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THE ROLE OF TREE SPACING IN MINIMISING FUEL LOAD IN *ACACIA MANGIUM* PLANTATION—A CASE STUDY IN SOUTH SUMATRA, INDONESIA

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SAHARJO, B. H. 1999. The role of tree spacing in minimising fuel load in *Acacia mangium* plantation—a case study in South Sumatra, Indonesia. A case study examining the role of tree spacing in minimising fuel load in *Acacia mangium* plantation showed that close rather than wide spacing tends to reduce fuel load. The lowest fuel load, 13.7 t ha^{-1}, resulting from the closest spacing (2 × 2 m), was still too high, compared to the fuel load reduction necessary to minimise fire risk. This means that reducing fuel load in the plantation will require not only close spacing, but also proper tree maintenance, i.e. weeding and pruning. This should be conducted regularly at 3-month intervals, and 2 × 3 m spacing is also recommended.

Key words : *Acacia mangium* - forest fire - fuel load - maintenance - South Sumatra - spacing

SAHARJO, B. H. 1999. Peranan penjarakan pokok bagi meminimumkan beban bahan api dalam ladang *Acacia mangium*—satu kajian kes di Sumatera Selatan, Indonesia. Satu kajian kes memeriksa peranan penjarakan pokok bagi meminimumkan bahan api di ladang *Acacia mangium* menunjukkan bahawa jarak yang rapat berbanding dengan jarak yang luas lebih cenderung untuk mengurangkan muatan bahan api. Muatan bahan api yang paling rendah, 13.7 t ha^{-1}, akibat daripada penjarakan terdekat (2 × 2 m), masih lagi terlampau tinggi berbanding dengan pengurangan beban bahan api yang sesuai untuk meminimumkan risiko kebakaran. Ini bermakna, pengurangan beban bahan api di ladang memerlukan bukan sahaja jarak yang dekat, tetapi juga penjagaan pokok yang betul iaitu merumput dan memangkas. Ia perlu dilakukan secara tetap pada setiap selang 3 bulan, dan jarak 2 × 3 m juga disyorkan.

Introduction

Products from industrial forest plantations, which are fulfilling consumer demands, have increased year by year, especially pulp and paper. Because of this, the success of plantation activities is very important. In addition, this success should also reduce cutting in natural forests. Large plantations, however, do not guarantee efficiency in production.

Fire is often the most important danger facing a newly established plantation in the tropics, and the greatest fires occur while a plantation is young, before canopy closure and suppression of ground vegetation (Evans 1992). Fire hazards increase as both living and dead biomass accumulates during the course of a planted forest's development (ITTO 1993). Of the many reasons for this, one is forest fire. In only three months of 1994, 17% of the total *Acacia mangium* planted in the research site in the present study was burnt. One of the reasons so much of the plantation was burnt was the high level of poorly maintained fuels on the adjacent land (Saharjo 1996). The key to saving industrial forest plantation from fire is fuel load reduction. If a plantation has a reduced fuel load, it can be said that the area is in good condition. In addition, ground vegetation should be treated until the tree canopies close. Weeding is recommended three months after planting, and proper tree planting spacing is also advised (Saharjo & Watanabe 1995, Saharjo 1996).

If trees are planted close together, their crowns and roots will soon close and full occupancy of the site is achieved early. High stand density induces small branches, slow diameter growth, a low degree of stem taper, and rapid increase in the length of the bases of the live crowns (Smith 1986). Wider tree spacing leads to some loss in total volume production per hectare, but individual trees grow larger. A stand of trees planted far apart will have a lower photosynthetic surface area per hectare to intercept light in the early years and, consequently, a lower yield at the outset. Wide spacing, however, enables individual trees to develop and maintain large crowns, and their root systems will occupy a large volume of soil before competition starts, both of which enhance growth (Evans 1992). The choice of initial spacing is determined by the end use of the plantation material, and to some extent by the tree form (Srivastava 1993). Onset of between-tree competition depends on species growth rate and initial spacing. Competition occurs when the presence of neighbouring trees begins to slow a tree's own development. Slow development may occur from competition between root systems or once branches touch and shade one another (Evans 1992).

The objective of this study is to clarify the role of tree spacing in minimising fuel load in *Acacia mangium* plantations.

Materials and methods

Site description

This research was carried out in a newly established *Acacia mangium* plantation (1.5, 3, and 6 y old) belonging to PT.Musi Hutan Persada, Barito Pacific Group, at the Subanjeriji forest block, South Sumatra, Indonesia, from August to September 1996 and from August to September 1997.

