in stabilizing a soil slope terrain. Despite vetiver grass (*Crysopogon zizanioides*) being one of the most widely used grasses in geotechnical and geo-environmental engineering applications, the study of its root effects on soil-water retention curves (SWRC) and permeability of soil is very rare. The purpose of the present study is to experimentally investigate the effect of vetiver grass on hydrological properties of laterite soil like suction, porosity and permeability which varies with root content and age of vegetation. The vetiver plants showed significant effect in improving the hydrological properties of laterite soil which implies its suitability to be used as a method to prevent slope instability due to rainfall in shallow slopes.

Keywords: Vetiver grass, soil water retention curve, root content, permeability.

1 Introduction

Landslides are one of the most destructive natural hazard that affects life and property. The major causes for this massive movement of soil and rock debris down the slope is earthquake and rainfall combined with the effect of geological factors and anthropogenic activities. As the frequency of occurrence of rainfall induced landslides are more, mitigation techniques that go hand in hand with nature need to be developed. The use of plants to increase the soil slope stability is of great importance in engineering design owing to its economic and environmental aspects and this requires proper design and

management. For vegetated soil when roots develop, mainly two changes occur to the soil system, one is transpiration which becomes effective by the absorption of moisture content through root system and the other one is the rearrangement in the distribution of micro pores due to the root spread and thereby the changes in porosity. Therefore, the presence of roots can induce significant changes in soil water retention curve (SWRC), porosity and permeability characteristics of soil. As rainfall induced landslides are primarily triggered due to loss of matric suction and increased pore water pressure, this paper investigates the effect of plant roots mainly vetiver (*Crysopogon zizanioides*) roots in modifying the hydrological properties of laterite soil.
The major triggering factor causing landslides is rainfall. During the rainfall event, water infiltrates into the soil resulting in high pore water pressure and low matric suction leading to the loss of shear strength of soil. Vegetation can influence this hydrological mechanism through interception by canopy and stem. Plants can influence the soil moisture by evapotranspiration process, and the soil shear strength by the root system (Ali and Osman, 2008; Tien and Fellow, 2013). Plants can influence the hydraulic properties of the soil by creating preferential flow paths along macro pores created by roots or by enhancing water infiltration through induced desiccation cracks (Charles et al. 2016). Laboratory and field tests have shown that vegetated soil could preserve suction of up to 20 kPa after rainfall, which is higher than that retained in bare soil. An increase in suction would increase the soil shear strength and reduce the hydraulic conductivity (Ng et al., 2016; Stokes et al., 2009). The SWRC is a characteristic of unsaturated soils that describes the relationship between the soil water content and matric suction. It has a great influence on slope stability analysis because the resistance properties (shear strength) depend on the soil water suction and the infiltration process is also affected by soil moisture patterns (Antinoro et al., 2017; Mukhlisin et al., 2011; Veylon et al., 2015). It was also reported that actively growing roots could reduce saturated permeability while decayed root would cause preferential flow path, increasing permeability (Leung et al., 2015, Ni et al., 2018). The behavior of vetiver roots in suction development and modification of hydraulic properties is dependent upon the type of soil, initial void ratio and grain size distribution (Jotisankasa and Sirirattanachat, 2017). From the literature review it can be concluded that proper study on the hydrological effect of vetiver plants on soil can help in quantifying its usability in a particular location.

2 Objectives

The fundamental theme of this paper is to experimentally investigate the effect of vetiver grass (Crysopogon zizanioides) on hydrological properties of soil. The main objectives are:

(i) To analyze the variation of root biomass in soil with different plant ages
(ii) To study the effect of vetiver grass roots on porosity and permeability functions of laterite soil for different root contents
(iii) To study the effect of grass roots on suction development in the root soil matrix using soil water retention curves

3 Materials and Methodology

Laterite soil collected from the College of Engineering Trivandrum campus was used for planting vetiver grass in the present study. This soil represents typical materials encountered in most of the bio-engineered slopes in Thiruvananthapuram district of Kerala. The properties of soil is given in Table 1.

Table 1. Properties of soil collected

Sl. No.	Properties	Result
1.	Grain size distribution	
	Gravel fraction (%)	33
	Sand fraction (%)	61
	Clay + silt fraction (%)	6
2.	Specific gravity	2.56
3.	Bulk density (g/cc)	1.71
4.	Maximum dry density (g/cc)	1.88
	Optimum moisture content (%)	18

The soil was filled in tanks at bulk density and vetiver plants were planted with suitable spacing as shown in Figure 1. Required numbers of vetiver saplings were collected from Kairali Agrifarm, Koliyakode, Thiruvananthapuram, Kerala.

