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# Contribution of root tensile of Pennisetum polystachion on shear strength of sandy soil in slope bio-engineering technique

**Z.A. Rahman*, A.E. Ettbeb, W.M.R. Idris and S.N.A. Tarmidzi**

Department of Earth Science and Environment, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, 43600, Malaysia

***Corresponding Author Email :** zarah1970@ukm.edu.my

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## Abstract

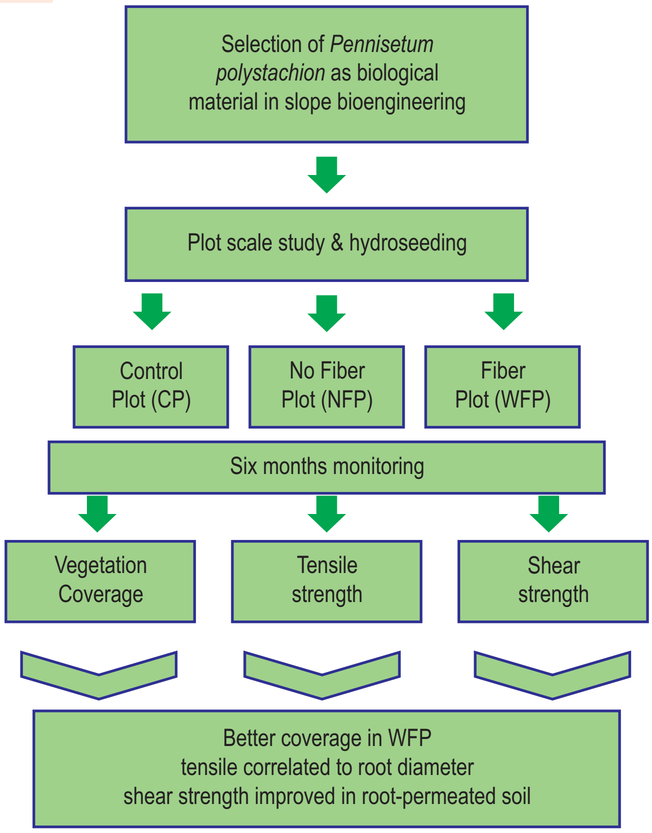
**Aims:** In soil bio-engineering, plant has been widely adopted as important material in promoting sustainable ecological function in slope instability measures. Plant canopy provides shelter and at subsurface level, root networking attributes toward stability of soil against erosion and slope failure. To investigate the potential of selected *P. polystachion* as biological material in soil bio-engineering for improving the soil shear strength of sandy soil planted with *P. polystachion*.

**Methodology:** The selected species was initially planted using hyroseeding technique on studied plots which facilated with and without fiber netting (made of paddy straw). A control plot was also prepared for reference of this study. The plots were routinely watered twice a day for six months before experimental program was scheduled for determining of root tensile and soil shear strength tests.

**Results:** The root tensile strength of *P. polystachion* exhibited a positive significant relationship between root tensile force and root diameter. The shear strength of soil was affected by the presence of root if compared to that of soil without root (control). Biomass analysist also agree with the soil water content, $w_s$. High biomass contributed to the increase in the values of soil shear strength parameter of cohesive, $c$ and angle of friction, $\theta$ for root-permeated soil with *P. polystachion*.

**Interpretation:** This study has suggested that the potential application of this selected species for slope vegetation in improving the erosion control and slope stability in soil-bioengineering scheme.

**Keywords:** Erosion, Pennisetum, Root tensile, Shear strength

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## Introduction

Erosion and slope instability are common features in tropical regions which experience heavy downpour during wet season. Malaysia is located near the equator and remains hot and humid throughout the year with temperature ranging from 23°C to 33°C. Rainy season is generally caused by North east monsoon from October and March that bring heavy rainfall mainly to the east coast states of Peninsular Malaysia. In highland areas, the temperature gets mild with temperature ranging between 17°C and 25°C. During wet season, several erosion and slope failures are observed annually that cause loss of properties and life.

