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ROOT NUTRIENT CONCENTRATIONS IN TEAK (*TECTONA GRANDIS* L.F.) PLANTATIONS AS INFLUENCED BY FERTILIZATION AND AGE

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ABSTRACT

Nutrient concentrations in teak roots as a result of fertilizer application were investigated in Peninsular Malaysia. Plant tissues are generally thought to exhibit pronounced effects of fertilizer and age, especially in tree roots. Numerous studies show that fertilization is most effective when trees are not water stressed. Present study revealed that almost all nutrients concentrations in roots of 1 and 2-year-old plants showed synergistic relationship with fertilizer additions. Nitrogen concentration in fertilized plants was 30%, P 16%, and Ca 5% higher than in unfertilized. Nitrogen, P, K, Ca, Mg, Mn and Zn were 183%, 200, 84, 241, 200, 59 and 42% higher, respectively in fine roots than in coarse roots. Results revealed that nutrient concentration decreased with increase in age and size. Highest nutrients concentrations were in roots of 1-year-old plants with >2.0mm diameter and decreased as tree advanced in age and diameter. Teak grows on a variety of geological formations; soil with pH 4.3 to 5.2, adequate porosity and drainage are the best soils for teak growth.

Keywords: Age, fertilizer application, nutrient concentrations, roots, soil/fertilization interactions, teak.

INTRODUCTION

The root system in a higher plant is an essential part of the plant body. It not only provides anchorage to the plant in its substrate but also takes up the transport of water and nutrients to the aboveground parts. Roots are also a site of synthesis of many metabolites that are essential for the plant as a whole (Dubrovsky *et al*., 2006). In addition, some root tissues serve as store house for assimilates and nutrients. Nutrient concentrations in the roots are controlled by the nutrient demand in different tissues, the availability and supply of nutrients in the soil. In addition, nutrient poor and acidic soil conditions may cause a high resource investment into the rhizosphere via excretion of root exudates that strongly influences root performance and nutrient acquisition, and which is able to create and maintain a favourable micro-environment for root growth (Tjoelker *et al*., 2005; Roumet *et al*., 2006). The overwhelming majority of studies conducted in forest nutrition have only documented above-ground dynamics, often due to the difficulty of sampling and estimating coarse and fine root biomass (Santantonio *et al*., 1977, Kepeluck and Van Lear, 1995; Adegbidi *et al*., 2005). Teak (*Tectona grandis*) is one of the highly sought after timbers of the world. It is a happy blend of beauty, strength and durability.

Root may comprise 10 to 30 percent of the total nutrient stores of the forest trees (Rodin and Bazilevich, 1967). However, information on the influence of fertilization and stand age on the storage of nutrients in roots is scarce. Earlier studies had suggested that roots respond to fertilization and may be more responsive to fertility changes than foliage (Dighton and Harrison, 1983; Adams *et al*., 1987; Helmisaari, 1991; James and Richards, 2005). Low nutrient supply also limits overall growth of forest trees (Judd *et al*., 1996; O'Connell *et al*., 2004).

Forest soils have marked physicochemical heterogeneity in pH, water content, hardiness and nutrient concentrations (Watt *et al*., 2006). Roots continuously adapt to the temporal and spatial fluctuations of their growth medium (Puhe, 2003). It is the area of rhizosphere biology where our understanding of roots is particularly limited. A better understanding of the nutrient dynamics of roots may improve the understanding of stand nutrient and help in developing techniques for detecting nutrient deficiencies of forest stands. This paper attempts to explore how teak roots absorb and store nutrients in pot and field conditions in response to fertilizer application and stand age.

MATERIALS AND METHODS

This study was conducted in the Forest Research Institute Malaysia (FRIM) substation at Mata Ayer Perlis. The soil samples and destructive sampling of teak roots were taken from plots of 40X50m^2 demarcated in different aged i.e.10 and 18- year -old plantations. The choice of the plots was based on uniform planting distance (4x4 m) and soil type.

