Research Journal of
Forestry

ISSN 1819-3439

Academic
Journals Inc.

www.academicjournals.com

Research Journal of Forestry 6 (1): 16-23, 2012
ISSN 1819-3439 / DOI: 10.3923/rjf.2012.16.23

Influence of Nitrogen on Growth of *Azadirachta excelsa*

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ABSTRACT

A fertilizer trial with three rates of N was conducted in a 2-year-old *Azadirachta excelsa* stand. Mean increments of tree volumes over two years ranged from 25.95 to 54.67 m^3 ha^{-1}. Growth of *A. excelsa* increased significantly with the addition of N. Foliar P concentration at 39 months was significantly higher with additions of N. The best growth was associated with foliar concentrations of 2.57% N. The rather substantial decrease in growth in the second half of the study period indicates the need to continually repeat fertilizer application to sustain the earlier achieved growth rate. General fertilizer prescriptions for *A. excelsa* plantations are presented.

Key words: *Azadirachta excelsa*, fertilizer trial, foliar concentration, growth performance

INTRODUCTION

In Peninsular Malaysia, *Azadirachta excelsa* (Jack) Jacobs plantations can be found across a wide range of soils and climates. An assessment by Forest Research Institute of Malaysia in 2000, estimated that some 5000 ha of *A. excelsa* plantation have been established in Peninsular Malaysia and of that, about 10% can be found in Labis in the state of Johore, Malaysia (T.H. Ong pers. comm). Regardless of previous land use, site preparation of *A. excelsa* usually involved clear felling and burning. These practices destroy the litter cover and residual plants and hence enhance nutrient loss through leaching. In addition, most of these plantations have been established on marginal lands in which productivity of the previous cultivated crops such as rubber (*Hevea brasiliensis*) and oil palm (*Elaeis guineensis*) were rather low. The low productivity of these areas may be due to deficiency in one or more of nutrients required for optimum growth. Thus, fertilizers will probably be required for optimum production on many of these sites.

NPK compound fertilizers are routinely applied at the time of planting and during the rotation of *A. excelsa*. However, applications are based on fertilization prescriptions for rubber. The dosages of nitrogen (N) and other nutrients that are optimum for *A. excelsa* growth in Peninsular Malaysia under different edaphic conditions have not been determined. Earlier studies (Ong *et al.*, 1999, 2002) have indicated that N and P are the nutrients that can limit *A. excelsa* growth. Furthermore, assessment of nutrient status using foliar analysis to help in recommending fertilizer regime has not been developed for *A. excelsa*. The results of the present study may provide some groundwork in meeting these needs.

The objective of this study was to identify the N requirement of *A. excelsa* in a plantation established in southern of Peninsular Malaysia. The experiment was designed to assess the effects of N fertilizer on stand growth and foliar nutrient concentrations. In addition, nutrient concentrations in their correlation with past and future growth were compared to assess their usefulness for guidance in nutrient management decisions.

MATERIALS AND METHODS

Site description and trial design: The experiment was established at a plantation located about 9 km south of Labis in the state of Johore, Malaysia (2°21'N and 103°02'E). The average annual rainfall is 2124 mm and the annual temperature varies from 25 to 28°C. The site is undulating and hilly with slopes ranging from 1 to 50%. The landform can be grouped into three slope classes: (1) nearly level -50%, (2) undulating -25% and (3) steep -25%. The soil is a clay loam with low pH and fertility (Ong and Lim, 2005). The plantation was established following clear cutting of a second rotation of rubber. The debris on the site was burned prior to planting seedlings.

Seedlings were fertilized at the time of planting with 50 g of 15 (N)-15 (P)-15 (K). The seedlings were planted at a spacing of 2.0×2.0 m. Operational schedules for application of fertilizers prior to experimental establishment were presented in Table 1. Weeds were cleared by herbicide application each time before fertilization, leaving no ground cover for most of the time. Thinning of small trees was carried out when stand was 21 month-old. The number of trees in the stand before the beginning of the experiment was approximately 2403 trees ha^{-1}. A completely randomized block design was implemented with six blocks with four rates of N as urea (0, 50, 100 and 150 kg ha^{-1}) when the stand was 26 month old.

The treatments were applied over three separate occasions over 12 months (Table 1). Individual plots were 100 m^2 in size and consisted of 25 trees. At least three rows of trees were used to separate blocks. The fertilizer was broadcasted between the rows of trees. In Malaysia fertilizers are broadcasted during scheduled fertilization in already established plantation both by small-holders and in estates.

