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CHRONOSEQUENCE AND CROWN STRATA EFFECTS ON FOLIAR NUTRIENT CONCENTRATIONS IN TEAK (*TECTONA GRANDIS* L.f) PLANTATIONS

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Abstract

Foliar nutrient concentrations, fertilizer and variation with crown location and tree age were quantified in 1, 2, 10 and 18-year-old teak plantations in Peninsular Malaysia. Concentrations of N, P and K decreased with tree age, while the concentration of Ca increased. Nitrogen concentration was same in 1 and 2-year old plants (1.9%) and decreased as tree progressed in age i.e., 1.6% in 10-year old and 1.4% in 18-year old trees. Phosphorus, K and Zn followed the similar trend, however, Ca, Mg, Mn and Cu increased with increase in tree age. Concentrations of P and K were greatest in the upper tier of the crown. Differences in N concentration among crown strata were small while Ca and Mg concentrations decreased with crown height. Our results suggest that sampling of teak leaves should be carried from the upper or middle crown positions for N, P, K and from the lower crown position for Ca, Mg, Mn and Cu.

Introduction

Foliar analysis has been proven to be a good indicator of nutritional stress in many tree species. This could be done by comparing vigorously and poorly growing trees, or trees with and without cholorsis (Bowen & Nambiar, 1984). The technique is found to be particularly suitable in plantation forestry, in combination with soil and fertilization trials. Fertilizers are applied to increase the productivity of plantation grown species. Foliar analysis is also important because of the fact that leaves are the site of the important metabolic activities of the plant (Walker, 1991; Oskarsson *et al*., 2006).

One of other important factors that govern the rate of nutrient accumulation in the foliage is the soil pool (Miller, 1984). Amir & Mona (1991) and Hytonen (2003) further elucidated that trees growing on fertile soils have higher nutrient concentrations compared to those on impoverished site. Likewise, Amir & Miller (1991) and Amir *et al*., (1993) distinctly showed that fertile sites are capable of sustaining higher site carrying capacity than on poor soils, based on an exhaustive review comparing the role of foliage and soil analyses as diagnostic tool for nutritional assessment.

The use of foliar analysis in studies on plant nutrient status and fertilizer response holds assumption that quantitative relationships exist between the level of an element or elements in the foliage and growth rate, or some other parameters (Richard & Bevege, 1972). Changes in foliar composition after fertilization help explain the observed responses and may lead to diagnostic index that is useful in predicting the response potential of yet unfertilized stands (Amir, 1995, 1996). For diagnostic purposes, foliage should be sampled when and where the concentrations of all essential elements are most indicative of the nutrient status of the trees. Foliage samples are generally collected from the upper crown during the dormant season, when nutrient concentrations are most stable (Zhang & Allen 1996). This sampling regime is based more on operational constraints than knowledge that such samples are most suitable for growth response predictions.