The mean annual rainfall is about 2800 mm, and monthly rainfall is about 209 mm ranging from 92 mm in July to 278 mm in February. According to the Schmidt and Fergusson (1951) system, the climate of this area belongs to rainfall type A. Mean maximum air temperature in this area is 32.6 °C in August, mean minimum air temperature is 22.6 °C in December and mean annual relative humidity is about 85%.

The soil is red yellow podsolic and the USDA soil classes are: Haplaquox, Dystropepts, Kandiudults, and Hapladux. This area has the following characteristics: slopes < 8 %, 5–125 m altitude, drainage varies from well-drained to imperfectly drained, soil mineral depth is 101–150 cm, cation exchange capacity (CEC) is 4.9–17.9 me 100 g^{-1}, base saturation is 5.6–21.8 %, available phosphorus is 0.4–3.2 ppm, total nitrogen is 0.11–0.20 %, organic carbon is 1.09–3.51 %, free salinity, and soil fertility based on Indonesian criteria are low (Hikmatullah *et al.* 1990).

Understorey vegetation is dominated by *Imperata cylindrica, Eupatorium pubescens, Clidemia hirta, Tetracera* sp., *Artocarpus anisophyllus, Macaranga javanica* and *Dillinia grandifolia* (Saharjo & Watanabe 1996).

Measurements and analysis

Data presented in this paper were derived from field experiments. Tree diameter, height, crown width and fuel load were measured at different ages and tree spacing.

One lot of about 40 × 40 m was established in the *Acacia mangium* plantations in each of several stand types that ranged from 1.5 to 6 y of age, at different tree spacings. At 1.5 y the five spacings used were 4 × 3.5 m , 4 × 3 m, 3 × 3.5 m, 4 × 2.5 m and 3.5 × 2.5 m. At 3 y the four spacings used were 4 × 4 m, 4 × 3 m, 3.5 × 2 m and 3 × 2 m. At 6 y the four spacings used were 4 × 4 m, 3 × 3 m, 3 × 2 m, and 2 × 2 m. All trees in the plantation were of the Subanjeriji provenance.

In each plot, tree diameter, height, canopy diameter and fuel load were measured. Diameter at breast height, i.e. 1.3 m above ground (dbh), and height of all trees in the plot were measured. Survival of trees, mean dbh, basal area and crown closure (using crown width data and a digital planimeter, PLANIX 7) were calculated.

Fuel load was measured by collecting and weighing all the living and dead materials in six quadrats of a subplot, each of area 0.25 m^2(0.5 × 0.5 m).

The data calculated were subjected to analysis of variance, and significant difference was tested with the Tukey test (Steel & Torrie 1981). A linear regression was developed to predict the effect of tree spacing and crown closure on tree diameter, height, basal area and fuel load.

Results and discussion

Survival

Survival rate of trees in the plot (Table 1) varied from 80.9% at 3.5 × 2.5 m spacing (3 y) to 95.0% at a 4 × 4 m spacing (6 y). In the oldest 6-y-old plantation, survival increased with increasing spacing; at a spacing of 2 × 2 m, 75 trees died (81.2% survival), the highest number, while the lowest was 5 trees at spacing of 4 × 4 m (95.0% survival). The causes of the death were probably due to high competition and natural disturbance, i.e. pests and diseases.

Tree growth

Height

Spacing had no significant effect on tree height in the 1.5-y-old and 3-y-old plantations but it was significantly different in the 6-y-old plantation (Table 1). If there is no difference in growth among trees in the stands at young ages, it is reasonable to assume that competition has not yet begun to impact on the growth of the stands (Larocque & Marshall 1993). Differences in height might be due to varied genotypes, enhancing early development. Increase of tree density (and tree cover) at closer spacing tends to increase tree height significantly at 3 and 6 y of age (Table 2).