Tree volume estimation: Tree volume was estimated by regression equations developed from harvested tree samples from these experiments. The total Volume (V) of *A. excelsa* tree was estimated using the following equation (Ong *et al.*, 2009):

$$V_{tob} = 9.85\times10^{-5}\,(d^{0.9737}\,h_t^{1.8106})$$

where, V_{tob} is total overbark volume; d is diameter at breast height and h_t is total height. (R^2 = 0.988, d (or diameter at breast height) range = 4.8-10.4 cm, h (or total height range) = 4.8-11.2 m).

The size range of *A. excelsa* trees used in this equation spanned the full range of tree sizes encountered in the plots. Mean values of d, h and V were calculated for each plot, and periodic growth was calculated by the difference between the means for two periods (data from living trees).

Foliar analysis: Foliage was sampled when stand was 39 and 51 month-old. The youngest, fully expanded leaves were sampled from the upper level of tree crowns. The samples were ground after

Table 1: Operations schedule for application of fertilizers and for monitoring growth and foliar nutrients of *Azadirachta excelsa* at the sungai karas plantation

Age (months)	Operation	Fertilizer application rate (g tree^{-1})/(kg ha^{-1} elemental)
0	Planting	50 g N (15)-P (15)-K (15)
4	Routine fertilizer application	50 g N (15)-P (15)-K (15)
8	Routine fertilizer application	50 g N (15)-P (15)-K (15)
12	Routine fertilizer application	50 g N (15)-P (15)-K (15)
16	Routine fertilizer application	50 g N (15)-P (15)-K (15)
20	Routine fertilizer application	50 g N (15)-P (15)-K (15)
26	Establishment of experimental plots	
	1st fertilizer application	N_{50}
27	1st measurement	
30	2nd fertilizer application	N_{50}
34	3rd fertilizer application	N_{50}
39	2nd measurement	
	1st foliage sampling	
51	3rd measurement	
	2nd foliage sampling	

over-drying (70°C, 48 h) and digested with sulphuric acid or H_2SO_4 and hydrogen peroxide or H_2O_2 (wet digestion method). Nitrogen was determined by a Kjeldahl procedure (Forster, 1995). Phosphorus was determined colorimetrically using the molybdenum-blue method (John, 1970). Potassium, Ca and Mg in the digest were determined by atomic absorption spectrophotometer.

Data analysis: Data were analyzed by standard analysis of variance procedures using SAS (1989). Institute for the effect of fertilizer and lime treatment on periodic increments in h, d or V and foliar nutrient concentrations. Significant differences between treatment means were then identified using Duncan multiple range test. Relationships between growth and foliar nutrient concentrations were examined using Pearson correlation coefficients.

RESULTS

Growth and foliar nutrient concentrations: Additions of N significantly increased d growth (Table 2). The response of *A. excelsa* to added N was greatest at the highest rate (Fig. 1). The linear effect of N treatments on d growth indicates that higher growth could still be achieved with higher rates of application of fertilizer.

The height increments after two years were not influenced by the treatments (Table 2). The effects of fertilizers on estimated volume yield were not significant (Table 2). The reason was associated with the fact that gains in volume reflected the combined effect of gains in diameter and height. Additions of N significantly increased foliar concentrations of P and K at 39 months (Table 3). At 51 months, only foliar Mg was significantly increased by N additions (Table 4).

Relationships between growth and foliar nutrients: The relationship between growth of *A. excelsa* and foliar concentrations varied markedly with age and tended to reflect the availability of these nutrients in the soils. At 39 months, diameter increment was significantly correlated with

Table 2: Effect of N on growth increment of *Azadirachta excelsa* trees at 51 months

Treatment	Diameter (cm)	Height (m)	Volume (m^3)
N kg ha^{-1}			
0	1.30^b	1.84	0.0176
50	1.43^b	1.90	0.0182
100	1.47^{ab}	2.10	0.0192
150	1.66^a	1.97	0.0202

Means in the same column followed by different letters are significantly different p<0.05)

Table 3: Effect of N on foliar nutrient concentrations (mg g^{-1}) of *Azadirachta excelsa* trees at 39 months

Treatment N kg ha^{-1}	N	P	K	Ca	Mg	N/P
0	15.4±5.9	1.4±0.4^b	8.8±0.9^c	3.0±0.6	2.08±0.1	7.3±2.2
50	18.4±6.3	1.7±0.4^b	9.7±0.5^c	3.4±0.3	2.24±0.1	7.0±3.1
100	19.6±6.0	2.0±0.4^b	12.0±1.0^b	3.2±0.5	2.15±0.1	6.2±2.1
150	25.7±11.2	3.2±0.4^a	15.9±1.1^a	3.0±0.5	2.10±0.1	7.0±2.3