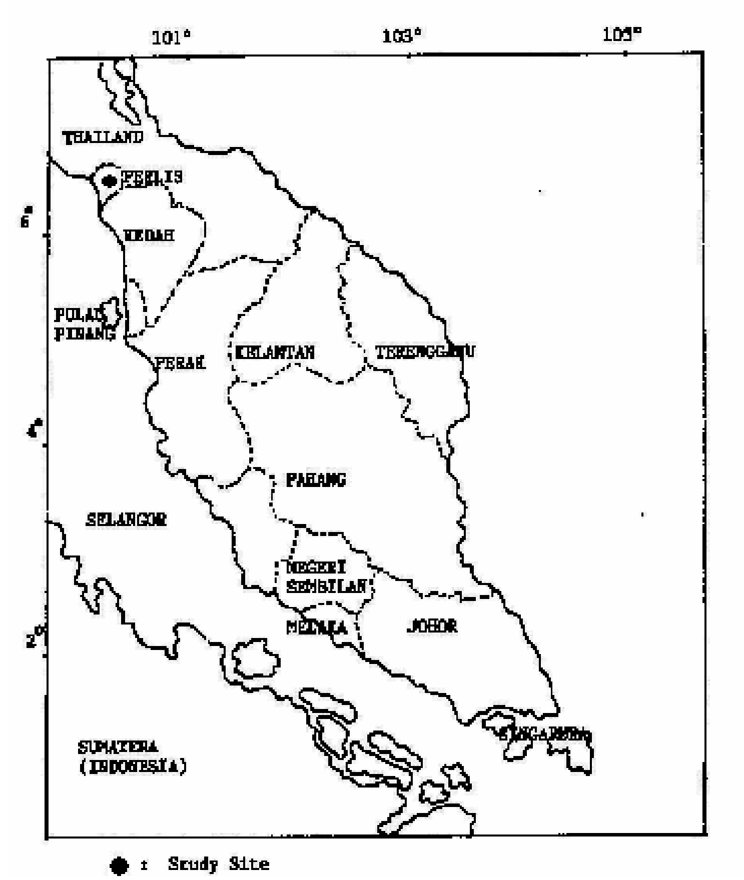

Fig. 1. Map of peninsular Malaysia showing the experimental area.

It is interesting to note that teak (*Tectona grandis*) leaf is exceptionally big in size which can measure from 15-20 cm diagonally. Young teak saplings (1-2 years) are already known to have big leaves and it is therefore necessary for the plants to absorb the right kind of nutrients in order to sustain the leaf biomass.

Landsberg (1986) and Khan *et al*., (2006 a) argued that our understanding of soil nutrient supply and fertilizer response is too limited to predict the quantitative effects of silvicultural practice. Thus, a better understanding of foliar status with respect to soil nutrient availability may improve our understanding of tree growth and physiological processes. Objectives of the present study were:

i) to evaluate fertilizer effect on foliage nutrient concentrations in teak
ii) to determine the variation of foliar nutrients with age of tree and crown location.

Materials and Methods

The site: This study was conducted at experimental site of 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 programme. The site is located at an elevation of 33 m above sea level. It falls within latitude 6^0 $40^/$ North and Longitude 100^0 $15^/$ East (Fig. 1).

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

In 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 said 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. Teak (*T. 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.

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 NH_4), 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.

The various levels of fertilizer applied are as shown in Table 1. The 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 experiment was designed at FRIM sub station, Mata Ayer, Perlis. Soils of this area consists of principal rocks like limestones, silt stones, granites, shales, 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 Meterological 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 flat 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 in to the field in July, 2001. The spacing between plants was 4x4 m. Dosage of fertilizers applied are given in Table 2.

Foliage samples of 1 and 2-year-old seedlings from all treatments were obtained from both pots and field plots, respectively. However, foliar samples of 10 and 18-year-old trees were obtained from plots of 50x40 m at compartment 17 of Mata Ayer Forest Reserve, Perlis. A total of 36 plants (six from each age group from pot and field trials) were harvested for the experiment.

One-year-old seedlings were carefully removed from the polybags, and dipped into distilled water to remove the dust etc., from the leaves. Twelve matured leaves per sample were collected from 6 trees from the respective ages. The leaves were taken from the previously demarcated outer whorls of three crown strata; Upper, Middle, Lower (Fig. 2).

In case of 1-year-old plants, the 3 branches were considered as crown positions because the crown was not established at this stage. The samples were taken in July, 2002. The best sampling position was determined on the basis of the least coefficient of variation (CV) for the different nutrient elements. The coefficient of variation was determined by using ANOVA. This is based on the assumption that the smaller CV value shows more stability in nutrient concentrations and is thus most appropriate for foliar sampling.

Foliar N, P, K, Ca, Mg, Cu, Zn and Mn (as independent variables) were correlated with tree height, diameter and total dry matter production (as dependent variables) of plants of age 1 and 2 years only. A stepwise multiple regression analysis was employed to examine the relationship between the independent and dependent variables.

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 applied to teak plants in field conditions.