Soil is prone to erosion especially barely open to erosion agents such wind and water. Soil erosion can occur even on flat and gentle slopes but at slow rate, however, can be extremely worst when the slope is openly barren, steep and having heavy rainfall (Osman *et al*., 2011). Gray and Sotir (1996) cited that the removal of slope vegetation is among the controlling factors that also contributes to slope instability. With prolong weathering, the soil strength is slowly degrades with time and begins to associate with small scale surface erosion. It almost the climatic elements become a triggering factor to the problem of soil erosion (Gray and Ohashi, 1983). Number of steps have been taken and million have been spent to tackle down this problem by imposing schemes that can improve the stability of slope, especially those associated with engineered soil slopes. Hard engineering such as retaining wall, shorcrete, nailing and netting etc., are among common options used in slope mitigation measures. The use of soil-bioengineering approach has been successfully utilized in combination with hard engineering. This technique manages to control soil erosion at embankment sites, river banks and ex-mined areas (Muzzi *et al*., 1997; Oliveira *et al*., 2012). Use of plants for slope erosion management can benefit soil environments which involves modification of soil biophysical, chemical and mechanical properties that finally stimulate the diversity and abundance of micro-organisma (Stokes *et al*., 2014). Mutual interaction between soil and root has been well acknowledged by researches. Ali and Osman (2008) and Mattia *et al*. (2007) stated that the role of vegetation on soil reinforcement is associated with factors related to soil types, plant species and coverage and soil moisture condition. Roots penetrate down into the ground and bind together soil particles and refrain soil movement through their tensile resistance, subsequently improving the shear strength of soil. Previous studies have reported that vegetated slopes are less vulnerable to erosion caused by water and wind actions (Coppin and Richards, 1990; Gray and Sotir, 1996; Preti and Giadrossich, 2009).

Many plant species like Vetiver (*Vetiveria zizanioides*), Signal (*Brachiaradecumbens*) and Bermuda (*Cynodon dactylon*) grasses have been used for slope application. These plants have been successfully able to control soil erosion and at sub-surface level improve the structure of soil through their root characteristics. Vertiver grass is characterized by densely tufted bunch and can easily established in many part of the world (Oshunsanya *et a*l., 2014). There are many native species that can also be adopted and should be examined their potential application as biological material. *Pennisetum polystachion* is a type grass species well established in many countries in tropical region (Bhattacharjee *et al*., 2007). Native plants are widely distributed and can offer cheaper maintenance and can definitely tolerate local environments (Lasamadi *et al*., 2013; Tosi, 2007). In addition, use of local species can be an added-value, ecomomically cost-effective and can diversify with the current products available in the market. In view of the above, this study aimed to investigate the tensile resistance, in terms of force for the selected *Pennisetum* species and to determine the effect of root-permeated soil on the shear strength of soil planted with *P. polystachion*. This species was initially planted in studied plots pre-installed with and wihout fiber net. Fiber net is also known paddy straw blanket which provided by supplier. A control plot was also prepared for reference and comparison.

## Materials and Methods

*Pennisetum polystachion* (Linnaeus) Schultes was selected for this study. This parrenial plant is commonly known as mission or foxtail grass. It can grow up to 2 m and has been introduced purposely as a fodder grass. It is believed that this species spread from Thailand into Malaysia in early 1980 (Bakar *et al*., 1990).This plant is a dominant weed in deforested lands, harmful to agricultural plants and treated as un-economically useful.

The selected plot study by the soil which developed from the weathering of granitic rock. The soil was yellowish red with abundant coarse quartz grains in the soil mass. The physico-chemical characteristics of soil is shown in Table 1.

**Preparation of plots and hydroseeding:** *P. polystachion* was initially planted in the plots following the hydroseeding technique. Prior to that, mature seeds were collected from various road sites from Gap to Fraser Hill. The studied plots were prepared at Fraser Hill's Research Center (PPBF UKM) with average slope angle of 40°. Bukit Fraser is a mountaineous area with elevation between 1000 to 1525 m above sea level with temperature ranging 18°C to 22°C (Sahibin *et al*., 2015). The average annual rainfall is 2624 mm and relative humidity 65% and 90%. The studied plots consisted of different type of plots namely control plot (CP), plot with fiber netting or paddy straw blanket (WFP) and plot without fiber netting (NFP). The dimension of each plot was 500cm x 200cm x 30cm and was built with sand brick.

