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Research Article

Investigation of Root Distribution and Tensile Strength of *Acacia mangium* Willd (Fabaceae) in the Rainforest

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ABSTRACT

The purpose of this study is to complement the existing body of knowledge on the root system of tropical plants and their contribution to slope stability. For this reason, four trees of *Acacia mangium* selected as randomly in rainforest along East-West Highway, Malaysia. Root area ratio (RAR) and tensile strength (Tr) data were collected and analyzed. RAR data were measured with the whole root system and Tr were measured by individual roots. The results showed that there is a power law equation between root diameter and Tr, with an average of 44.11 Mpa (in average root diameter of 0.9mm). There was a wide variation in the RAR in relation to soil depth. Generally, RAR reduced with the increasing soil depth. Similarly, additional cohesion by plant roots conducted by Tr and RAR. In conclusion, in order to assess soil reinforcement by vegetation roots, root distribution and tensile strength data with soil depth in different vegetation and sites is necessary.

Keywords: Additional cohesion, Root system, Slope stability, Soil reinforcement.

INTRODUCTION

Plants can significantly improve slope stability and avoid soil slippage by hydrological mechanisms dropping pore water pressure (Gyssels et al., 2005) and over mechanical reinforcement of soil by roots (Nilaweera and Nutalaya, 1999; Burylo et al., 2011). Slope stability is greatly dependent on the shear strength of soil; therefore an increase in soil shear strength can successfully improve slope stability (Pollen, 2007; Zhang et al., 2010). Soil stabilization is one of the least recognized influences of roots in woody shrubs and trees, and reinforcement of sloping ground.Soil shear resistance is affected by changes in vegetation over various periods. Loss of reinforcement because of root deterioration and changes to the hydrology of slopes are the other parameters that affect soil resistance (Van Beek et al., 2008).

The greatest important issues governing the soil stabilization are RAR and tensile strength of the roots (Abdi et al., 2010a; Genet et al., 2010). By measuring tensile strength and distribution of roots within the soil, the effect of tree roots on slope stability can be recognized. These two structures, control the major mechanisms of stability such as soil reinforcement, soil arching and defense and root anchoring (Nilaweera and Nutalaya, 1999). Soil reinforcement increased by the presence of vegetation roots (Makarova et al., 1998) due to the fact that soil cohesion, increase with the presence of vegetation as well as the increase in soil shear strength (Cazzuffi et al., 2006)

Plant root affords further cohesion to the soil and root-permeated soils are hence much stronger than soils alone to survive soil damage procedures such as mass movements. Soil reinforcement due to the roots are influenced by numerous variables, including root systems such as root distribution with depth, root distribution over different root diameter classes and root tensile strength (Nicoll and Ray, 1996; Li et al., 2007; De Baets et al., 2008; Sun et al., 2008; Stokes et al., 2009; Loades et al., 2010; Burylo et al., 2011), root number, root diameter (Wu et al., 1979), root architecture (Duputy et al., 2005) and pullout resistance (Nilaweera and Nutalaya, 1999).

Nilaweera and Nutalaya (1999) compared root mechanical properties of some tropical plantsin rainforest in Thailand. In this study, seven different species of tropical rainforest plants were selected, then root tensile strength and root resistance of these species were compared. Root tensile strength decreased by increasing root diameter and for root diameters above 2.5 mm, *Diptrocarpus alatus* (dominant vegetation types of Diptrocarpaceae family in evergreen tropical rainforest) showed the highest tensile strength, for roots smaller than 2.5 mm, *Hopea odorata* (Diptrocarpacea family) gave the highest tensile strength.

The aim of this study is investigating the RAR and root tensile strength as a function of root reinforcement. Therefore, improving the existing body of knowledge about the root system is an important key for selecting species in soil erosion control, that is because of their magnitude in root strength against shallow landslide. The hypothesis of this research are: RAR values decrease by soil depth and Root tensile strength decrease with increasing root diameter.