Commercial fertilizer	Elements	Level 1	Level 2	Level 3 (g/plant)
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)

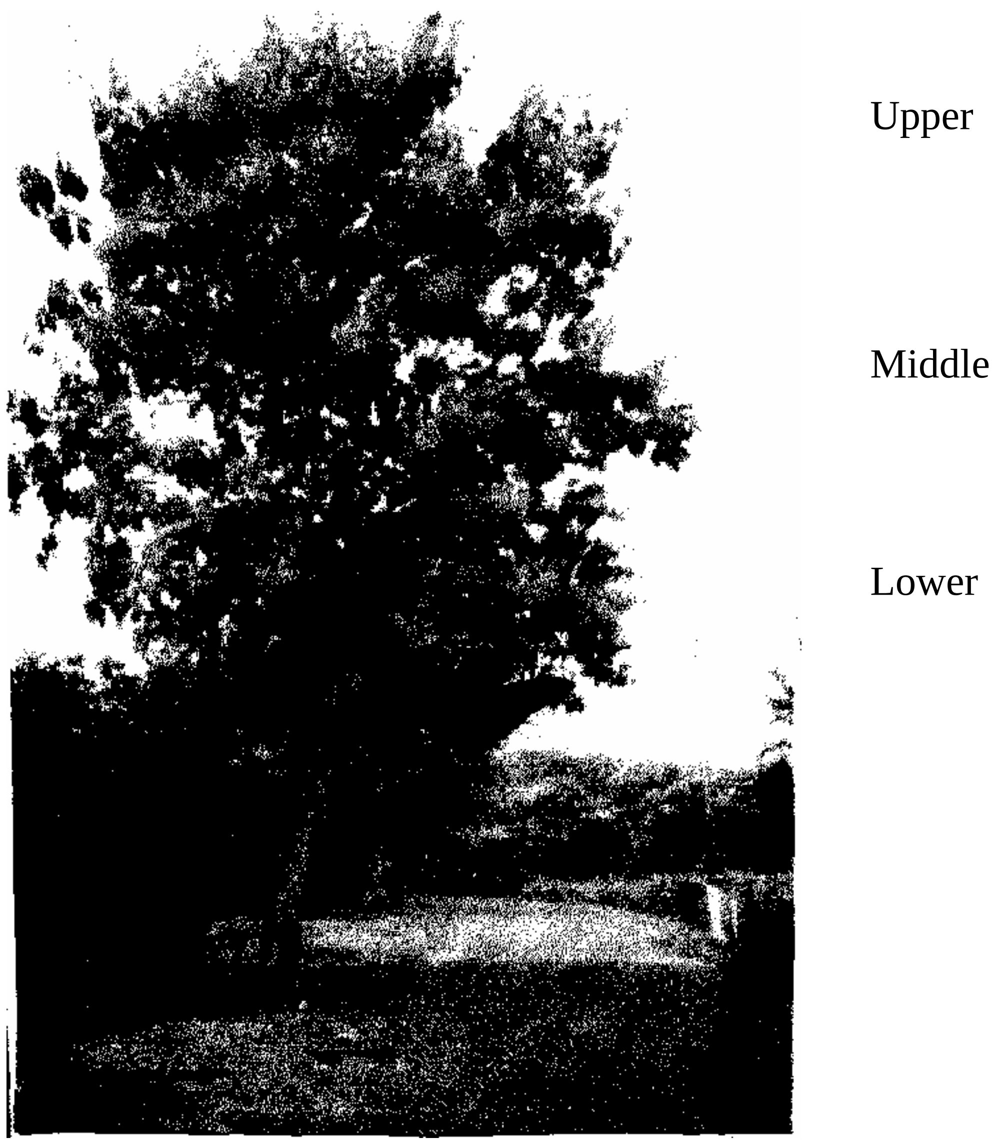

Fig. 2. Foliar sample positions in the crown.