The Site

The experimental site is situated at the Forest Research Institute Malaysia (FRIM) sub-station, 17 milestone, Jalan Padang Besaar, Mata Ayer, Perlis. It is 8090 ha in area of which 2020 ha has been allocated to Forest Department for teak afforestation programmes. The site is located at an elevation of 33 m above from sea level. It falls within latitude 6^o 40$^/$ North and Longitude 100^o 15$^/$ East. Characteristics of soil are given in Table 7 and chemical properties of soil under different aged teak plantation have been given in Table 8.

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Table 1. Level of nutrients (g/plant) applied to teak plants in pot trial.

Commercial Fertilizer	Elements	Level 1	Level 2	Level 3
Ammonium sulphate (21%N)	N	0.20 (150 kg/ha)	0.75 (564 kg/ha)	0.90 (677 kg/ha)
Triple Superphosphate (48%P_2O_5)	P_2O_5	0.20 (150 kg/ha)	0.40 (300 kg/ha)	0.60 (451kg/ha)
Muriate of Potash (60%K_2O)	K_2O	0.10 (75 kg/ha)	0.20 (150 kg/ha)	

Table 2. Level of nutrients (g / plant) applied to teak plants in field conditions.

Commercial Fertilizer	Elements	Level 1	Level 2	Level 3
Ammonium sulphate (21%N)	N	0 (0 kg/ha)	160 (100 kg/ha)	320 (200 kg/ha)
Triple Superphosphate (48%P_2O_5)	P_2O_5	0 (0 kg/ha)	240 (150 kg/ha)	480 (300kg/ha)
Muriate of Potash (60%K_2O)	K_2O		320 (200 kg/ha)	320 (200 kg/ha)

Table 3. Main effect of age, fertilizer and diameter on the nutrient concentrations in roots of 1 and 2-year-old teak trees.

	N	P	K	Ca	Mg	Mn	Zn
Treatment							
C	0.30b	0.06a	1.52b	0.40b	0.22a	104.2a	74.6b
F	0.39a	0.07a	1.48a	0.42a	0.20a	120.3a	86.3a
LSD	0.03	0.02	0.11	0.11	0.08	20.7	30.3
Age (yr)							
1	0.36a	0.08a	1.45a	0.33b	0.28a	130a	106.3a
2	0.32a	0.06b	1.28b	0.50a	0.14b	94.6b	54.2b
LSD	0.06	0.01	0.15	0.06	0.04	10.1	8.5
Diameter							
<2mm	0.34a	0.06a	1.42a	0.41a	0.21a	112.0a	80.1a
2-10mm	0.20b	0.03b	0.93b	0.28b	0.12b	87.9b	72.8b
>10mm	0.12c	0.02b	0.77c	0.12c	0.07c	70.3c	56.1c
LSD	0.02	0.01	0.09	0.03	0.02	57.	4.5

Note: Values sharing same letter are not significant. C = Control; F = Fertilized; LSD = Least significant difference.

The study consisted of two experiments i.e. pot and field experiments.

In the pot experiment, soil samples belonging to Penambang series and sand in the ratio of 3:1 was used as potting medium. Soil samples were collected from compartment 17 of the above mentioned site. Soil from the top 30 cm was collected for the present experiment. The soil and sand were mixed thoroughly with an automated mixer. The soil sand mix was then sieved to remove stones and unwanted materials before filling 4 kg of the mixture into polythene bags each measuring 10cm x 4cm diameter. *Tectona grandis* seedlings used in this study were raised from seeds germinated in specially made seedbeds with adequate drainage and under 50% shade (using linen net). The seedlings were transplanted into polybags at four-leaf stage. Levels of nutrients applied in greenhouse are given in Table 1.

The experiment was a 3x3x2 factorial design arranged in Randomized Complete Block (RCB) with each treatment replicated six times. There were altogether 114 polybags involving 18 treatment combinations including the control ($N_0P_0K_0$). Nitrogen (as N), phosphorus (as P_2O_5) were applied at three levels and potassium (as K_2O) at two levels. The fertilizer applied were ammonium sulphate, triple superphosphate and muriate of potash. The study was conducted under a fiberglass shading for a period of 12 months.

Table 4. Effect of fertilizer application on nutrient concentrations in roots of 1 and 2-year-old teak trees.