Fig.1. Vetiver specimen after planting

The spacing of plants was selected on the basis of lateral spreading of vetiver roots which generally varies from 0.15 m to 0.2 m. The growth of vetiver was monitored in the interval of 30, 60, 90 and 120 days and its hydrological effects on laterite soil were determined for each time interval. The specimens were sampled in a split cylindrical sampler having diameter 0.15 m and height of 0.3 m as shown in Figure 2.

Fig.2. Sampling of specimen using split cylindrical sampler

For each collected sample, the first stage of experiment was soil suction measurement using filter paper technique as per ASTM D 5298-10. Whatman No.42 filter paper was used for suction measurement followed by permeability test. After the permeability test, the sample was taken for studying the root morphology. In order to obtain the root biomass content the specimen was dismantled and the final moisture content of soil was determined. The remaining rooted soil sample was washed with water and passed through sieve of 1 mm opening size to expose the roots. Roots that were washed away and passed through the sieve were considered small and not included in measuring the root biomass. These roots were then dried in the oven at 105°C overnight to determine the dry biomass of roots, used for calculating the root biomass per soil volume, $\boldsymbol{\rho_r}$, (kg/m³).

4 Results and Discussion

From the suction measurement, permeability tests and root biomass determination following results were obtained.

4.1 Variation of root biomass with plant age

The increase in root biomass improves the hydro-mechanical behavior of the vegetated soil mass. Osman and Barakbah (2011), gave a positive correlation between root biomass and plant age. In the present study, the root biomass in laterite soil was determined at intervals of 30, 60, 90 and 120 days and is shown in Table 2 and Figure 3.

Table 2. Root biomass with different ages of vetiver grass

Sample age (days)	Root biomass (kg/m^3)
30	1.72
60	3.50
90	4.42
120	5.40

It can be observed that as the age of plants increases, root biomass increases subsequently and there is a linear relation between age of plants and the root biomass content in laterite soil as seen in Figure 3. The increase in root biomass can affect the performance of root soil matrix as discussed in the sections below.

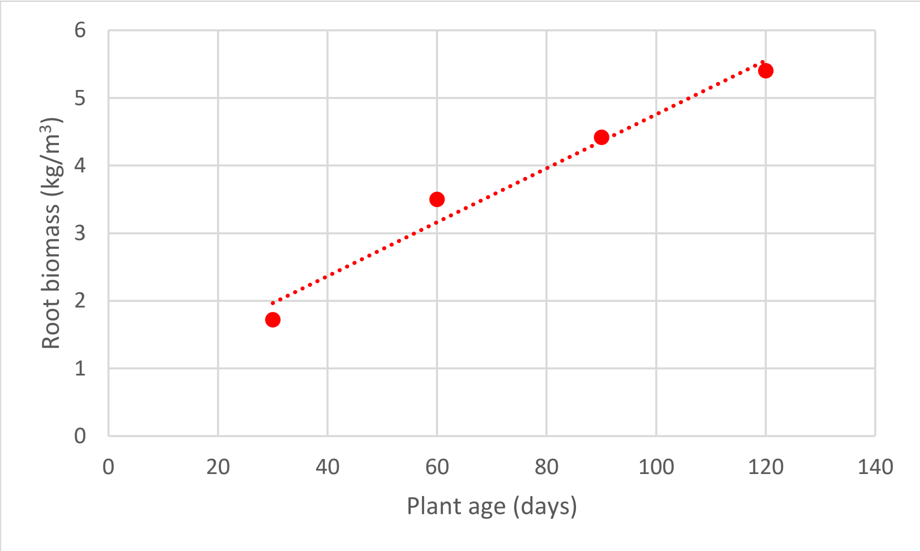

Fig. 3. Variation of root biomass with age of plants

4.2 Effect of roots on SWRC

The presence of plant roots in soil directly affects soil hydraulic properties, including soil water retention. Hence proper study of SWRC can help in analyzing the effect of plant roots in soil. Filter paper method is used to determine the soil suction. After determining the moisture content of filter paper, suction is determined from a calibration curve corresponding to the moisture content of filter paper. The plot of SWRC is developed with Y axis being the volumetric water content (Defined as the ratio of volume of water to the total volume of the sample) and X axis having the values of matric suction in logarithmic scale. Figure 4 shows the variation of SWRC with different age of plants.