MATERIAL AND METHODS

Study Area

The study area is located on the East-West dual carriage Highway, which is one of the major road in the northern part of Peninsular, Malaysia between N 05° 27′ 32.0″ E 101° 07′ 42.3″ to N 5° 42′ 11.15″ E 101° 49′ 54.74″. Theroad span an approximate distance of 119 km linking two districts of Gerik in Perak and Jeli in Kelantan. The climate of the study area is humid and annual mean precipitation is about 1957.5 mm, with an altitude around 283 meters above the sea level (Lateh et al., 2013). The soil texture is sandy, clay and loam (Lloyd et al., 2001). Between the years of 2007 and 2008, 43 shallow landslides were identified along East-West Highway. Although there are about 23 shallow landslides where no particular record was found. About 85% of total landslides occurred in June and December 2007 (Lateh et al., 2013).

Acacia mangium is a fast growing species (Butcher et al., 2000; Galiana et al., 1990; Voigtlaender et al., 2012) with annual wood production by 17-20 m^3 ha^{-1} $year^{-1}$ during a period of 10-12 years (Galiana et al., 1990). This species is from Fabaceae family, fix nitrogen in the soil, generally used in agroforestry with higher beneficial components to the plants for its nitrogen fixation (Jeyanny et al., 2010).

Root Area Ratio

RAR investigated using a vertical trench profile wall method, set out in other studies (Bischetti et al., 2005, 2009; Greenwood et al., 2006; Abdi et al., 2010a, b; Ji et al., 2012; Schwarz et al., 2012). Four trees of *A. mangium* were selected along East-West highway, then one trench with a distance of 1 meter was dug (Abdi *et al.*, 2010b). The dimension of profiles were 50 cm long × 70 cm depth. Layers 10 cm thick were marked on the vertical profile walls by counting roots and measuring the mean root diameter. Root numbers were then counted and separated into different diameter classes between 1 and 10 mm (Bischetti et al., 2005), i.e., 0-1, 1-2 mm, 2-5 mm and 5-10 mm (Genet et al., 2008; Ji et al., 2012) and >10mm. Roots belonging to the two first range were classified as fine roots, the others being denoted thin roots (Ji et al., 2012). Eq. (1) was used for measuring root area in each root diameter class.

$$Root\ Area = \sum_{i=1}^{n} \frac{\pi}{4} di^2 \qquad (1)$$

Where di is the average root diameter in class i.

RAR was measured by Eq. (2) in different soil depth.

$$\mathrm{RAR} = \sum_{i=1}^{n} \frac{Ari}{A} \qquad (2)$$

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

Root tensile Strength

Root tensile strength is a basic for evaluating root reinforcement (De Baets et al., 2008). For each selected plant species, after the RAR measurement, roots were randomly collected around each tree with each diameter class and depth (Genet et al., 2008, 2010; Ji et al., 2012), through excavation method (De Baets et al., 2008). Afterward all roots cut off and conserved in a plastic bag to preserve their moisture content (De Baets et al., 2008) and transfer to the laboratory in a refrigerated box (Bischetti et al., 2005). The roots were put in alcohol solution (15% ethanol) at a temperature of 4℃ to conserve them for several months after data collecting (Bischetti et al., 2009).

In laboratory, roots were washed and then cut in a specific length. The maximum root length in some researches is 0.1 m, and 0.2m (Docker and Hubble, 2008; Burylo et al., 2011). Zhang et al. (2012) consider 50 mm as the minimum root length and Comino and Marengo (2010) neglected root length less than50 mm due to the difficulty to place the roots on the tensile strength device.

In this study, a minimum root length of 5.5 cm to 15 cm were selected. Root tensile strength (Tr, MPa) tests were conducted in a laboratory with a Universal Testing Machine. Before testing, root diameter was measured in five points along the root length. The key point in the machine is the following: 1) constant strain rate of 10 mm/min, based on the other authors Bischetti et al. 2005; 2009; De Baets et al. 2008; Abdi et al. 2010a; Hudek et al. 2010; Burylo et al. 2011; and 2) the only specimens which broke in the middle of the root length would take into consideration, ensuring that the rupture is due to tensile force, not root structure or stress due to clamp (Vergani et al., 2012).