Table 1. Diameter, height, basal area, crown width, crown closure, and fuel load, at 1.5-, 3- and 6-y-old *Acacia mangium* plantations at different tree spacings

Spacing (m^2)	N ha^{-1}	No. $plot^{-1}$	Survival (%)	Height (m)	dbh (cm)	Basal area (m^2 ha^{-1})	Crown width (m)	Crown closure (%)
1.5-y								
4 × 3.5	714	102	89.5	5.3 ± 0.7a	7.7 ± 2.6a	3.5	2.9 ± 0.9a	47.5 ± 9.8a
4 × 3	833	125	93.3	5.5 ± 0.6a	7.4 ± 2.3a	3.7	2.8 ± 0.8a	52.9 ± 9.3ab
3 × 3.5	952	129	84.9	5.5 ± 0.7a	8.0 ± 2.5a	4.0	2.7 ± 1.1a	56.5 ± 10.6bc
4 × 2.5	1000	145	90.6	5.4 ± 0.7a	7.4 ± 2.9a	4.2	2.6 ± 0.9a	62.6 ± 9.3cd
3.5 × 2.5	1142	183	93.9	5.8 ± 0.9a	7.4 ± 2.4a	5.1	2.7 ± 0.8a	65.4 ± 10.4d
3-y								
4 × 4	625	84	84.0	11.6 ± 0.9a	9.6 ± 4.5a	5.2	3.4 ± 1.6a	60.3 ± 16.6a
4 × 3	833	119	88.8	11.7 ± 0.8a	9.7 ± 3.8a	6.4	3.2 ± 1.3a	68.1 ± 11.2ab
3.5 × 2.5	1142	152	83.1	11.8 ± 0.7a	9.2 ± 4.8a	8.0	3.1 ± 1.6a	72.9 ± 15.0ab
3 × 2	1666	216	80.9	12.0 ± 0.2a	9.3 ± 4.8a	11.0	2.9 ± 1.4a	79.8 ± 18.0b
6-y								
4 × 4	625	95	95.0	18.1 ± 0.3a	18.7 ± 5.9a	16.9	3.9 ± 1.3c	66.8 ± 21.1a
3 × 3	1111	151	84.8	18.7 ± 0.5b	15.9 ± 4.9b	24.0	3.3 ± 2.8b	79.1 ± 17.1b
3 × 2	1666	221	82.8	19.5 ± 0.8c	13.5 ± 4.7c	25.5	3.2 ± 1.7b	86.3 ± 11.1b
2 × 2	2500	325	81.2	20.6 ± 0.5d	11.3 ± 3.7d	26.7	2.3 ± 1.2a	87.3 ± 15.5b

* Means are significantly different when standard errors are followed by different letters ($p \leq 0.05$).

Diameter

Spacing also had no significant effect on diameter growth in the 1.5-y-old and 3-y-old plantations. A significant effect was seen in the 6-y-old plantation where wide spacing tends to increase diameter more than close spacing (Table 1). This finding was also reported by Kohan (1996). Closer spacing (Table 2) tends to decrease tree diameter significantly at 6 y of age as neighbouring canopies touch each other, as shown by the high percentage of crown closure (Table 3). Diameter increment of individual trees begins to show the effects of between-tree competition at the onset of canopy closure, the effects appearing last in the most widely spaced plots (Evans 1992).

Table 2. The effect of tree density on tree diameter, height, basal area, crown width, crown closure, and fuel load

Parameter	Plantation age		
	1.5 y old	3 y old	6 y old
Diameter (cm)	$Y = 8–4.7 \times 10^{-4}X$ ns $r^2 = 0.09$	$Y = 9.8–3.8 \times 10^{-4}X$ ns $r^2 = 0.51$	$Y = 20.6–3.9 \times 10^{-4}X$ * $r^2 = 0.96$
Height (m)	$Y = 4.6+4.4 \times 10^{-4}X$ ns $r^2 = 0.64$	$Y = 11.4+3.8 \times 10^{-4}X$ * $r^2 = 0.98$	$Y = 17.2+1.3 \times 10^{-3}X$ * $r^2 = 0.98$
Basal area (m^2 ha^{-1})	$Y = 0.7+3.6X$ * $r^2 = 0.90$	$Y = 1.0+6.4X$ * $r^2 = 0.98$	$Y = 20.58+2.25 \times 10^{-3}X$ ns $r^2 = 0.32$
Crown width (m)	$Y = 2.3–0.04X$ ns $r^2 = 0.62$	$Y = 2.6+0.05X$ * $r^2 = 0.98$	$Y = 2.1+0.12X$ * $r^2 = 0.85$
Crown closure (%)	$Y = 16.74+0.04X$ * $r^2 = 0.96$	$Y = 51.50+0.02X$ * $r^2 = 0.94$	$Y = 64.50+0.01X$ * $r^2 = 0.79$
Fuel load (t ha^{-1})	$Y = 22.8–4.8 \times 10^{-3}X$ * $r^2 = 0.94$	$Y = 21.9–1.3 \times 10^{-3}X$ * $r^2 = 0.98$	$Y = 20.96–3.06 \times 10^{-3}X$ * $r^2 = 0.92$

* Significant at $p \leq 0.05$; ns, not significantly different.