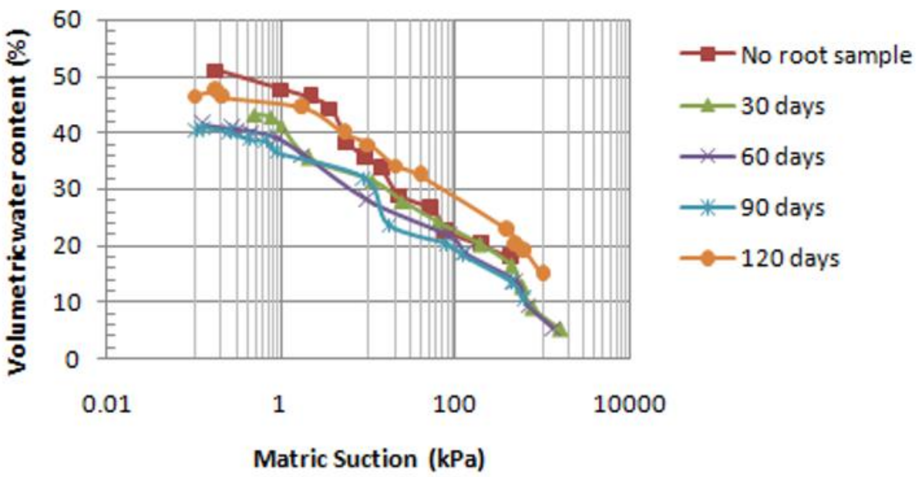

Fig. 4. SWRC of soil with various root content

As the root content increased from 1.7 kg/m³ to 5.4 kg/m³ significant changes are seen in the SWRC characteristics. When root density increases transpiration becomes more effective consequently the suction pressure developed in the soil increases. It is observed from Figure 4 that SWRC plots corresponding to root biomass of 3.5 kg/m³ and 4.42 kg/m³ are steeper than those of lesser root content. That is for a given amount of moisture absorption, steeper SWRC will induce higher suction. The decrease in saturated volumetric water content from 50% to 40% is due to the decreased pore sizes of soil mass because of the roots occupying the pore spaces.

When root biomass increased beyond 4.42 kg/m³ and reached 5.4 kg/m³ i.e. during growth period between 90 and 120 days, the suction curves shift upward and become more flat. The reason for this shift in SWRC is the fragmentation (development of massive finer roots) of fibrous root system which break the micro pores in the soil, and hinder the development of matric suction, especially when root density is high. Therefore, the rate of increase in matric suction is only significant up to a threshold root concentration beyond which the rate becomes slightly smaller.

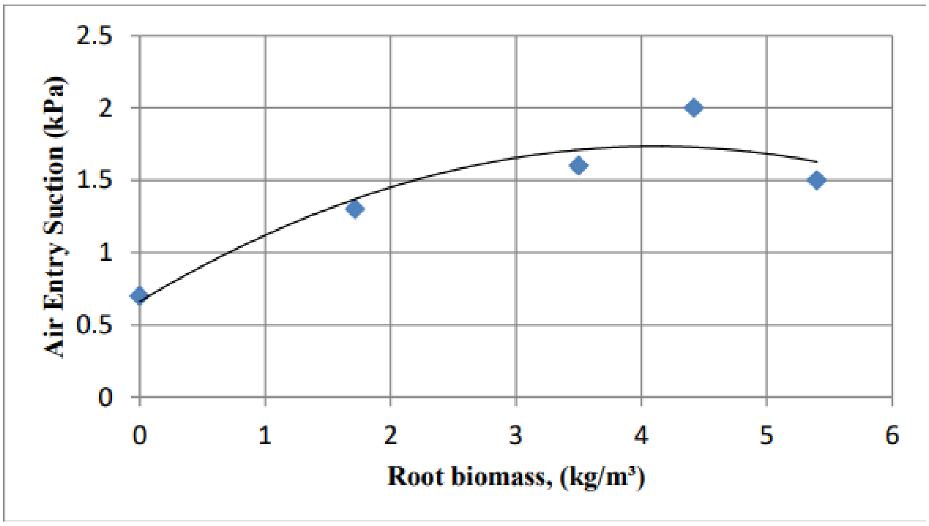

Fig. 5. Variation in AEV with root biomass

The change in the behaviour of SWRC primarily affects the air entry suction created in the soil. Changes in the Air Entry Values (AEV) have significant effect on suction regime, slope stability and time for failure of slopes during rainfall. In the present study the AEV of bare soil is estimated as 0.7 kPa which further increased upto 2 kPa with increase in root bimass from 1.7 kg/m³ to 4.42 kg/m³ as shown in Figure 5. The increasing trend in AEV is seen only up to the threshold root biomass beyond which AEV decreased to 1.5 kPa as shown in Figure 5. A higher magnitude of AEV represents a bioengineered slope with greater factor of safety and longer time for slope failure, which means that vegetated slopes with sufficient quantity of root biomass can stabilise the soil slope.

4.3 Effect of plant roots on porosity and permeability

Porosity and permeability have significant effect on the stability of soil slopes. Higher porosity results in higher water infiltration rate and it also affects the permeability of soil. Hence the effect of roots on porosity and permeability is to be properly studied to examine the suitability of plant roots in soil slope. Porosity of rooted specimen was calculated using Equation 1 and the variation of porosity with increasing root biomass was analysed.

$$n = \frac{V_v}{V} = \frac{V - V_S - V_r}{V} \quad (1)$$

Where n is the porosity of the soil, V is the total volume, V_v is the volume of voids, V_s is the volume of soil and V_r is the volume of roots.