Tensile strength at rupture (Mpa) calculates by dividing the peak load (N) by the cross-sectional area of the roots (mm^2) estimated as the average of root diameters measured with a bark before traction in five points along root length by Eq. (3) (Zhang et al., 2012).

$$T_r = \frac{4F}{\pi\, d_i^2} \qquad (3)$$

Where, F is the maximum load at rupture (N), di, is the average root diameter along root length in five points.
Equation (4) showed that there is a power law correlation between$T_r$and root diameter (Gray and Sotir, 1996):

$$Tr = \alpha\, d^{-\beta} \qquad (4)$$

In this formula α is scale factor and β is a strength decay rate (Bischetti et al., 2005).

Data analysis

SPSS 20 statistical software was used to analyze gathered data. Cure regression was used to obtain mathematical function between RAR and soil depth, Tr and root diameter and TF and root diameter. The normality of the data was used by Shapiro-Wilk test and if the normality was violated, log transformation of the data was performed before the data analysis. Spearman correlation was used to correlate the relation between RAR and soil depth.

RESULTS

Root tensile strength

Table 1 showed results about root tensile strength data and the parameter values as in Eq. (4).

Table 1: Number of root samples, average of root diameter and tensile strength, percentage of successful measurement and the amount of α and β.

Species	Root number	Measurement success (%)	Root diameter (mm)	Tr (MPa)	α	β
Acacia mangium	168	67.7	0.9	44.11	29.825	0.5

The range of tensile strength varied between 214.36 MPa (for a root diameter of 0.26 mm) and 3.15 MPa (d=0. 45mm) with the mean value of 44.11 MPa (average value of d= 0.9mm). The percentage of correct failure that roots rupture in the middle of root length not near the jaws which is influenced by a clamping device was 67.7%, i.e. 126 of root specimen rupture in the middle of root length of 186 of the tested roots. Root tensile strength decreased with increasing root diameter. The figure 1 shows the relation between Tr (MPa) and d (mm).

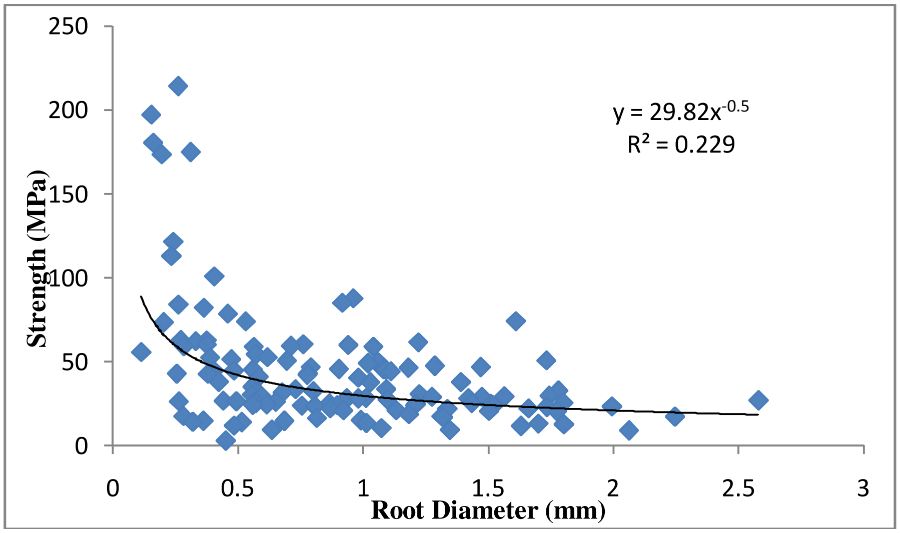

Figure 1: relationship between root tensile strength and root diameter

The fitting curve between tensile strength and root diameter also showed that there is a power law correlation between root tensile strength and root diameter with the highest R square (Operstein and Frydman, 2000; Mattia et al., 2005; Abdi et al., 2010a) and lowest standard error (Abdi et al. 2010a).

The results showed that the tensile breaking force (TBF) increased with increasing root diameter (Figure. 2), the best relationship between TBF and root diameter not only the highest R Square, but also the lowest standard error which is well described by a power curve. (Figure 2).

