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Study of root distribution of *Macaranga tanarius* (L.) Müll. Arg. (Parasol leaf tree) on East-West highway slope, Malaysia

ABSTRACT

Vegetation influences the stability of slope by both hydrological events and mechanical reinforcement of the soil. The magnitude of such effects is subject to the root system growth, which in turn is a purpose of the genetic properties of the species and site appearances. In this study, we investigated the root distribution of *Macaranga tanarius* (L.) Müll. Arg. as a native species in Malaysia, with an aim to rise our knowledge on root area ratio distribution inside the soil. Concerning the estimation of root distribution within the soil, we assessed the root area ratio (the proportion between the area occupied by the roots in a slice area of soil) according to its depth for four samples in the rainforest. Results show that the root area ratio (RAR) declined with depth, and the higher RAR values were calculated in the higher layers. RAR values were between 0.950% and 18.477%. There is a plentiful diversity of root density in depth classes. Also, the result showed that about 50% of the roots are located in the first 10 cm layer, and about 87% of roots were in the fine root diameter (>2 mm). There is not a significant difference between RAR and soil depth. Spearman correlation showed no significant and negative correlation between RAR and depth. The maximum RAR percentage was in the first layer 0-10 cm (44.59%). Also, the results showed that the amount of RAR decreased with depth in fine roots (d<2mm), but RAR in thin roots (2<d<10mm) has an unexpected change. Also, the fine root number was much higher than the number of thin roots, but the RAR value in thin roots was much higher than of the fine roots.

Key words: root distribution, RAR, *Macaranga tanarius* (L.), slope stability

Introduction

Plants can significantly recover slope stability and avoid soil slippage in two ways, through hydrological mechanisms dropping pore water pressure (Gyssels et al., 2005) and through mechanical reinforcement of soil by roots (Nilaweera & Nutalaya, 1999; Burylo et al., 2011).

The most important factors of the root system leading soil fixation are root density, depth and tensile strength (Genet et al., 2008). The anchorage of roots and the enhancement of slope stability depends on the possessions of root systems such as the root distribution and tensile strength, root number, root diameter or rooting depth, root system architecture and pull out resistance (Wu et al., 1979; Nilaweera & Nutalaya, 1999; Duputy et al., 2005; Nicoll & Ray, 1996; Stokes & Guitard, 1997; Li et al., 2007; Sun et al., 2008).

It has been stated that there is a close relationship of root system resistance moment with the root number, as well as variations in the root angle and diameter (Sun et al., 2008). Root area ratio (RAR) has been used as an index of root density by many authors (De Baets et al., 2008; Abdi et al., 2010a, 2010b; Comino & Marengo, 2010; Burylo et al., 2011). Authors have reported earlier that reinforcement may be resulting from an upsurge in the RAR at the shear plane (Loades et al., 2010). The impact of tree roots on the slope stability can be reflected in terms of their strength and distribution within the soil. These two elements control the major stabilization mechanisms such as soil reinforcement, buttressing, soil arching and root anchoring (Nilaweera & Nutalaya, 1999).

Many authors suggested to use RAR as a part of slope stability characterization in their research. Abdi et al. (2010a) analyzed the RAR in ironwood (*Parrotia persica*) and found that root density normally decreases with depth according to an exponential function. Maximum RAR values were located within the first 0.1 m layer. Root distribution in three hardwood species was analyzed by Abdi et al. (2010b). The results show that the RAR declined with depth and the maximum RAR value were detected in the higher layers.

Bischetti et al. (2009) indicated that there is a decrease trend in RAR with depth, with the exception of the first two or three layers, where it generally increases in some of forest species in the Italian Alps. Burylo et al. (2011), show a significant difference between RAR and depth as well as decreasing number of roots with depth. Type of species (size, order) and site description such as climate, land use management, type of soil, related vegetation societies, spatial variability of vegetation belongings (density, age), etc., also influence the RAR (Genet et al., 2008; Abdi et al., 2010b).

The main purpose of this research was to get the information about *Macaranga* roots distribution in Malaysia, especially on the East-West highway. The main objectives were: (1) Investigation of differences in root area ratio (RAR) in 50 cm of soil depth (upper depth and lower depth); and (2) Investigation of root distribution in different soil depth in the study area.