V was computed by taking the measurements of the diameter and height of the cylindrical rooted sample. Soil and roots were separated carefully and weighed as detailed in Section 3 and the corresponding volumes were computed using the specific gravity of soil and roots obtained as 2.56 and 0.998 respectively from density bottle experiments. The soil in undisturbed state had a porosity of 52% which decreased up to

44.29% with increasing root biomass from 1.71 kg/m³ to 5.4 kg/m³ as shown in Table 3.

Table 3. Porosity with different ages of vetiver grass

Sample Age (days)	Porosity (%)
30	47.65
60	46.24
90	45.12
120	44.29

The coefficient of permeability k for bare soil sample at 70% of bulk density was 1.03 x 10^{-3} m/s. As the root content increased and rate of infiltration reduced the permeability also decreased to 2.87 x 10^{-7} m/s i.e permeability of given laterite soil varied from silt range to clay range due to decrease in porosity as shown in Figure 6.

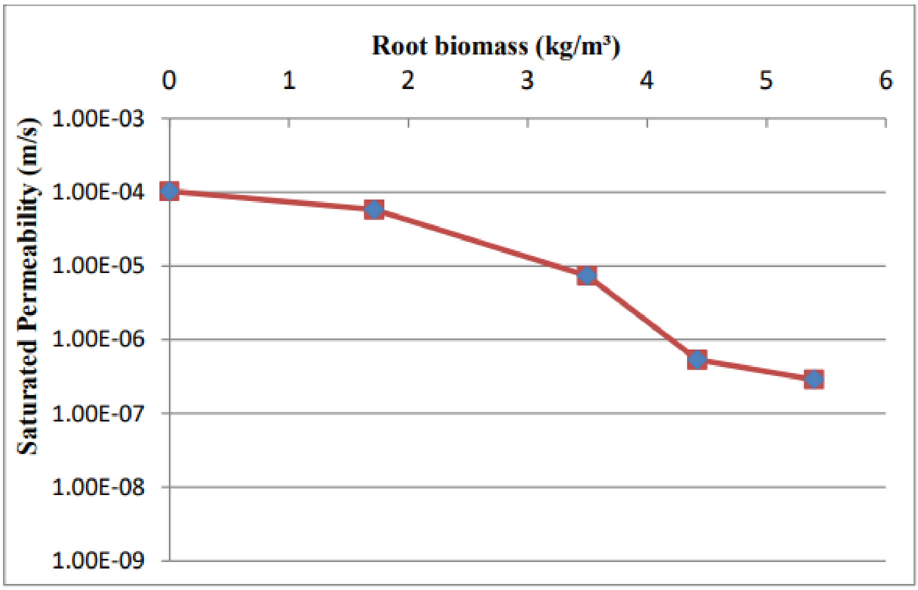

Fig. 6. Variation of permeability with root biomass

The effect of root on permeability is abrupt that with a minor increase of root content the water flow was blocked. The distribution of macro pores would be affected by roots to a greater extend. It is also speculated from the graph that beyond the threshold root content the rate of decrease in permeability is unnoticeable which is because of the decreased effect of soil suction due to root fragmentation.

5 Conclusion

In this study the effectiveness of vetiver roots in stabilising lateritic soil slope is investigated by analyzing its hydrological effect in the root soil matrix by conducting various laboratory experiments and studying root morphology. The following conclusions were derived.

- Root biomass has significant effect in deciding the behaviour of Soil Water Retention Curves of vegetated soil, with increase in root biomass from 1.7 kg/m^3 to 4.4 kg/m^3 SWRC became steeper and shifted downwards with AEV increasing from 0.7 kPa to 2 kPa.
- When root biomass increased beyond 4.4 kg/m^3 and reached 5.4 kg/m^3 SWRC shifted upward and became less steep with decrease in AEV up to 1.5 kPa.
- Higher AEV for root soil matrix indicates that vegetated slopes with sufficient quantity of root biomass can stabilise the slope.
- The porosity of vegetated soil reduced with increase in root biomass from 0 to 5.4 kg/m^3 which can also be correlated to the decrease in coefficient of permeability from 1.03×10^{-4} m/s to 2.87×10^{-7} m/s i.e. k decreased by thousand times.
- The rates of increase in matric suction is significant up to a threshold root concentration beyond which the rate became slightly smaller hence for the given lateritic soil the optimum root biomass is approximately within in the range of 4.42 kg/m^3 – 5.40 kg/m^3

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