Leaves were isolated from the selected branches and their fresh weights recorded. Composite samples were made and brought to Universiti Putra Malaysia for further processing and analysis. Samples were dried in a Forced Drift Oven at 70°C for 48 hours and their dry weights taken. Sub samples from composite samples were prepared for analysis. Samples were ground and passed through 1 mm sieve prior to chemical analysis. The samples were digested, using Sulphuric acid and hydrogen peroxide in the presence of selenium. Nitrogen and P were determined on the autoanalyser. Potassium, Ca, Mg, Mn and Zn were determined on the atomic absorption spectrophotometer. Nutrient composition of the leaves is expressed either as percentage or as parts per million (ppm) of oven dry weight concentrations.

Results and Discussion

Relationship between foliar nutrient concentrations and growth: A stepwise multiple regression analysis was employed to examine the relationship between independent and dependent variables. This regression technique was used to identify the major foliar nutrient elements affecting seedling growth. Table 3 presents the results of stepwise multiple regression analysis. It showed that height, diameter and dry matter production of 1-year-old plants were significantly ($p<0.05$) related to foliar N and K. In the 2-year-old plants, height and diameter were significantly ($p<0.05$) related to foliar N and K while dry matter production was related to foliar N only.

Fertilizer effects: Perusal of the data showed that additions of N, P and K fertilizers resulted in increased concentrations of N, P, K, Ca, Mn and Zn in the leaves of 1- and 2-year-old fertilized trees (Table 4). Nutrient increase was in the order 43.6, 33.0, 64.0, 17.7 and 2.5% for N, P, K, Ca, Mn and Zn, respectively in 1-year-old plants. Magnesium and Cu concentrations, however were higher in the unfertilized plants than in the fertilized plants (Table 4). This reduction might be due to dilution factor. In 2-year-old plants the increase in nutrient concentration was as follows: N 100 .0, P 33.0, K 68.8, Ca 75.7, Mn 0.9 and Zn 133.8%. Magnesium and Cu concentrations reduced in response to fertilizer application in 2-year-old plants.

Chronosequence: The foliar nutrient concentrations of all the nutrients tested viz., N, P, K, Ca, Mg, Zn, Cu and Mn were observed to be influenced by age (Table 5). Foliar N concentration was high in young leaves and decreased with the maturity of the foliage in 10- and 18-year old trees (Table 5). Phosphorus concentration was significantly higher in 1-year old seedlings than in 2-10-and 18-year old trees. Phosphorus concentration was found to decrease with increase in plant age, but the difference however, was not significant in 2- 10- and 18 year-old trees. Potassium concentration was maximum and significantly high ($p<0.05$) in the 1-year old plants and decreased with increase in age. Calcium, Mg, Zn and Cu concentrations were maximum in 18-year old trees (Table 5). This implies that concentrations of these elements increased as the tree progressed in age. Although maximum concentrations of Mg and Cu were found in 18-year-old trees, it was not significantly ($p<0.05$) different from rest of the age groups.

Crown strata: Two distribution patterns became evident from the results of the present study. Firstly, N, P and K were generally higher in the upper and middle crown of 1- and 2-year-old trees than those of 10- and 18-year old. Secondly, Ca and Mg concentrations tend to be greater in the lower crown layers of the older stands (Table 6). Results indicated the allocation of different nutrients in three strata of the crown as under:

Table 3. Stepwise multiple regression between growth parameters and foliar nutrient concentrations.

Growth parameters	Regression equation	R2	F-value	SEE
1-year-old				
Height	-81.23+20.59*N+21.61*K	0.89	17.21**	13-64
Diameter	-2.81+0.45*N+0.63*K	0.76	4.41*	0.50
Dry matter Production	-49.31+16. 58*N+I9.68*K	0.83	23.21**	12.02
2 year-old				
Height	-16.28+1. 88*N+7.97*K	0.86	7.60*	4-53
Diameter	-23.33+2.24*N+10.97*K	0.83	5.13*	2.56
Dry matter Production	-1209.31+610.31*N	0.47	3.63	5.58

Note: SEE is standard error of estimates

Table 4. Effect of fertilizers on foliar nutrient concentrations in 1 and 2 -year-old teak seedlings.