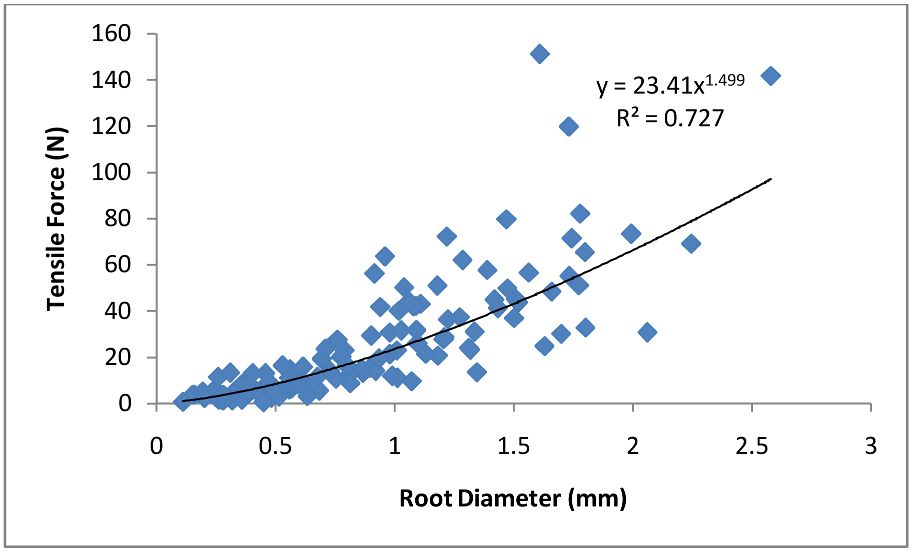

Figure 2: the relationship between tensile force (N) and root diameter (mm)

Root Area Ratio

There is a great variation in RAR regards to soil depth. RAR values regarding to soil depth increase until the second layer and again decrease, and this trend continues until the last soil layer (70cm). The lowest RAR values are recorded in the 70 cm of soil layer and the highest RAR values are located in the second soil layers. RAR values ranged between 2.09% at the first 10 cm of soil layer to 0.26% of the 70 cm soil layer depth. The lowest value of RAR is located at the 70 cm of soil depth by 0.26% and the highest RAR value was in the second soil depth by 6.71%, but the overall trend followed the reduction of RAR in relation to soil depth (Table 2). Number of roots and the amount of RAR showed in Table (3). According that the number of roots decreased by increasing root diameter, but the amount of RAR increased by increasing root diameter.

Table 2: Average number of roots and RAR distribution in soil depth (n= 4 replications)

Soil depth (cm)	Roots number	RAR (%)
10	6.75	2.09
20	2.15	6.71
30	1.65	4.05
40	1.35	6.30
50	0.9	2.33
60	1	3.23
70	0.35	0.26

Table 3: Average root number v.s. root diameter class and RAR (mm^2/m^2)

Root diameter classes (mm)	Roots number	RAR (mm^2/m^2)
0-1	4.82	13.51
1-2	3.11	78.39
2-5	1.28	176.62
5-10	0.61	382.99
>10	0.28	320.41

DISCUSSION

The result of RAR values is in agreement with the findings of Burylo et al. (2011). In contrast, the highest RAR values were found to be in the first soil layer in the research conducted by Comino and Marengo (2010) in three different shrubs in Northern Italy. The maximum RAR values for beech was in the fourth layer in downslope and in the third soil depth for upslope as indicated by Abdi et al. (2010b) Bischetti *et al.* (2005) stressed that the general trend of RAR value decreased with soil depth, but in most cases the highest RAR values are in the first 30 cm soil profile. In Burylo *et al.* (2011) research, RAR values significantly decreased with soil depth and the highest root distribution were in the upper 200 mm soil depth.

Root distribution in soil depth is one of the factors for analyzing the effect of vegetation on slope stability. This study indicates that, RAR values decreased with soil depth which is in agreement with the result of earlier authors such as (Abdi et al., 2010 a, b; Bischetti et al., 2005; Burylo et al., 2011). Furthermore study shows that the highest RAR values are located in the second soil depth as indicated by the other authors (Burylo et al., 2011), and third soil layers (Bischetti et al., 2005; Abdi et al., 2010b). The decline of RAR with soil depth is due to the reduction of nutrition and aeration in lower levels and presence of bedrock and compacted soil layers (Bischetti et al., 2005; Chiaradia et al., 2012).