Hydroseeding mixture consisted of soil tacifier, seed, water, fertilizer and paper mulch made up hydroseeding mixture. The amount of each component was prepared based on the

**Table 1:** Physico-chemical characteristics of soil

| Parameters | Soil |
|---|---|
| pH H20 (1:1; w/v) | 5.67±0.58 |
| Spesific gravity, $G_s$ | 2.63±0.15 |
| Organic cont. (%) | 5.50±1.27 |
| Water cont. (%) | 31.79±9.52 |
| Sand (%) | 69.35±2.13 |
| Silt (%) | 19.28±3.05 |
| Clay (%) | 11.37±1.26 |
| Texture | Sandy loam |
| Hydraulic conduct., *K* (sm/j) | 0.15-0.63 |

standard procedure provided by the supplier, Hydroturf Services (M) Sdn. Bhd. Recycled papers for paper mulch material were soaked in water for several days and the water was change everyday till the pH of water was neutral. The soaked papers then were blended before oven-dried at 70°C for a week. The predetermined paper mulch and seed were mixed with distilled water and left for 36 hr. The soil tacifier and organic fertilizer were added. The mixture was then thoroughly blended again until it had a slurry texture. The amount of each component in hyroseeding mixture is shown in Table 2. Hyroseeding slurry was manually and uniformly sprayed on each plot. Each type of plot was duplicated to allow statistical analysis. The plots were monitored for six months and watered twice a day.

**Vegetation coverage:** The studied plots were monitored every month up to six months period. To assess the performance and influence of fiber net which was installed prior to hydroseeding to *P. polystachion* during this period of observation. Fiber net or paddy straw blanket was also supplied by Hydroturf Service Sdn Bhd (M). Paddy straws were layered and woven by polypropylene of mesh size 13mm x 13mm. This product can absorb and dissipate energy from raindrops which will benefit the hydroseeding material and top soils from being washed away to the toe of the slope. It also offers surface roughness to decrease the velocity of runoff, subsequently reduce the sediment transportation (Won *et al*., 2012). Each plot was divided into 10 grids of 1 $m^2$ each. Every month, the vegetation coverage area was determined by measuring the boundary of successful growth of *P. polystachion* over total area of the plot.

**Root tensile strength test:** Root sampling was carried for tensile resistance test. This was carried out after six months for physical characterization. Selected plants from each plot were carefully dug and washed with tap water to remove dirt attached to the roots. Roots were for root diameter using a venier caliper. This measurement was carried out at three different points of the root. Root samples were cut into 10 cm length and then weighed using balance (Model Mettle PJ3000, made in Japan). Each end of the root sample was wrapped with sand paper (ASTM D3379-75 1989). The root was then clamped into the entire wedge grip

**Table 2 :** Proportion amount of each component in hydroseeding

| Component | Quantity |
|---|---|
| Seed (g $m^{-2}$) | 27 |
| Paper mulch (g $m^{-2}$) | 125 |
| Soil tacifier (ml) | 3 |
| Fertilizer (g $m^{-2}$) | 31.25 |
| Distilled water (ml) | 300 |
| pH | 5.48 |

length to ensure better grip with little risk of slippage during the test. The rate of 5 mm $min^{-1}$ was applied to pull vertically up of the root sample. The root was carefully monitored until failure occurred and the reading of maximum force was recorded automatically by software embedded with Universal Testing Machine (UTM). This device can apply extension force up to 50kN (Instron, Model 5566, USA). The tensile force at the point of rupture was taken as peak load (*Fmax*) (Abdi *et al*., 2010; Genet *et al*., 2011; Vergani *et al*., 2012). The diameter of root was measured again after the test at several points close to the point of ruptures and average value was recorded.

The relationship between tensile force and root diameter is shown in Eq.1.

$$T_f = \alpha \cdot d^{\beta} \qquad \text{Eq. 1}$$

Where, $T_f$ is the tensile force (N), *d* is the average root diameter (mm). (Genet *et al*., 2011; Schmidt *et al*., 2001; Tosi, 2007). Tensile stress was determined by dividing the tensile force over the cross-sectional area of the root at rupture point (Abdi *et al*., 2010). Arguments arose as a result of the difficulty in achieving accurate measurement at the point of rupture and uncertainty in the exact point of rupture especially for finer roots. In addition, the diameter of root usually reduce after the test caused by tensile strain and the rupture, process is associated with a small proportion root rather than a single infinitesimal section (Vergani *et al*., 2012).