Treatment	Age	N	P	K	Ca	Mg	Mn	Zn	Cu
		%					ppm		
Control	1	1.6	0.1	2.1	0.8	0.3	83.2	88.1	7.7
Fertilized	1	2.3	0.2	2.4	1.0	0.3	100.8	109.1	6.6
Control	2	1.6	0.1	0.9	0.6	0.8	76.9	27.8	8.6
Fertilized	2	2.2	0.1	1.5	1.1	0.1	83.9	65.0	5.4
Average*		>2	0.2	1.1	0.9	0.4	85.0	72.0	7.0

*Average; Derived from Drechsel & Zech (1991)

Table 5. Foliar nutrient concentrations (%dry wt.) in an age series of un-fertilized *T. grandis* plantations.

Age	N	P	K	Ca	Mg	Mn	Zn	Cu
(yr)	%					ppm		
1	1.9a	0.17a	2.31a	0.94b	0.36a	92.0ab	98.6a	7.2a
2	1.9a	0.14b	1.34b	0.91b	0.54a	77.9b	46.4b	7.0a
10	1.6b	0.13b	0.81c	1.01b	0.40a	99.7a	13.1bc	10.4a
18	1.4b	0.12b	0.65c	1.71a	0.56a	105.1a	26.7c	10.1a
LSD	0.24	0.02	0.41	0.35	0.22	17.7	16.1	3.76

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

Table 6. Nutrient concentrations in different crown positions in different ages (year).

Age	Crown position	Foliar nutrient concentration							
		N	P	K	Ca	Mg	Zn	Mn	Cu
1	U	2.3a	0.1 b	2.1a	0.8a	0.3b	83.2b	103. la	7.7a
	M	1.8b	0.2a	2.4a	1.0a	0.3b	105. 8a	119. la	6.7a
	L	1.6b	0.1b	2.la	0.7a	0.9a	120. 3a	86.7a	45.0a
2	U	2.2a	0.1b	1.0b	0.6b	0.7a	90.3a	31.3b	8.3ab
	M	2.0 a	0.1b	1.7a	1.1a	0.1c	83 .9a	65.0a	5.4b
	L	1.6b	0.1b	1.4ab	0.4b	0.4b	43 .2b	25.9b	12.0a
10	U	1.8a	0.la	1.la	2.8a	0.5a	23. 8a	52.2a	3.9a
	M	1.7b	0.la	1.3a	3.5a	0.6a	24.0a	67.7a	7.0a
	L	1.7b	0.la	I.0a	4.2a	0.5a	30.0a	66.8a.	6.4a
18	U	2.1a	0.la	0.9b	l.5a	0.6a	21.06b	78.92a	5.5a
	M	1.9ab	0.1a	l.0ab	1.2a	0.5a	27.56a	62.08a	12.4a
	L	1.8b	0.12a	1.44a	l.4a	0.5a	28.50a	75.22a	10.0a

U= Upper crown, M= Middle crown, L= lower crown values with same letter are not significant

Foliar P concentration was significantly high ($p<0.05$) in the middle stratum of 1 and 2-year-old trees but there was no significant difference in all the three crown strata for the 10- and 18-year old trees (Table 6). Maximum P concentrations of 0.20, 0.16, 0.13 and 0.13% were observed in the middle crown positions of 1- 2- 10- and 18-year old trees, respectively.

Potassium concentrations were not significantly different ($p<0.05$) in crown positions of 1- and 10- year old trees while it was maximum and significantly high ($p<0.05$) at middle and lower crown positions of trees aged 2 and 18 years, respectively (Table 6). In general, a gradient in K concentrations was observed from the middle to the lower stratum in all age groups. Calcium concentration was maximum at the middle strata of 1- and 2-year old trees. But in trees aged 10 and 18 years, the trend was different and Ca concentration was maximum at the lower strata of these trees (Table 6). In general, no significant difference ($p<0.05$) in Ca concentration was found among all the crown strata of trees from the respective age group. A general increasing trend in Ca concentration was observed from top to lower crown layers regardless of age in old trees. There was no significant difference in Mg concentrations for all the crown strata of 10- and 18-year-old trees (Table 6).