Materials and Methods

Site details

The study area is located on the East-West highway, which is one of the major roads in the Northern part of Peninsular Malaysia between N5°27′32.0″ E101°07′42.3″ to N5°42′11.15″ E101°49′54.74″. The length of the highway is about 119 km and links two districts namely Gerik in Perak and Jeli in Kelantan. The climate of the study area is humid and the annual mean precipitation is about 1957.5 mm. The altitude is 283 meter above the sea. The type of soil is sandy, clay and loam, and the lithology consist of schist, phyllite, slate and limestone.

Macaranga (mahang) is a genus which is extensively dispersed in Malaysia. The populations are generally found in the village-thickets, wastelands, at the edge of forest assets or in marshy forests. In Malaysia alone, there are 27 species of *Macaranga* from the whole of 280 species worldwide. *Macaranga* genus is soft-wooded, fast growing, evergreen trees attainment a height of 20 m (Zakaria et al., 2008).

Macaranga tanarius (L.) Müll. Arg. is natural in Malaysia, planted for a diversity of uses. This small tree grows as a decorative tree in landscaping and for projects of reforestation in warm tropical regions around the world. The following uses of *M. tanarius* are listed by World Agroforestry Centre (2002). Average annual rainfalls in the areas that *Macaranga* grows varies from 40 to over 80 (100 over 200 cm) with average temperatures ranging from 10 to over 20°C in January to over 30°C in July (Hammond, 1986). In these regions, *M. tanarius* grows up to an elevation of 1,500 m (4,921 ft) and is mutual in secondary forests, especially in logging areas, and also is found in thickets, brushwood, village groves, and beach vegetation (World Agroforestry Centre, 2002). *M. tanarius* grows in a diversity of soil types including loam, clay as well as in the lowlands (World Agroforestry Centre, 2002).

Sampling method, collecting and analyzing the data

RAR is specified as the fraction of the soil cross-sectional area occupied by roots in each unit area (Gray & Leiser 1982; Abdi et al., 2010a). RAR was studied by using a vertical trench profile wall method (Bischetti et al., 2009; Schwarz et al., 2012) and the values were measured by recording the size and location of all roots crossed by vertical profile walls (Abdi et al., 2010b).

In this study, trenching method was used to analyze root distribution. First four trees, which had average 13 cm in Diameter Breast Height (DBH) were selected. The distance between samples was about 2 m. The soil condition in the samples was the same at each tree. One trench was dug at a distance of 25 cm from the stem and the profiles were 50 cm long × 50 cm depth (Ji et al., 2012) (Figure 1). Layers of 10 cm thick were marked on the vertical profile walls by counting roots and measuring the mean root diameter with a vernier caliper (Hudek et al., 2010). Root numbers were counted and divided into different diameter classes i.e., 0-1, 1-2, 2-5, 5-10 mm and >10 mm, according to the equal organization in the study of Ji et al. (2012). Roots fitting in the two first ranges were classified as fine roots, the two second groups represented thin roots. Then, in each depth the contribution of RAR in percentage was calculated. The RAR distribution with soil depth for all sized roots was considered.

RESEARCH ARTICLE

The area that was occupied by roots in each layer was determined using the following equation:

$$\text{Root area} = \sum_{i=1}^{n}\left(\frac{\pi}{4}.d_i^{\,2}\right)$$

where d_i is the diameter of the i-th root in millimeters (Abdi et al., 2010b). The area of roots in every layer was divided by the whole area of the soil layer (500 * 100 mm for every layer), and RARs were found.

For checking the normality of the data, a Kolmogorov–Smirnov test was used and where the assumption of violation is recognized, the test of homogeneity of variances was used for investigating the normality of the data. For investigation of the mathematical function that exists between RAR and depth, curve estimation was used. Then, ANOVA employ to match RAR values between different soil depths. For these analyses, the software SPSS 20, and excel were used.