**Soil sampling and direct shearbox test:** The collection of soil samples for direct shearbox test was carried out from different types of plots (CP, NFP and WFP). A box sample technique was adopted and random sampling was applied for each plot. A metal knive was used to dig out a box sample and each box sample had approximate dimension of 200mm x 200mm x 100mm. The sample was carefully dug out from the ground and was wrapped with several layers of plastic film to maintain its moisture content prior to laboratory test. In laboratory, the box sample was unwrapped and was the trimmed to fit into brass box of direct shearbox equipment (60 mm x 60 mm x 25 mm). Then brass box with sample was attached back to the shearbox machine and the sample was horizontally sheared at a strain rate of 1.2 mm $min^{-1}$. Three samples were prepared for each type of plot. Each sample from the plot types would be sheared under apllied normal loads,

$\sigma_n$ of 10, 20 and 30kPa. The procedure of perfoming shearbox test for soil was accordance to the British Standard Institution 1377 (1990).

The equation of Mohr-Coilomb's soil shear strength was applied to establish the shear strength parameters of angle of friction and cohesion values (Eq.2) .

$$\tau = Cs + \sigma . \tan \theta \quad \text{Eq. 2}$$

Where, $C_s$ is the soil cohesion; $\theta$ the angle of friction, $\sigma$ the normal load and $\tau$ is the soil shear strength. In the case of the presence of root in soil matrix, this equation should take into account the role of root in providing resistance toward failure which contribute to additional shear strength to the soil by $c_r$ as shown in Eq.3 (Bischetti *et al*., 2009; Cislaghi *et al*., 2017; Roering *et al*., 2003; Wu, 2017).

$$\tau = Cs + Cr + \sigma . \tan \theta \quad \text{Eq. 3}$$

After the completion of shearing, the moisture content and root biomass were determined for each sample. The sheared sample was weighed and transferred into the oven at 105°C for an overnight. The sample was weighed again to measure the moisture content. The sample was gently washed to remove soil and the roots were oven dried in an oven at 60°C.

## Results and Discussion

Vegetation cover was measured every month up to six months. The results of this observation is shown in Fig. 1. The control plot was empty as this plot was left barren without hydroseeding. Early coverage up to 30 days was slow but plot with fiber net (WFP) reached 47.5% whilst plot without fiber net (NFP) only achieved 32.5%. The following months (60 days), vegetation coverage for WFP and NFP reached 75% and 57.5%, respectively. It took 90 days for WFP to establish 100% vegetation coverage, while NFP managed 95% up to the end of observation period. Difference in vegetation coverage between these two plots may be attributed to removal of some seeds by water run-off from the plot without fiber net (NFP). The presence of fiber net can shelter or trap seeds and create optimum condition for the seedling process. Based on this study, the use of fiber net to plot can produce successful growth of studied species at quicker phase when compared with plot having no fiber net.

A series of tensile resistant tests were performed on root samples which were collected after six months. Forty-eight root samples were uprooted carefully and cleaned before the samples were prepared for the test. The root diameters ranged between 0.19 and 0.49 mm with average of 0.36 mm. The tensile force values ranged between 2.10 N and 9.98 N with average of 5.35 (Table 3).

The relationship between root tensile force and root diameter is shown in Fig. 1. This relationship can be best represented by a power low equation to encompass the scattered values of tensile force and diameter (Eq.4).

$$T_f = 22.79d^{1.448} \; R^2 = 08018 \quad \text{Eq.4}$$

The relationship between tensile stress and root diameter resulted in inverse power law equation. However, there were some doubts in accuracy, a preferable approach was to used tensile force instead of stress. Small variation can be clearly seen in Fig. 2, however this relationship in power law equation is supported by good correlation ($R^2$=0.8018). This study indicates that higher root tensile force reflects its tensile strength towards better resistance to tension force when slope experiences soil movement (Stokes *et al*., 2009). The potential failure plane will be refrained from movement when the root networking binds the soil particles and failure plane together (Ghestem *et al*., 2014). At this state, the slope still stable and tension force driven by slope was below the maximum root tensile strength. The stability of particular slope can be extensively improved as roots infiltrate deep and anchors to slope materials. In addition, factor such as density, network and types of root can vary and contribute to the stability of slope (Dupuy *et al*., 2005; Mickovski *et al*., 2007).