The average number of roots decreased with increasing soil depth, and shows a more systemic trend when compared with root area ratio. Table 3, shows that root numbers decrease with increasing root diameter, but RAR values increase with increasing root diameter. Therefore RAR and root diameter have the same trend and implies that RAR values are more sensitive to root diameter than root numbers (Ji et al., 2012). Danjon et al. (2008) claimed that RAR is more sensitive to larger roots compare to thin roots, this result is in agreement by the present study.

Values of root tensile strength decrease with increasing root diameters as studied by many other authors and can be well described by power law equation (Mattia et al., 2005; Tosi, 2007; Abdi et al., 2010b; Burylo et al., 2011). In the power law equation, the parameters depend on the plant species and environmental conditions.

Bischetti et al., (2005) believed that for a specific species, the highest value of α and the lowest value of β, regarding the strength-diameter relationship, produce the highest tensile resistance against shallow landslide and this finding useful for selecting a species in order to erosion control ad slope stability.

For a landslide engineer, the changes of tensile strength as regards to root diameter is the main consideration in slope stability analyses (Stokes et al., 2009).

Empirical constant of tensile strength data in this study were compared with those studied on tree species in the laboratory on conserved roots around the world. The amount of α and β value for *Tamarix canariensis* were 31.74 and -0.89 respectively by De Baets et al. (2008). For *Betula laminifera* the amount of values were 79.4 and -0.63 by Genet et al. (2010). For *Salix purpurea*, which was studied by Bischetti et al. (2009), the parameters were 26.33 and -0.95 respectively. It is important to consider that these species are in different environmental conditions, therefore the difference in tensile strength is so obvious. As Nilaweera (1994) mentioned, the value of α is between 29.1 and 87.0 and for $\beta$the range is between -0.8 and -0.4, which is in agreement with this result.These differences imply that more studies should be conducted about the different species in different environmental conditions to gain more species model.

In the research were conducted by De Baets et al. (2008), they investigated the tensile strength of some of species similar to the species considered in the study conducted by Operstein and Frydman (2000); Mattia et al. (2005). Surprisingly, the results showed that the strength- diameter relationship was different between the same species in different habitats. De Bates et al., (2008) concluded that the differences in environmental conditions explain the differences in root strength. Schmidt et al. (2001) believed that The growth habits of trees are highly variables even whitin a single species growing in different environment.

Tensile resistance results conducted by Nilaweera and Nutalaya (1999) showed that *Diptrocarpus alatus* had the highest result ($TF = 54.1559\, d^{1.5533}$) followed by Hopea odorata ($TF = 68.3618\, d^{1.3072}$). These results can be compared with the result of the present study (both of the research conducted in rainforest) and showed that the root tensile resistance of *Acacia mangium* ($TF = 23.412\, d^{1.4997}$) was much less than species from Diptrocarpaceae family. Therefore, according to the results of De Baets et al. (2008); Mattia et al. (2005) andOperstein and Frydman (2000) showed that for the same species in different habitats, Tr-diameter results were different. Furthermore the results of Nilaweera and Nutalaya (1999) compare with the present study showed that for different species in the same habitats also the root tensile results are different.

Thus site-specific analysis and more experimental data are needed to investigate the spatial variability of root mechanical properties due to the variety of species and environment (Bischetti et al., 2005). Genet et al. (2005) believed that cellulose content decreased significantly with increasing root diameter in a linear correlation, strong roots are a result of more root cellulose content. On the other hand, environmental conditions affect root cellulose content (Genet et al., 2005; Hales et al., 2009).

The mean tensile strength of this study is 44.11 MPa which compared with other hardwood species, including Persian Ironwood 31.34 MPafor downhill and 25.20 for uphill (Abdi et al., 2010b), *Quercus robur* 32 MPa (Greenway, 1987), *Alnussubcor data*16.29 MPa (Naghdi et al., 2013). Therefore tensile strength is influenced by plant species and root diameter.

In conclusion, root systems of different species in different environments have different characteristic architectures and adaptability to the environment and thus show different mechanical properties. Therefore, further studies on different species in different environment are required to upgrade existing body of knowledge about root mechanical properties and selecting the species in slope stability analysis.

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