Age		Root diameter	Nutrient Concentration						
			%				Ppm		
			N	P	K	Ca	Mg	Mn	Zn
1	C	<2.0 mm	0.32b	0.07b	1.3b	0.29b	0.32a	124b	104b
	F		0.43a	0.09a	1.6a	0.37a	0.24b	136a	108a
	C	2-10 mm	0.19b	0.04b	1.12b	0.22b	0.16a	98b	92b
	F		0.22a	0.06a	1.16a	0.27a	0.13b	109a	102a
	C	>10 mm	0.11b	0.02b	0.78b	0.12b	0.09a	88b	76b
	F		0.13a	0.03a	0.82a	0.17a	0.07b	93a	83a
2	C	<2.0 mm	0.29b	0.05b	1.2b	0.42b	0.17a	84b	44b
	F		0.34a	0.06a	1.42a	0.55a	0.11b	104a	64a
	C	2-10 mm	0.18b	0.03a	0.63b	0.32b	0.08b	80a	44b
	F		0.21a	0.02b	0.79a	0.38a	0.11a	64b	52a
	C	<10.0 mm	0.11b	0.01b	0.72b	0.09b	0.05b	56a	36a
	F		0.13a	0.02a	0.76a	0.11a	0.06a	44b	29b

Note: C = Control; F= Fertilized. Values sharing same letter are not significant at 5% level of probability.

Table 5. Nutrient concentrations in roots of unfertilized teak trees.

Age (yr)	N	P	K	Ca	Mg	Mn	Zn
1	0.20a	0.04a	1.08a	0.33a	0.15a	104.0a	91.0a
2	0.19a	0.03ab	0.86b	0.23b	0.16a	74.0b	48.2b
10	0.16b	0.02ab	0.50c	0.22b	0.09ab	41.6c	21.8c
18	0.16b	0.01b	0.39c	0.17b	0.06b	20.7d	20.4c
LSD	0.01	0.01	0.04	0.01	0.08	2.67	2.42

Note: values with same letter are not significant. LSD: Least significant differences.

Table 6. Main effect of diameter on the nutrient concentrations in roots of unfertilized teak trees.

Diameter (mm)	N	P	K	Ca	Mg	Mn	Zn
<2 mm	0.28a	0.04a	0.98a	0.38a	0.16a	72.8a	52.8a
2-10 mm	0.16b	0.02b	0.63b	0.21b	0.13a	61.0a	49.7a
>10 mm	0.09c	0.01c	0.52b	0.12c	0.05b	46.5a	33.5a
LSD	0.02	0.01	0.04	0.05	0.07	2.31	2.10

Note: Values with same letter are not significant. LSD: Least significant difference

The fertilizer levels were chosen on the basis of the recommendations of a preliminary study conducted by Sundralingam (1982) on teak in Malaysia. The treatments were applied randomly in all possible combinations and permutations.

Field trials

Field experiment was designed at FRIM sub station, Mata Ayer, Perlis. Soils of this area consists of principal rocks like limestones, silt stones, granites, shales, and sandstones (Amir, 1982). Some alluvial soils derived from weathering of these rocks are also found deposited by Sg. Chuchoh that drains the whole reserve. The precipitation as recorded by the Mata Ayer Metrological Station indicated that a distinct drought period is experienced from month of December to March with a monthly rainfall of less than 80 mm recorded for the particular period. Generally the site is comparably dry with an average monthly precipitation of 136 mm.

The experimental design was a randomized complete block (RCBD) with nine treatments and four replications. Four month old uniform size seedlings were transplanted to the field. The spacing between plants was 4x4 m. Dosage of fertilizers applied and treatment combinations are given in Table 2.

Tissue sampling

Roots of six 1-year-old plants were obtained by tearing the polybag and separating them carefully from the adhering soil a total of six, two and two trees were sampled from the 2, 10 and 18 years-old stands. For root sampling a circle with a radius of 1 or 2 meter from the tree stumps was marked around the leaf drop area. A wedge shaped portion representing 1/16 of the total area of the circle was then demarcated as the sampling zone. This zone was further divided into 6 individual compartments.