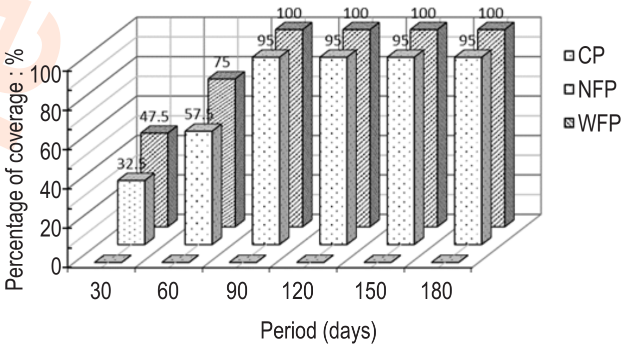


**Fig. 1:** Trend of vegetation coverage of studied species over six months period

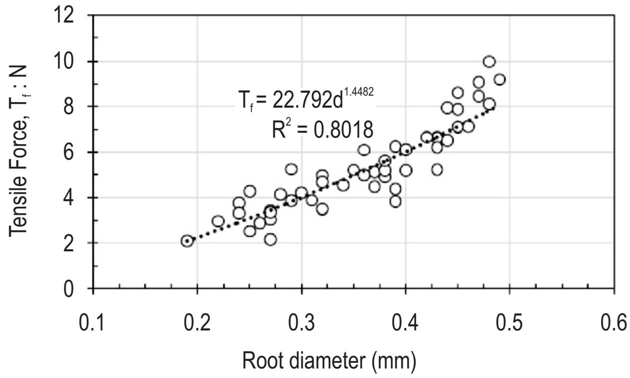


**Fig. 2 :** A positive relationship of tensile force against root diameter.

A series of direct shearbox test were performed to the samples of root-permeated soil. Stress against displacement curves for different plot treatment can be seen in Fig. 3a, b, c. All stress-displacement curves showed a typical behavior where stresses initially climbed linearly up to early displacement approximately below 0.5 mm. The rate of stress over displacement gradually decreased before achieving the resistance peaks, followed by constant values. Three different normal loads were applied to achieve peak values for each type of sample. The resistance peaks increased as the applied normal stress increased. Samples from NFP showed peak resistances close to the end of the tests, suggesting a characteristic of strained hardening behavior or non-compacted soil (Ali Rahman *et al*., 2010; Maffra *et al*., 2019).

The shear strength parameter, biomass and water contents for different plot treatments are shown in Table 4. For control plot (CP) with applied normal load of 10 kPa, the shear

**Table 3:** Root diameter and tensile force values for studied species

| Root diameter (mm) | | | Tensile force (N) | | |
|---|---|---|---|---|---|
| **Minimum** | **Maximum** | **Mean** | **Minimim** | **Maximum** | **Average** |
| 0.19 | 0.49 | 0.36±0.08 | 2.10 | 9.98 | 5.35±1.94 |