Foliar zinc concentrations were maximum at the lower crown positions of 1-, 10 and 18- year old trees while in the 2-year old trees it was maximum at the upper crown layer. In general, Zn concentration increased from top to bottom layers in all age groups except in the 2- year old where the reverse trend was observed. There was a marked difference ($p<0.05$) in Zn concentrations among crown positions of 1-, and 2-year-old trees while there was no significant difference in the l0-, and 18-year-old trees. Manganese concentrations were maximum at the middle crown of 1-, 2- and 10- year old trees while it was higher at the upper crown position than other crown positions in the 18-year-old trees (Table 6). Manganese concentration was not statistically different ($p<0.05$) in all crown positions of the 1-, 10- and 18- year-old trees. However, there was significant difference ($p<0.05$) in Mn concentration at crown positions of 2- year-old trees. In general, there was no consistent trend observed at various crown positions of different aged trees.

Copper concentration was high at the upper and the lower crown of the 1- and 2-year-old plants, respectively while Cu concentrations were high at the middle crown of the 10- and 18-year old trees (Table 6). However, the difference in all the three crown positions in all age groups was not significantly different ($p<0.05$) except in the 2-year old trees where there was significant difference among all the three crown positions.

Effect of crown strata on nutrient variability: Coefficient of variation for each of the element tested, viz., N, P, K, Ca, Mg, Zn, Mn and Cu in each of the three crown layers in relation to age series was calculated as presented in Table 7. For the one-year old seedlings, N was generally less variable in the middle than in the other two crown positions while in 2-, 10- and 18-year old trees, there was less inability in the upper crown positions than in the lower ones. In one-year old seedlings the middle crown position showed the least CV of 10.5% whereas in 10- and 18-year-old trees, it was the upper position which showed the least CV of 5.0, 2.9 and 5.4%, respectively. The range was 10.5-19.2 for 1-, 6.8 for 2-, 2.9-4.9 for 10- and 5.4-8.3% for 18-year old trees.

Phosphorus exhibited less variability in the lower crown position than in the middle crown position in all age groups except in the l8-year old trees in which the upper position gave the least CV percentage (Table 7). The least CV of 4.7 per cent was recorded at the lower crown position of the 10-year old trees.

Potassium was more variable at the upper crown layers than at the lower ones. The least CV recorded were 7.0, 8.0 and 23.9% in the lower crown strata of 1-, 2- and 10-year old trees, respectively (Table 7). The least CV (17%) was recorded in the upper crown stratum of 18-year old trees. The range of variability was 7.0-37.6, 8.0-69.9, 23.9-39.7 and 17.5-40.1% in 1-, 2-, 10- and 18-year old trees, respectively.

For Calcium, the smallest CV was recorded at upper crown positions of the 1- and 10-year old trees while smallest CV values were calculated at middle crown positions of the 2- and 18-year old trees (Table 7). The range of variability was 14.2-69.8, 23.3-29.5, 58.2-69.5 and 71.1-80.5% in 1-, 2-, 10- and 18-year-old trees, respectively. Magnesium exhibited mix trend of variability. The smallest CV was recorded at middle crown positions of the 1- and 2-year-old trees while the smallest CV values were observed at the upper crown positions of 10- and 18-year-old trees (Table 7). The range of variability was in the order of 18.6-37.0, 34.5-76.0, 13.8-23.1 and 13.2-38.7% in 1-, 2-, 10- and 18-year old trees.