The zone was divided into four horizontal sections, with a side length of 120 cm for all of these sections. Each section was further sub-divided into three vertical sections each of 30 cm, down to a depth of 90 cm. Beginning from the surface, roots within each soil compartment were obtained by excavating the volume of the soil and picking out all served living roots. Most of the soil adhering to the roots was removed and the roots were placed in linen bag for further laboratory treatment. The excavated roots were divided into the following classes according to their diameter size: <2.0 mm, 2-10 mm and >10.0 mm. Persson (1983), Vogt *et al*. (1983) and Abod (1988) classified roots of less than 2.0 mm diameter as fine and greater than 2.0 mm as coarse roots. The roots were washed with tap water immediately after excavation. Roots with >20 mm diameter were then separated into bark and woody matter. All root samples were brought to the University of Putra Malaysia for analysis. All samples were dried at 70°C for 48 h and their dry weight recorded.

The samples were digested in H_2SO_4 and H_2O_2 in the presence of selenium. Nitrogen and P were determined on the Autoanalyser while K, Ca, Mg, Zn and Mn were determined on an Atomic Absorption Spectrophotometer.

Soil samples were also collected from the 1-year-old seedlings and 2-year-old trees, one year after fertilization. Samples for the 2, 10 and 18-year-old teak plantations were taken at two depths i.e., 0-30 cm and 30-60 cm. the samples were collected by auguring randomly at four points in the plot and composting them into one. A total of 24 soil samples (six from each age class) were analyzed.

The results were analyzed according to the effects of the treatments, age and diameter classes on nutrition concentrations in the roots by employing an analysis of variance. Furthermore, the Duncan's New Multiple Range Test was used to compare the mean values between nutrient concentrations and show significant differences between them. The power of the tests of significance was presented by calculating the least significant difference between averages.

RESULTS AND DISCUSSION

In the current study, there is pronounced effect of

Table 7. Characteristics of Penambang series soils at Mata Ayer, Perlis.

Soil Series	Parent material	Pedological features
Penambang	Alluvial deposits	Deep, sandy clay loam soils; friable to slightly firm; weak to slightly strong, fine to medium to coarse sub angular blocky, yellowish brown.

Table 8. Soil properties under different aged teak plantations growing in Mata Ayer Forest Reserve, Perlis.

Age (year)	Soil properties				
	pH	Org. C (%)	Total N (%)	Extract-able P (ppm)	Soluble K (%)
a) Soil Depth 0-30 cm					
1	4.3c	1.22b	0.12a	5.12a	0.24a
2	5.2a	1.42a	0.11ab	3.53b	0.18b
10	4.9b	1.40a	0.08c	2.22c	0.11c
18	4.9b	1.41a	0.09bc	1.95d	0.22a
LSD	0.03	0.02	0.02	0.09	0.2
b) Soil Depth 30-60 cm					
2	5.1a	1.37b	0.09a	2.55a	0.16a
10	4.5a	1.39a	0.07a	1.75b	0.10b
18	4.6a	1.39a	0.08a	1.70c	0.19a
LSD	0.6	0.02	0.02	0.02	0.04

Note: LSD: Least significant difference.Values with same letter are not significant at 5% level.

fertilizer application on some nutrient concentrations (Table 3). The results revealed that N concentration is 34% more in fertilized 1-year-old tree in fine roots, 15% in 2-10mm roots and 18% in coarse roots. P exhibited similar trend with 28% more in fertilized fine roots, 50% in both 2-10 mm and coarse roots. All other nutrients also exhibited similar trend except Mg which is high in unfertilized roots of all diameter classes. In 2-year-old fertilized trees N concentration reduced from 0.43% to 0.34% in fine roots, 0.22% to 0.21% in 2 -10 mm whereas there is no change in concentrations of coarse roots (Table 4). P concentration reduced from 0.09% to 0.06 to 0.03 and in fine, 2-10 mm and coarse roots, respectively. All other nutrients also followed similar trend in response to fertilizer and diameter classes (Table 4).

A significant reduction in nutrient concentrations was observed as tree advanced in age. Nitrogen concentration is maximum (0.20%) in 1-year-old plant and minimum (0.16%) in 10 as well as in 18-year-old trees. Table 5 also showed 25% reduction in N concentration in 18-year-old tree compared to 1-year-old. Phosphorus, K, Ca, Mg, Mn and Mn also exhibited marked reduction in nutrient concentrations. However, the reduction is not significant in 10 and 18-year-old trees in case of K, Ca and Zn (Table 5).