Table 3. The effect of crown closure percentage on tree diameter, height, basal area and fuel load

Parameter	Plantation age		
	1.5 y old	3 y old	6 y old
Diameter (cm)	$Y = 7.58–0.01X$ ns $r^2 = 0.16$	$Y = 10.89–0.02X$ ns $r^2 = 0.49$	$Y = 40.5–0.3X$ * $r^2 = 0.90$
Height (m)	$Y = 4.45+0.02X$ ns $r^2 = 0.50$	$Y = 10.3+0.02X$ * $r^2 = 0.96$	$Y = 11.1+0.1X$ * $r^2 = 0.77$
Basal area (m^2 ha^{-1})	$Y = -0.35+0.08X$ * $r^2 = 0.83$	$Y = 16.0+0.4X$ * $r^2 = 0.90$	$Y = -13.2+0.04X$ ns $r^2 = 0.98$
Fuel load (t ha^{-1})	$Y = 24.4–0.1X$ * $r^2 = 0.92$	$Y = 25.55–0.07X$ * $r^2 = 0.96$	$Y = 36.0–0.2X$ * $r^2 = 0.81$

* Significant at $p \leq 0.05$; ns, not significantly different.

Crown width and crown closure

The percentage of crown closure increases significantly (Table 1) at closer spacing in each planting age. As a tree gets older and its crown width expands (Table 1), the percentage of canopy cover also increases at closer spacing where tree density is also high (Table 2). Once crown closure takes place, the differences will be as keen as before, even though the more heavily stocked stand will continue to decline (Shepherd 1986). The onset of competition within a stand occurs when the crowns of individual trees begin to interfere with each other for light (Long & Smith 1984, Evans 1992).

Basal area

Basal area increases with closer spacing and age (Table 1). This is especially pronounced in the 3-y-old plantation (at 3 × 2 m spacing) and the 6-y-old plantation (at all spacings but the widest) (Table 1). The basal area increase is due more to the greater number of standing trees with increase of tree density at closer spacing than to diameter increment since at the same age closer spacing tends to have a negative effect on diameter growth, especially at ages 3 and 6 y (Tables 1 & 2).

Role of tree spacing

Wide spacing tends to give a higher fuel load than close spacing in all the plantations (Table 4). However, in the 3-y-old plantation, spacing did not have a significant effect on fuel load. Fuel load has been reported to increase up to the second year of planting and then decrease in the third and fourth years (Saharjo & Watanabe 1996). This is probably due to the fact that 1–2 y after planting, tree canopy gradually closes as crown width expands (Table 2). Table 3 shows that fuel load at all the years of planting tends to decrease significantly as crown closure increases. At 1.5 years and 3 years, the fuel load was dominated by that from the live component (Table 4), i.e. from the understorey vegetation such as *Imperata cylindrica* and shrubs, rather than from the trees themselves, i.e. fallen leaves, pod, and branches. As trees get older and space is gradually occupied by the canopy, competition starts especially for light. This competition also indicates unsatisfactory conditions, especially with close spacing. Fuel load tends to decrease significantly at close spacings at all the years of planting (Table 2). In rubber plantations, at low planting density, competition from *I. cylindrica* restricts tree growth, but at a higher planting density, this grass is controlled (Menz & Grist 1996). Once the canopy of a stand closes, weeds become suppressed by shading (Evans 1992). This is one reason fuel load (especially for live fuel, i.e. *I. cylindrica* and shrubs) decreases. The suppression of the understorey vegetation leads to the fuel load being contributed mainly by fallen leaves, pods and branches. Lower branches of closely planted trees usually die rapidly and are sometimes shed (Lim 1993).

The lowest fuel load, 13.7 t ha^{-1}, (Table 4) was found at a spacing of 2 × 2 m (6 y), but this fuel load was too high compared to the fuel load permitted to remain in the plantation, 3 t ha^{-1} (Saharjo & Watanabe 1997). This means that, with all the fuel loads measured, wildfires such as those in 1994 and 1997 will destroy the plantations. Wildfires are particularly destructive to timber and soil (McArthur 1962). Thus depending on close spacing alone to minimise fuel load in the forest plantation without proper tree maintenance is inadequate to prevent forest fire. Neglect of weeding is probably the most important single factor contributing to the failure of forest plantation in the tropics (Jackson 1983). This is especially important in a young plantation, as Table 4 shows, where weeds and live fuel load are dominant.