Zinc showed less variability at the upper crown positions in all age trees except in the 2-year old trees where less variability was found at the lower crown position. Table 10 shows the pattern of variability in Zn. The range of variability in the l-year-old plants was 9.0-19.1% and 31.2-41.9% in the 2-year old plants. 16.4% in the 10-year old and 29.6-42.2% in the 18-year old trees. Manganese showed a general gradient in variability from the middle to the upper and the lower crown positions in the l- and 2-year old plants. In case of the 10- and 18-year old trees, less variability was recorded at the lower crown positions (Table 7). The range of variability was between 28.0-56.0, 30.3-50.9, 18.5-63.4 and 44.4-49.7 per cent in 1-, 2-, 10- and 18-year old trees.

Copper showed the least CV values at lower crown positions in all the age groups except in the 1 -year-old plants where it was the least at the middle crown position also (Table 7). The upper crown positions showed the smallest value of 25.0%, 32.0 and 42.0% in 2-, 10- and 18-year old trees. However, the smallest value of 24 % was recorded at middle crown position of the 1 -year old plants. The variability range was 24.0-45.0, 25.0-57.0, 32.0-88.0 and 42.0-83.0% in 1-, 2-, 10- and 18-year old trees, respectively.

Table 7. Coefficient of variation of foliar nutrient concentrations in un-fertilized trees at various crown positions and ages.

Age	Crown position	Element							
		N	P	K	Ca	Mg	Zn	Mn	Cu
1	U	19.2	22.6	17.6	14.2	37.0	19.1	44.8	45.0
	M	10.5	13.4	7.0	40.6	18.6	19.1	28.4	24.0
	L	19.2	11.1	37.6	69.8	35.8	9.0	56.0	24.0
2	U	9.9	12.4	69.9	76	24.4	41.9	50.9	57.0
	M	16.8	20.1	8.0	34.5	23.3	38.5	30.3	34.0
	L	16.4	16.1	46.2	45.8	29.5	31.2	45.9	25.0
10	U	2.9	5.7	23.9	58.2	13.8	31.0	32.2	61.0
	M	4.9	9.1	39.7	69.5	23.1	22.8	63.4	88.0
	L	4.7	4.7	25.5	65.8	18.4	16.4	18.6	32.0
18	U	5.4	7.2	25.4	80.5	13.2	42.2	49.7	83.0
	M	6.0	22.5	17.5	71.1	30.6	33.1	49.5	52.0
	L	8.3	16.6	40.1	79.4	38.7	29.6	44.4	42.0

Note: U= Upper crown, M= Middle crown, L= lower crown
The least variable crown position in each age group is set in bold face

Table 8. Analysis of variance (F-values) on crown positions and age of teak trees.

Nutrient concentrations	Sources of variation		
	Main factors	Interaction	
	Position	Age	Position* Age
N	11.34**	12.76**	11.27**
P	12.39**	10.44**	4.19**
K	2.32ns	19.22**	1.22ns
Ca	0.82ns	22.76**	0.70ns
Mg	10.63**	1.96ns	11.63**
Zn	0.73ns	82.67**	6.36**
Mn	5.92**	16.25**	2.85*
Cu	2.98ns	1.34ns	1.60ns

Note: **-Highly significant, *- Significant at 5% level of probability, ns- Non-significant

The least variable crown position in each age group is set in bold face upper crown position of the 18-year old trees, 11.1% in the lower crown position of 1- and 16.1% in the 2-year old trees. The range of variability was in the order of 11.0, 1.0-22.0, 6.0, 16.1-20.1, 4.7-9.1 and 7.2-22.5% in 1-, 2-, 10- and 18-year old trees, respectively.

Analysis of variance was carried out to determine the effect of crown positions and tree age on foliar nutrient concentrations of teak seedlings (Table 8). Analysis of variance revealed that the main effects of crown position and tree age and their interaction significantly ($p<0.01$) influenced the concentrations of N, P and Mn in the foliage (Table 8). Potassium and Ca concentrations were affected by age only. Magnesium concentration was influenced by position only while Zn was affected by age and their interaction. Copper was unaffected both by the main effects and their interactions.