Values are Means±SD, Means in the same column followed by different letters are significantly different (p<0.05)

Table 4: Effect of N on foliar nutrient concentrations±mg g^{-1} of *Azadirachta excelsa* trees at 51 months

Treatment N kg ha^{-1}	N	P	K	Ca	Mg	N/P
0	19.2±4.5	1.1±0.4	13.1±4.6	2.7±1.4	2.07±0.8^b	16.5±2.4
50	21.0±4.5	1.4±0.4	14.0±5.1	2.6±0.9	2.52±0.7^b	15.5±2.9
100	24.8±8.3	1.8±0.8	14.3±3.8	2.8±1.5	2.25±0.6^b	14.4±2.3
150	22.1±5.9	1.8±0.7	12.8±5.2	2.6±1.3	3.25±1.8^a	12.8±2.9

Values are Means±SD, Means in the same column followed by different letters are significantly different (p<0.05)

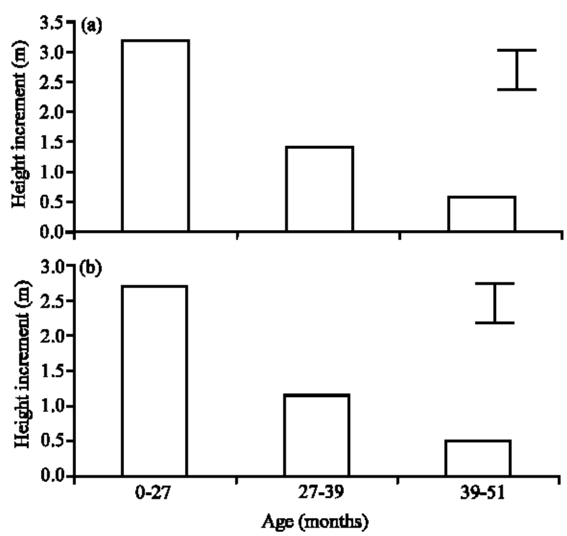

Fig. 1(a-b): Mean (a) height and (b) diameter increments of *Azadirachta excelsa* in treatment involving the highest rates of N addition (e.g., N_{150} at 39 and 51 months). Values are means of six block means. Vertical bars are critical differences from DMR test (p<0.05)

foliar P (Table 5). At 51 months, height increment (for the second year) was strongly correlated with foliar Ca (Table 5).

Table 5: Correlation coefficients between foliar nutrient concentrations and size of trees at 39 and 51 months, growth increment from 39-51 month

Nutrient and sampling age	Age 39 months	Age 51 months		Two-year increment		
	Diameter	Diameter	Height	Diameter	Height	Volume
Age 39 months						
N						0.40*
P	0.34*	0.36*		0.39*	0.35*	0.52***
Age 51 months						
Mg					0.35*	
Ca			0.43**		0.38*	

Correlations at age 39 and 51 months were between growth and foliar nutrients of individual trees (n = 12). Only significant correlations are presented (two-tailed test of significance: *p<0.1, **p<0.05, ***p<0.01

DISCUSSION

Responses to fertilizer additions: Previous trials on rubber tree indicated N alone or combined with K improved growth (Sivanadyan, 1983). The early forest fertilization studies in Malaysia were carried out in pine plantations, mainly *Pinus caribaea*. Phosphorus was considered the most important nutrient element for growth (Sundralingam and Ang, 1975) and addition of N further enhanced the growth (Lim and Sundralingam, 1974). Similarly, Paudyal (1995) and Tahir (1998) found that a combination of N, P and K resulted in favourable growth responses in *A. mangium* and *Tectona grandis* respectively in Malaysia.

In the present study, the diameter increment of *A. excelsa* was found to be influenced by N addition. The total diameter increment of trees at the highest dosage being 16% higher than that of trees receiving the lowest N addition. The rapid drop in growth response after the last fertilizer application, the first year increment being 70% higher than the second year, coupled with significant difference in tree size between the highest and the lowest application of N addition suggest that the fertilizer regimes were suboptimal, and that fertilization needs to be continued to maintain high growth. Assuming that at planting the average diameter of seedlings was 1.0 cm and prior to commencement of the experiment, 2 years after planting, the average diameter was 6.2 cm, mean diameter increment of the stand in the first two years was 2.6 cm year^{-1}. However, in the present study, total diameter increment, after 2 years of monitoring, was only 1.5 cm. The poor growth may due to the following reasons:

- The soil in the present study site is clay loam with relatively low fertility status (Ong and Lim, 2005). Prior to the commencement of the study, the site was found to be low in exchangeable K and Mg and moderate in organic C, N and P according to a fertility rating by Kanapathy (1976). The choice of fertilizer may influence the loss of nutrients applied, such as through leaching, volatilization and immobilization. Substantial losses of applied N through volatilization were reported when urea was applied to during dry periods (Fisher and Binkley, 2000). In the present study, two of three applications of urea were carried out during fairly low rainfall months. Applied N can also be rapidly immobilized by the microorganisms and other understorey vegetation (Cole *et al.*, 1990)
- Levels of fertilizer applied were insufficient to support an exponential rate of growth as the plantation ages. The rate of nutrient uptake is not constant with stand age. As the stand ages prior to the first closure of the canopy, the need for nutrient from soil increases. This site was

fertilized with 375 kg ha^{-1} $year^{-1}$ of N (15)-P (15)-K (15) or 56.25 kg ha^{-1} $year^{-1}$ of N, phosphate (P_2O_5) and potash (K_2O) respectively prior to the establishment of the trial. The application was carried out every four months. Paudyal (1995) suggested the best regimes of fertilizer to increase *A. mangium* in Peninsular Malaysia that established on ultisol were 500 kg ha^{-1} of urea. In the present study, the highest application rates were only 150 kg ha^{-1} N

- Competition for nutrient and water between trees. The competition for space, nutrient and water within stand becomes more evident as plantation ages. In many instances, thinned stands benefited more from fertilizer application than unthinned stands (Brix, 1983; Snowdon and Waring, 1990). Schonau and Coetzee (1989) recommended that thinning should only be carried out in eucalypts plantations when they are grown for sawntimber, veneer logs or transmission-line poles. These authors suggested that commencement of the first thinning should be at the third year. In the present study, the plantation was established for sawtimber with a spacing of 2×2 m or 2500 tree ha^{-1}. Thus thinning should be considered to reduce competition for space among trees

Foliar concentrations of P at 39 months were significantly increased by addition of N. In contrast, diameter of *A. excelsa* was significantly increased by addition of N at 51 months. The significant N additions on tree size at 51 months indicate there was a carryover effect of the previous application of fertilizer at 34 months. Thus, N fertilizer could therefore be applied in the years prior to canopy closure.

Fertilizer prescriptions: In the present study, higher growth increment at 39 months was recorded with additions of 150 kg N ha^{-1}. The growth responses were associated with increased foliar concentrations of P. The highest rates of N increased foliar N and P to about 2.57 and 0.32%, respectively. Responses of foliar N to additions of N at 39 months were proportionally smaller than responses of foliar P, resulting in low foliar N/P at 39 months. These results indicated that there is a greater demand for P relative to N. According to Cromer *et al.* (1981) and Schonau and Herbert (1983) highly significant growth responses to N application can be expected if foliar N/P ratio is low. The present study is in agreement with their finding. In contrast, the optimum foliar N/P ratio at 51 months of between 14 and 16 is probably due to low P-uptake resulting from the low availability of P.

The growth rate decreased significantly compared to the previous year in the present study. This suggests that there is a need for repeated additions of fertilizers in the years prior to canopy closure. Ong *et al.* (2002) found significant growth responses of *A. excelsa* seedlings to fertilizers when foliar concentration of N was higher than 3.0%. The substantial increment in foliar concentration of N due to the highest dosage of N addition plus the highest N foliar concentration in the present study was only 2.57% at 39 months, suggesting the need for higher rates of N addition. We recommend that N be added at rates not less than 200 kg ha^{-1} $year^{-1}$ (the application can be over three occasions) on sites of three-year-old stands established on similar type of soils. Rates of fertilizers additions in subsequent years should be maintained or increased depending on stand requirement.

CONCLUSION

Estimates of total stem volume increment for 24 months after commencement of the experiment (at 51 month-old) ranged from 25.95 to 54.67 m^3 ha^{-1}. Only diameter (at breast height) growth was positively affected by addition of N. Foliar concentrations of P and K were significantly increased by additions of N at 39 months but this was not found at 51 months suggesting the need for continual application of fertilizers. Based on the results of the present study, it is suggested that foliar P concentration could be used to predict the growth of *A. excelsa*.

ACKNOWLEDGMENTS

The authors thank Mr. Phoon Ah Kow, the owner of the plantation for access. We also like to thank Mr. Abdul Razak Sulong, Mr. Zakaria Taha, Mr. Salim Ahmad and Mr. Mohamed Yusof Yaacob for the technical help. Funding for this research was through IRPA grants (Grant No. 01-02-04-0504 to Dr. Jugah Kadir and Grant No. 01-02-04-0056-EA001 to Dr. Lim Meng Tsai) from Ministry of Science, Technology and Environment of Malaysia.

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