In general, fine roots are considered to be the rich in nutrient concentration. The presented study also revealed that maximum nutrient concentrations were found in fine roots i.e. N ranges from 0.28% in fine roots to 0.09% in 0.09% in coarse roots (Table 6). The diameter classes were found to have a remarkable reduction in P (300%), K (88%), Ca (216%), Mg (220%), Mn (56%) and Zn (64%) in coarse roots as compared to fine roots (Table 6). The level of nutrient concentrations in different sizes of roots studied for all the elements can be summarized as 2mm > 2-10mm > 10 mm diameter. Except for P, the differences between the root sizes for all the elements are statistically significant. The fine roots (<2mm) recorded significantly higher concentrations of nutrients compared to the 2-10 mm and >10mm sizes; there was no significance between the latter two sizes.

There were very few differences in soil properties in different aged tree plantations. In 0-30 cm soil depth, pH ranged from 4.9 to 5.2 and organic carbon ranged from 1.40 to 1.42 with no statistically significant difference. Total N, extractable P and soluble K were found to be significantly different in all 2, 10 and 18-year-old plantations.

In 30-60 cm depth, pH ranged from 4.5 to 5.1, total N ranged from 0.07to 0.09% having no significant difference in all age (Table 8). However, organic carbon, extractable P and soluble K exhibited inconsistent trend in all the three age classes of teak plantations. The soil at the study site consist mainly of alluvial, lateritic and shale derivatives with some degree of limestone. The trees were only selected from the alluvial soils of Penambang Series, belonging to T2 terrace formation. The soil is deep, yellow brown in colour with sandy clay loam texture. The general characteristics of the study site are as presented in Table 7. The chemical properties of soil samples are as given in Table 8.

Teak grows on a variety of geological formations but quality of growth depends on the depth, structure, porosity, drainage and moisture-holding capacity of the soil. The pedological features of Penambang Soil series as described in Table 7 were found to be suitable for growth of teak. As the soils are sandy clay loam, they have good moisture retention ability and aeration. Soil pH ranged from 4.3 to 5.2 (Table 8) and the nutrients were higher in the upper than the lower soil horizons. Mean total N and available P concentrations were relatively low while K concentration was high. All nutrients analyzed, in general, decreased significantly with plantation age.

The results of the present study revealed that fertilizer, age and root size act additively in influencing the concentrations of nutrients in teak roots. Fertilized plants consistently recorded higher levels of nutrients. Small diameter roots however, always contain higher nutrient concentration compared to large sized roots. The nutrient concentrations also act inversely to the age of the plant i.e., from 1 to 18 years studied.

The increase in nutrient concentration in fertilized plants may be due to the increased rate of mineralization and other aeration-dependent soil processes. As fertilization affects many of the soil properties (Jacobsson and Nohrstedt, 1993), causing changes in competition for light, water and nutrients. In addition, fine root production and nutrient assimilation has also been documented (Nambiar, 1987; Persson *et al.*, 1995; Sikstrom, 2005). Similar findings have also been recorded by Graciano *et al.* (2005) in *Eucalyptus grandis* and Saarsalmi and Tamminen (2005) in Norway spruce stands. Increase in nutrients not only reflects site redistribution of the original fertilizer material but also treatment effects on root exploitation and nutrient uptake from deeper soil horizons (McCarthy and Stone, 1991; Lucash *et al.*, 2005). It may also be due to immobilization within roots of available nutrients in the soil solution. Increase in root N and P concentrations suggest that conditions were more favorable for increased translocation from shoot and/or nutrient uptake from the soil. According to Adam *et al.* (1987) root systems are often more developed under low moisture conditions and may be able to utilize added nutrient more readily. This ability could be especially important for acquisition of a relatively immobile nutrient such as phosphorus. Similar trends of increases in nutrient accumulation resulting from fertilizer additions had also been reported for radiata pine (Turner and Lambert, 1988), slash pine (Harding and Jokela, 1994), loblolly pine (Lucash *et al*., 2005) and for poplar and alnus (Sayyad *et al*., 2006).