Table 4. Distribution of total, dead and live fuels at the 1.5-, 3- and 6-y-old plantations at different spacings

Spacing (m^2)	Fuel load ($t\ ha^{-1}$)		
	Total	Dead	Live
1.5-y			
4 × 3.5	(19.6 ± 1.1)a	(2.9 ± 0.5)b	(16.7 ± 1.1)a
4 × 3	(18.6 ± 0.8)ab	(2.8 ± 0.1)b	(15.8 ± 0.9)a
3 × 3.5	(18.1 ± 0.8)ab	(2.6 ± 0.2)ab	(15.5 ± 1.2)a
4 × 2.5	(17.9 ± 1.3)ab	(2.5 ± 0.3)a	(15.4 ± 0.7)a
3.5 × 2.5	(17.5 ± 1.1)b	(2.3 ± 0.1)a	(15.2 ± 1.3)a
3-y			
4 × 4	(21.2 ± 1.8)a	(7.7 ± 0.6)a	(13.5 ± 0.9)a
4 × 3	(20.8 ± 2.4)a	(7.5 ± 0.1)a	(13.3 ± 0.7)a
3.5 × 2.5	(20.5 ± 1.8)a	(7.3 ± 0.4)a	(13.2 ± 1.1)a
3 × 2	(19.8 ± 1.0)a	(7.1 ± 0.3)a	(12.9 ± 0.6)a
6-y			
4 × 4	(19.0 ± 1.5)a	(15.9 ± 1.3)b	(3.1 ± 0.4)b
3 × 3	(18.2 ± 1.3)a	(15.5 ± 1.8)b	(2.7 ± 0.2)ab
3 × 2	(14.8 ± 1.2)b	(12.7 ± 12.7)a	(2.1 ± 0.3)a
2 × 2	(13.7 ± 1.7)b	(12.2 ± 0.4)a	(1.5 ± 0.4)a

* Means are significantly different when standard errors are followed by different letters ($p \leq 0.05$).

High fuel loads found in young *A.mangium* plantations both at wide and close spacings showed that maintenance activities, i.e. weeding and pruning, were not done well. To obtain optimum tree growth, completely clean weeding and removing all competing and flammable vegetation are the best measures (Jackson 1983, Saharjo 1996). Otherwise a situation is created where the plantation is at a high risk of fire invasion, especially in the dry season. Reducing fuel load with closer spacing is helpful, but only as a complement. Therefore choosing the correct spacing depends on two major factors, ecology and economics. Spacing should have the ability to reduce fuel load due to the role of the closed canopy to prevent fire invasion and spread, and its stand should also be of good quality.

A narrow spacing, for instance 2 × 2 m, is an option, but if the stand quality is not good, the choice is unacceptable. Wide spacing (4 × 4 m) gives a good quality stand with fewer tree deaths, but the high accumulation of fuel load found in the stand is also a negative factor. Wide spacing that delays canopy closure may lengthen the period of fire hazard. As mentioned by Evans (1992), very close spacing is extremely expensive and very wide spacing grossly underuses the site. It is also commonly observed that *A.mangium* grown at wider spacing produces multishoots, with more and heavier branches that prune poorly and persist for long periods (Srivastava 1993). We suggest that for a pulp and paper plantation, 3 × 2 m spacing is recommended. Table 4 shows that at 3 × 2 m spacing, fuel load production was not significantly different from that at the closest spacing of 2 × 2 m. Live and dead fuels at both spacings also have no significant differences.

To keep the plantation free from fire risk, it is also highly recommended that weeding be conducted every three months after planting, with good tree maintenance.

Conclusion

The results of this research show that close spacing tends to minimise fuel load production in the plantation. The lowest fuel load resulting from the closest spacing of 2 × 2 m at 6 y was 13.7 t ha^{-1}. Unfortunately this fuel load is still too high compared to the safe fuel load level of 3 t ha^{-1}. The decrease of fuel load at closer spacing as trees get older is caused by light competition resulting from increasing crown width and crown closure. When light competition starts, fuel load composition mainly from *Imperata cylindrica* and shrubs is replaced by fuel load mainly from trees, i.e. branches, pod, and dry leaves.

Close spacing also affects tree growth. Trees in close spacing tend to produce low diameter and crown width, but high tree height, basal area and crown closure. In addition, many trees die and tree quality is not as good as that at a wider spacing.