Variation in nutrient concentrations depends on the developmental stage of foliage and nutrient uptake. The concentrations of mobile nutrients i.e., N, P and K were higher in 1- and 2-year old foliage than in 10- and 18-year old trees. The higher concentrations of these nutrients in young leaves have been considered to result from greater metabolic activity of young leaves. Rapidly developing leaves are strong nutrient sinks, and nutrients are preferentially translocated in to meet their growth demand (Marschner, 1986) while the concentrations of these nutrients declined with leaf elongation. Apparently, teak foliage can be a major site for nutrient storage, similar to what has been reported for other broad-leaved trees (Lee & Jose 2006) and evergreens (Zhang & Allen 1996).

The results of the present study revealed significant increase in foliar nutrient concentrations due to fertilizer additions in all nutrients except Mg and Cu. Higher nutrient concentrations are not surprising because of synergism process. The increase in nutrient levels might be due to increased organic matter decomposition as a result of the stimulation of microbial activity through the added nutrients (Salonius, 1972).

The increase in nitrogen might be due to the fact that fertilizer N can be rapidly immobilized by the microorganisms and incorporated into the pool of total soil N. This is especially true when the N is added as urea or ammonium as the latter was the source of N in the present study. The increase in the concentrations of the mobile nutrients N, P and K in young leaves could also result from the substantial retranslocation of nutrients immediately prior to abscission. This response has been attributed as synergistic. Evidence found in other studies also indicate that growth rate is probably more important than soil nutrient availability in controlling translocation (Fife & Nambiar, 1982; Helmisaari, 1990; Khan *et al*., 2006b).

Unlike mobile nutrients, the concentrations of the immobile nutrient Ca is continuously with foliage age. Theoretically, when foliage was completely mature, most Ca required for foliage growth should have already been incorporated into leaf structure. However, Ca concentration increased in mature tree foliage and reached a level that was higher than that needed for foliage growth and metabolic processes for teak. The possible interpretation for this observation is that because Ca was also added by triple super phosphate which contains 20% Ca. The immobility and low translocation rate of Ca resulted in the accumulation in older trees. The accumulation of Ca with foliage age have been reported by Marschner (1986), Zhang & Allen (1996), Hytonen (2003), Coyle & Coleman (2005), Safou-Matondo *et al*., (2005), Oskarsson *et al*., (2006) in their studies.

The results of this study are in agreement with that of Lopez-Serrana *et al*., (2005) who reported increase in nutrient concentration as a result of fertilizer additions in Australia. Our results also accord with the findings of Laclau *et al*., (2000) and van den Driessche *et al*., (2003) who reported foliar nutrient concentrations and biomass in eucalyptus and poplar species, respectively. Similar effects of fertilizer addition to foliar nutrient concentrations have also been reported in temperate species and sub- tropical pines (Herbert & Schonau, 1989; Hytonen 1995). On the contrary, Cromer & William (1982) have reported decreased concentration of N due to fertilizer application on *Eucalyptus globulus* in Australia. This reduction might be due to dilution factor.

The results of the present study indicated that concentrations of nutrients especially N, P, K concentration decreased and that of Ca and Mg increased as tree advanced in age. The high nutrient concentrations in young stands might be due to the great demand of nutrients for their early growth and establishment. According to Miller (1989) nutrient uptake is at peak in early years of a tree crop when green canopy is being formed. Bonneau (1986) described this as an effect of youth. As a general rule, smaller trees use nutrients less efficiently than bigger ones where a dilution effect tends to decrease the mean concentrations. This observation has also been made by van den Driessche (1974) and Ranger *et al*., (1995). Nutrient uptake tends to decrease with stand age. According to Ranger *et al*., (1995), this phenomenon is controlled by three parameters: (i) the decrease of foliar biomass with age well correlated with litter fall; (ii) the variation of the current annual stand increment and (iii) the decrease of nutrient immobilization rate with stand age according to the dilution effect linked to cumulative growth. Similar patterns of nutrient distribution within the crown were reported by Kual *et al*., (1979); Negi, *et al*., (1990) and Negi *et al*., (1995).

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