Results

Root area ratio (RAR)

There is an unlimited variation in the quantity of RAR and depth. RAR values normally decreased with depth in the fine roots (d < 2 mm). Also, in the root diameter 5-10 mm, the maximum RAR is in the last layer of 50 cm. RAR vertical profiles showed different trends with esteems to diameter classes. A RAR of fine roots (0 < d < 1 mm and 1 < d < 2 mm) declined with soil depth. On the opposing, RAR of thin roots (2 < d < 5 mm and 5 < d < 10 mm) first dropping with the depth up to a 20 cm (in the diameter 2 < d < 5 mm) and after that increasing, but in the 5 < d < 10 mm the RAR decreasing up to the depth 30 cm and after that increasing again. Influence of thin roots (2 < d < 10 mm) is much larger than fine roots (d < 2 mm) (Table 1). Matching between the mean RAR of different diameter classes, 0-1 mm and 5-10 mm diameter classes had individually the lowest and the highest values (4.05, 42.23) (Table 1).

ANOVA is carried out on RAR within each root diameter class, in order to investigate the differences with regards to diameter classes. For all root diameter classes, there is not a significant difference between RAR and root diameters ($F = 2.660$, $p > 0.05$, ANOVA). Figure 2 shows the RAR (%) in different root diameter in the samples. Also, the distribution number of roots in different soil depth and diameter classes showed that the number of roots is more in fine roots than in thin roots (Figure 3). Figure 4 shows that the RAR percentage is much more in the thin roots than in fine roots, and then thin roots have more influence on RAR.

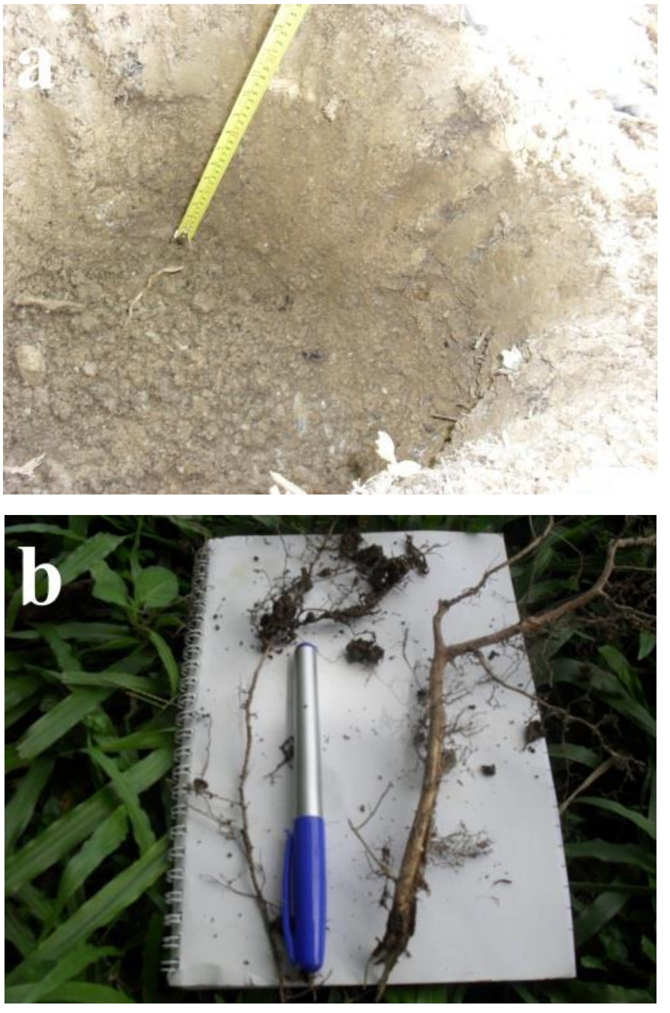

Figure 1. *Root distribution. a - location of roots, b - sample of Macaranga roots.*

Distribution of RAR with regards to soil depth

The relationship between RAR and soil depth analyzed by ANOVA, and the results show that there is not significant differences between RAR and soil depth ($P > 0.05$). The percentage of RAR in different soil depth regarding to samples is presented in Figure 5. The largest RAR percentage was in the first layer (44.59) (Figure 6).

Also, the RAR values in depth was tested by some mathematical functions, where the exponential distribution obtained not only the highest R square ($p < 0.05$), but also a low standard error of estimation (Table 2; Figure 7).