The nutrient concentrations in teak roots were in agreement to earlier studies on teak (Hase and Foelster, 1983; Negi *et al*., 1990; Negi *et al*., 1995). Nutrient concentrations were found to decrease with increase in root diameter (Table 3). The highest nutrient concentrations were found in the various ages of fine roots. The gradual decrease in nutrient concentrations with increase in root diameter is not unusual. Similar patterns of nutrient reduction have also been reported in other tree species. Sollins *et al*. (1980), Fogel and Hunt (1983) and Sands and Mulligan (1990) reported smaller nutrient (N, P, K, Ca, Mg) concentrations in Douglas-fir roots of > 5mm diameter than in roots < 5 mm diameter. Vogt *et al*. (1987) also found a decrease in nutrient concentration with a decrease in root diameter of *Abies amabiis* while Mier *et al*. (1985) reported a decline in N and P concentrations with increase in root age and coarseness. According to Puhe (2003) root systems exposed to increased nitrogen and increased acidity exhibit a tendency towards a decline in fine root growth.

The present study showed that roots with <2mm diameter recorded higher nutrient concentrations with a gradual decrease in nutrient concentrations with increase in root diameter may indicate a decline in the rate of uptake of nutrients per unit length, distance from the root tip. This reduction in nutrient concentration may be due also to high mobility of nutrients (N, P and K). According to Mier *et al*. (1985) internal redistribution within below ground components may provide a major portion of fine root N and P requirements. Another important factor contributing to the nutrient uptake is the high rate of fine root turn over (Poszwa *et al*., 2002). In contrast to coarse and woody roots, fine roots may turn over after only a few weeks (Vogt and Bloomfield, 1990). In general, fine roots contribute more nutrients to organic matter accumulation because of their higher annual litter inputs and their faster decay rates. In addition, fine root mortality will contribute to a spatially homogenous distribution of organic matter compared to the other root diameter classes (Konopka *et al*., 2006).

Soil pH decreased with depth of soil and plantation age (Table 8). Observations in the present study were similar to Beets *et al*. (2004) who found a decrease in soil pH with depth of soil and suggested that leaching losses of cations from more acidic soils could be substantial. Soil N and P also decreased with increase in age of the plantations. This might be attributed to leaching of these nutrients or due to high rate of volatilization in the study site. The low concentration of P is due to its low solubility in the soil solution and slow mobility of phosphate ions toward absorbing plants roots. The fraction of soil phosphate thought to be easily available to plant is present within the root hair cylinder (van Diest, 1991; Graciano *et al*., 2005).

In general, the fine roots appeared to have substantially more nutrients than the coarse roots. Fertilization has been shown to have a pronounced influence on the growth strategy of fine roots and their morphology (Persson, 1983; Graciano *et al*., 2005). Enhanced root surface area and growing root tips become active with the addition of nutrients in the soil profile, absorption ability of different parts of the root, the availability of nutrients in the soil and the transport of nutrients to the roots (Bowen, 1984; Nilson and Orland, 1999). The high concentration of nutrients in the fine roots is due to the presence of large number of active root tips (Ahlstrom *et al*., 1988) and due to the presence of mineral nutrients in the root medium which resulted in an adequate uptake of nutrients (Ingestad and Lund, 1979; Puhe, 1994).

CONCLUSIONS

Present results provide an insight to the importance of fertilizer application in the soil in fast growing teak plantations in Peninsular Malaysia and assimilation of various nutrients in coarse and fine roots. It is evident from the results that there is reduction in nutrient assimilation with the increase in diameter and age of the trees. Fine roots are more nutrient rich as compared to the coarse ones. Another outcome of these data was cations and anions have different mechanism in the soil and some become mobile while others become immobile due to heterogeneity of the soil factors. Finally, we should point out that there is a complexity of interaction in the soil layers and further work on the status of root biomass, length, number of root tips and other root parameters with regard to nutrient status of soil over the seasons is required. It is especially necessary to use methods that provide more accurate estimates of root characteristics. Parallel studies on the aboveground compartments of teak trees will be of great value.

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