To minimise fuel load in the plantation in order to reduce the high risk of fire it is not sufficient to depend only on close spacing without proper tree maintenance. Proper tree maintenance, especially weeding and pruning and removal of flammable vegetable matter should be done until the tree canopy closes. A 3 × 2 m spacing is recommended.

References

EVANS, J. 1992. *Plantation Forestry in the Tropics.* 2nd edition. Clarendon Press, Oxford. 403 pp.

ITTO. 1993. ITTO *Guidelines for the Establishment and Sustainable Management of Planted Tropical Forests.* 38 pp.

HIKMATULLAH, A., HIDAYAT, A., AFFANDI, U., SUPARMA, E., CHENDY, T. F. & BUURMAN, P. 1990. *Explanatory Booklet of the Land Unit and Soil Map of the Lahat Sheet (1012), Sumatra.* Centre for Soil and Agroclimate Research, Bogor. 135 pp.

JACKSON, J. K. 1983. Why do forest plantation fail? Pp. 277–285 in Wiersum, K. F. (Ed). *Strategies and Designs for Afforestation, Reforestation and Tree Planting.* Pudoc, Wageningen.

KOHAN, S. 1996. Research on intensive cultural treatments in poplar stands in the Latorica River area in Vychodoslovenska Nizina lowland. *Lesnictvi* 42(12):556–563.

LAROCQUE, G. R. & MARSHALL, P. L. 1993. Evaluating the impact of competition using relative growth rate in red pine (*Pinus resinosa* Ait.) stands. *Forest Ecology and Management* 58:65–83.

LIM, M. T. 1993. Growth and yield. Pp. 149–161 in Awang, K. & Taylor, D. (Eds). *Acacia mangium : Growing and Utilization.* Winrock International and FAO, Bangkok.

LONG, J. N. & SMITH, F. W. 1984. Relation between size and density in developing stands: a description and possible mechanisms. *Forest Ecology and Management* 7:191–206.

MCARTHUR, A. G. 1962. *Control Burning in Eucalypt Forest.* Leaflet Forest Timber Bureau Australia, No. 80. 31 pp.

MENZ, K. M., & GRIST, P. 1996. Increasing rubber planting density to shade *Imperata*: a bioeconomic modelling approach. *Agroforestry Systems* 42(12):291–303.

SAHARJO, B. H. & WATANABE, H. 1995. Fire behavior in a newly established *Acacia mangium* plantation in South Sumatra, Indonesia. Paper presented at the 106th annual meeting of the Japanese Forestry Society. Hokkaido, Japan, April 2–5, 1995.

SAHARJO, B. H. 1996. Disappearance of a newly establish *Acacia mangium* Willd. plantation by fire in South Sumatra. *Tropical Forest Management Journal* 2(1):65–72.

SAHARJO, B.H. & WATANABE, H. 1996. Fire threatens industrial forest plantation: the case study in South Sumatra, Indonesia. Paper presented at the 13th Conference on Fire and Meteorology: International landscape fires. October 27–31, 1996, Cumberland Conference Center, Lorne, Australia. 23 pp.

SAHARJO, B. H. & WATANABE, H. 1997. Did close spacing reduce fuel load in an *Acacia mangium* plantation ? Paper presented at the 7th annual meeting of the Japan Society for Tropical Ecology. Shiga, Japan, June 21–22, 1997.

SCHMIDT, F. H. A. & FERGUSSON, J. H. S. 1951. *Rainfall Type Based on Wet and Dry Periods of Ratios from Indonesia with Western New Guinea.* Verhandelingen No.42. Directorate of Meteorology and Geophysics, Jakarta. 77 pp.

SHEPHERD, K. R. 1986. *Plantation Silviculture.* Martinus Nijhoff Publishers, Dordrecht. 322 pp.

SMITH, D. M. 1986. *Tree Practice of Silviculture.* 8th edition. John Wiley and Sons, New York. 527 pp.

SRIVASTAVA, P. B. L. 1993. Silvicultural practices. Pp. 113–147 in Awang, K. & Taylor, D. (Eds.) *Acacia mangium : Growing and Utilization.* Winrock International and FAO, Bangkok.

STEEL, R. G. D. A. & TORRIE, J. H. 1981. *Principles and Procedure of Statistics: A Biometrical Approach.* 2nd edition. McGraw-Hill, Inc., New York. 633 pp.