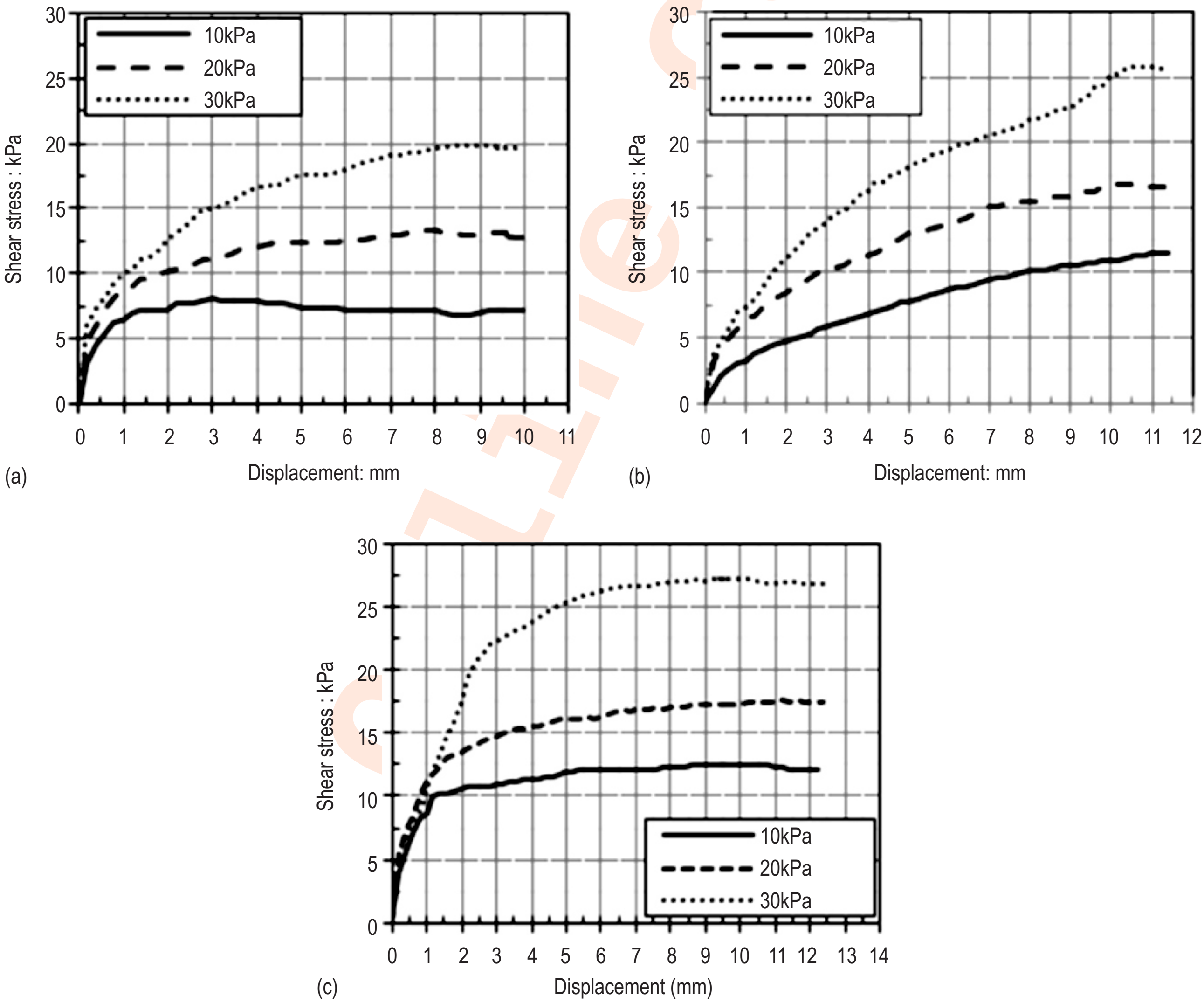


**Fig. 3 :** Stress-displacement curves for different type of treatments (a) control plot (CP); (b) plot with no fiber net (NFP) and (c) plot with fiber net (WFP).

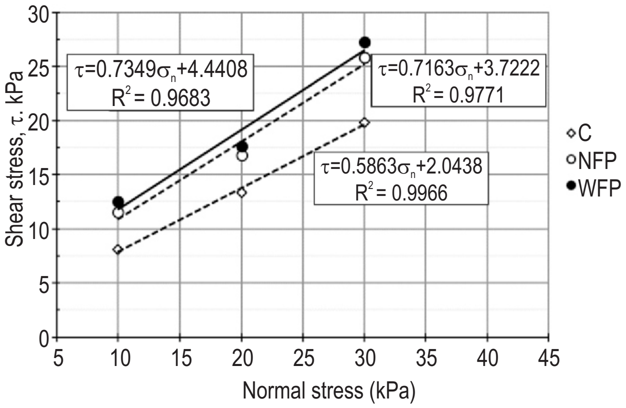


**Fig. 4 :** Comparison of shear strength envelopes for samples from different plot treatments.

stress achieved its peak resistance at 8.1 kPa (Fig. 3a). While for higher applied stress of 20 kPa and 30 kPa, the peak resistance reached higher values of 13.4 kPa and 19.8 kPa, respectively. The cohesion and friction angle values for CP sample, lower than the NFP and WFP samples. The internal friction angle of sample from CP was 30.4° while for NFP and WFP it was 35.6° and 36.3°, respectively (Table 4). Apparently, the presence of root exhibited increase in shear strength mainly by increase in the internal friction angle. Since this soil is dominated by sand fraction, the small value of cohesive is expected for sandy soil.

The cohesion value from CP plot was 2.04 kPa and increased to 3.72 kPa and 4.44 kPa for NFP and WFP samples, respectively. These results showed that the root-permeated soils have higher shear strength parameters if compared to that of sample from control plot (CP) with no root. A study conducted by Maffra *et al*. (2019) also showed that the shear strength of sandy soil is due to the presence of roots. They found that the shear stress significantly increased between sandy soil without root and root-permeated soil. Studies also showed that the internal friction angle of sandy soil underwent minor rearrangement caused by roots (Ali and Osman, 2008; Veylon *et al*., 2015). Sandy soil has little cohesion, and resistance effectively comes from friction due to interaction between particles. Roots establish interconnection between two parts of soil which is splitted by potential surface of failure and may fail to rupture once the root tensile strength is overcome (Gray and Sotir, 1996; Maffra *et al*., 2019). As a result, the soil deformation will delayed at higher strain and achieve resistance peak which causing the increment of cohesion (Maffra *et al*., 2019).