RESEARCH ARTICLE

Table 1: *Percentage of RAR at each depth in different root classes (N=4 replications)*

Depth (cm)	0-1 (mm)	1-2 (mm)	2-5 (mm)	5-10 (mm)	>10 (mm)
10	2.17	6.75	5.75	15.84	14.08
20	0.95	2.53	2.30	2.64	0
30	0.45	2.01	8.62	0	0
40	0.31	0.95	6.32	5.28	0
50	0.16	0.95	3.45	18.48	0
Total	4.05	13.19	26.44	42.23	14.08

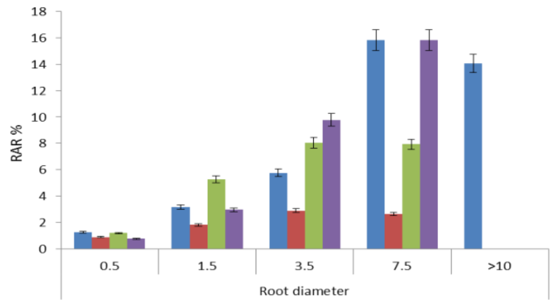

Figure 2. *Percentage of RAR of different diameter classes (mm).*

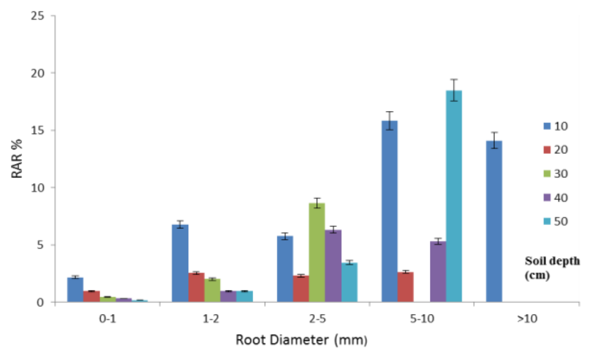

Figure 4. *RAR percentage in different root diameter (mm).*

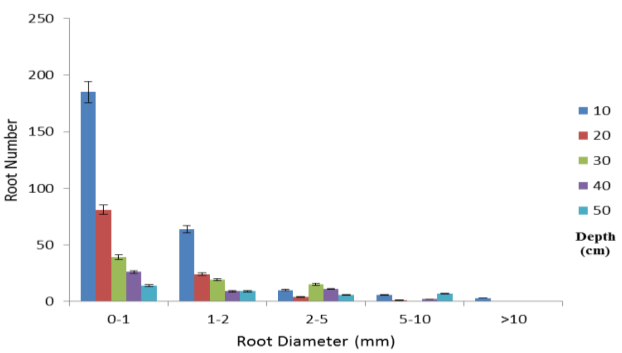

Figure 3. *The number of roots in diameter classes in different soil depth.*

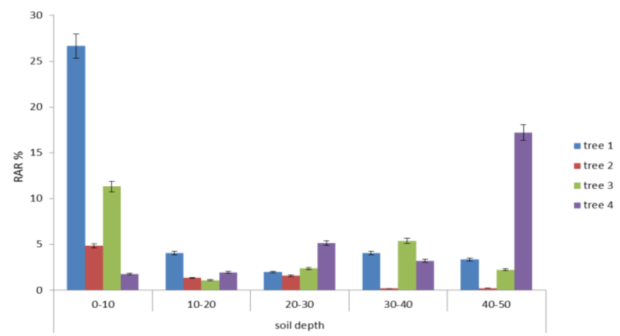

Figure 5. *The percentage of RAR in different soil depth (cm).*

Table 2. *Model summery for mathematical functions were tested to derive the relationship between RAR and depth.*

Model	R square	Adjusted R square	Std. error of the estimation
Linear	0.042	-0.006	2170.84
Logarithmic	0.101	0.051	2108.007
Inverse	0.160	0.114	2037.583
Quadratic	0.236	0.146	1999.669
Cubic	0.265	0.128	2021.570
Compound	0.070	0.018	1.185
Power	0.106	0.056	1.162
S	0.138	0.090	1.141
Exponential	0.070	0.018	1.185

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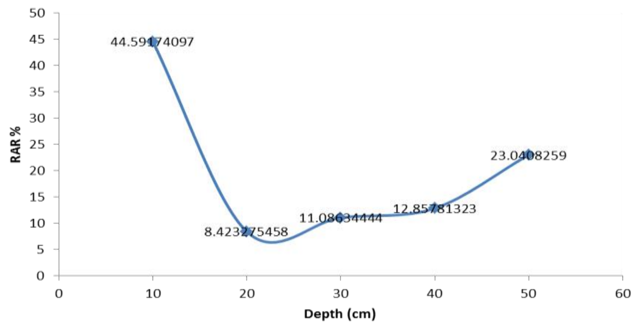

Figure 6. Percentage *RAR in soil depth.*

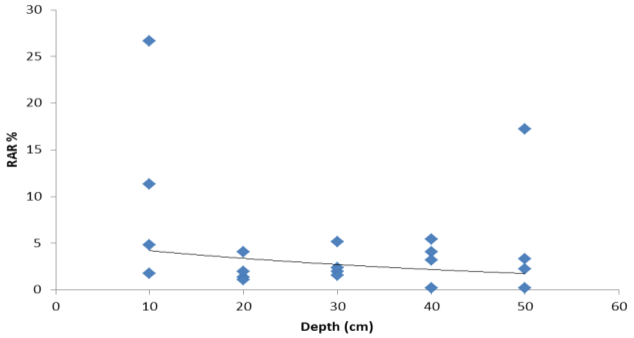

Figure 7. *Exponential regression curve of RAR (% vs. soil depth).*

Discussion

The effect of tree roots on the stability of a slope can be considered in terms of their strength and distribution within the soil (Nilaweera & Nutalaya, 1999). Root area ratio measurements showed a high variability within depth, but there is not a significant difference between RAR and depth, in contrast to other researches (Burylo et al., 2011). RAR values decreased in depth as the other authors mentioned (Abdi et al., 2010a, 2010b; De Baets et al., 2008; Bischetti et al., 2009; Burylo et al., 2011). RAR decreases with depth due to decrease in nutrients and aeration, and also the presence of more compacted soil layers and bedrock (Bischetti et al., 2005). The decline of RAR with depth exposed as exponential function is in agreement with other authors (Abdi et al., 2010).

RAR in the fine roots shows the decrease with depth. These results are in agreement with Ji et al. (2012). They mention that in the fine roots there is decrease with depth (as our results), but in the thin roots there is great variability that at the first there is a decrease in the RAR and after that there is increasing. Chiaradia et al. (2012) mentioned that, roots in fact, tend to grow near the surface because of the richness of nutrients, water and gases. Nonetheless, plant roots can run very long in depth (meters below soil surface) if the above factors are limited in shallower layers, but their density dramatically decreases with depth. Di Iorio et al. (2005) also stated that the larger cross-sectional area of the roots can only be due to the greater mechanical stresses. These results indicate the presence of some stresses in the lower layers that influence the root diameters and root numbers and it is a kind of adaptability in response to the environment.

The number of roots also decreased with depth as the other authors reported (Abdi et al., 2010b; Schwarz et al., 2012; Abernethy & Rutherfurd, 2001). The number of fine roots (d < 2 mm) is higher than the number of thin roots (2 < d < 10 mm), but the values of RAR are much higher in the thin roots (Table 1). This was also stated by Ji et al. (2012) in their research, and they concluded that RAR is more sensitive to the root diameter than to the root number (Ji et al., 2012).

Some authors found significant differences between RAR and soil depth (Ji et al., 2012; Abdi et al., 2010b), but this study showed that there is no significant differences. The RAR values are strongly influenced by both genetics and local soil and climate characteristics (Bischetti et al., 2005). Species, soil type and site conditions have an effect on root systems (Stokes et al., 2008). When RAR and root density in general, are used to estimate the root contribution to stability, then the use of average values should be avoided because they can lead to a dramatic overestimation of the additional cohesion at the sliding surface (Bischetti et al., 2009).

This research indicated that the RAR values are higher compared to previous reports. For example, the maximum RAR value in Abdi et al. (2010b) was 6.6444%, and also in Bischetti et al. (2008) it was 0.35%, but in this research the maximum of RAR value is about 18%. Also, Abernethy & Rutherfurd (2001) mentioned that soil shear strength increases linearly with increasing the root mass, and root reinforcement is a function of root distribution within the soil.

Desirable plant characteristics for slope stability as mentioned by Stocks et al. (2008), such as ready propagation from cuttings and root suckers, also have been seen in the study area and also in *Macaranga tanarius* as an investigated plant in the area. Therefore, the results showed that this species is suitable for slope stability functions.

RESEARCH ARTICLE

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