The failure envelopes for different plots of CP, NFP and WFP are presented in Fig. 4. In comparison between these failure envelopes show that the internal friction angle of the soil (angular coefficient) and cohesion values (cohesive intercept) were located higher in the root-permeated soil samples than soil with no roots. As seen in the figure, the failure envelope for CP soil was distant below the envelopes for NFP and WFP soils. Both failure envelopes for root-permeated soils were located slightly close to each other. Different values for internal friction angle and cohesion values between NFP and WFP plots were 0.7° and 0.72 kPa, respectively. The contents of root biomass in NFP and WFP samples had contributed slightly to different shear strength parameters (Table 4). Installation of fiber netting to WFP plot provides a better approach to protect the hydroseeding mixture (seed, fertilizer etc) from being washed away by surface runoff during heavy rainfall. The amount of water content has subsequently improved for sample from WFP (43.4%) compared to that of sample from NFP (23.7%). This coupling effect of fiber net and root biomass has attributed to the moisture content of soil. Beside, roots can intercept the failure plane, additional shear strength can be attributed to matric suction as root water uptake causes partial saturation of shallow soil layers which results in increased matric suction (Simon and Collison, 2002; Yildiz *et al*., 2019). Pallewattha *et al*. (2019) also concluded that the shear strength of root-permeated sandy is governed by the level of applied suction.

*Pennisetum polystachion* was studied for its potential use as biological material in bio-engineering technique for soil slope erosion. Wide distributed and easy adaptation of this plant offer

**Table 4** : Summary of shear strength parameters, biomass and water content

| Treatments | Normal pressure (kPa) | Peak shear stress (kPa) | Internal friction angle (°) | Cohesion value (kPa) | Average biomass (g) | Mean water content (%) |
|---|---|---|---|---|---|---|
| Control plot | 10 | 8.1 | 30.4 | 2.04 | n.a* | 20.5 |
| | 20 | 13.4 | | | | |
| | 30 | 19.8 | | | | |
| Plot without fibre | 10 | 11.5 | 35.6 | 3.72 | 0.59 | 23.7 |
| | 20 | 16.8 | | | | |
| | 30 | 25.8 | | | | |
| Plot with fibre | 10 | 12.6 | 36.3 | 4.44 | 1.14 | 43.4 |
| | 20 | 17.6 | | | | |
| | 30 | 27.3 | | | | |

*n.a = not available (no plant); CP-control plot; NFP-plot without fiber; WFP-plot with fiber economical maintenance and eco-friendly to natural environments. The scope of investigation was concentrated on the root tensile strength and attribution to soil shear strength. The tensile resistance was measured based on tensile force at peak instead of stress due to some ambiguity in accuracy of diameter measurement. It is clearly that the tensile force exhibited positive relationship with root diameter of *P. polystachion*. The result of root tensile displayed a significant positive relationship between tensile force and root diameter ($R^2$=0.8018). The shear strength of root-permeated soil also improved significantly when compared to soil with no roots. The presence of fiber netting slightly improved the shear strength of the plot with fiber net. The increase in shear strength parameters of plot with fiber net coincided with the amount of root biomass which was higher than the plot with no fiber net. *Pennisetum polystachion* exhibited full coverage in shorter period than plot with no fiber net facilty. The soil moisture content was also significantly higher than the soil samples from control and no fiber plots. Thus, the results indicate that this species can be adopted for hydroseeding approach and with combination of fiber netting, the slope stability can be improved at economic cost of maintenance.

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### Add-on Information

**Authors' contribution : Z.A. Rahman:** Shear strength analysis of the soils; **A.E. Ettbeb:** Growth performance of the species; **W.M.R. Idris:** Soil characteristics and hydro-seeding; **S.N.A. Tarmidzi:** Root tensile of the species.

**Research content:** The research content is original and has not been published elsewhere

**Ethical approval:** Not Applicable

**Conflict of interest:** The authors declare that there is no conflict of interest.

**Data from other sources:** Not Applicable

**Consent to publish:** All authors agree to publish the paper in *Journal of Environmental Biology*.

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