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TREE GROWTH AND POTENTIAL YIELD OF PLANTATION GROWN *DRYOBALANOPS AROMATICA* OF PENINSULAR MALAYSIA

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AHMAD ZUHAIDI, Y., VAN GARDINGEN, P. R. & GRACE, J. 2003. Tree growth and potential yield of plantation grown *Dryobalanops aromatica* of Peninsular Malaysia. The study focused on the growth of 50- to 70-year-old planted *Dryobalanops aromatica*, potential yield and factors affecting its growth within the research area of the Bukit Lagong Forest Reserve at the Forest Research Institute Malaysia (FRIM). Trees were evaluated on periodic annual diameter increment over a period of four years (1997–2000) consisting of six experimental plots with sizes ranging from 0.21 to 0.96 ha. The observed periodical annual diameter increments (P_{obs}) were significantly different between plots and years, with a mean of 0.28 ± 0.01 cm year^{-1} (ranging from 0.21 ± 0.02 to 0.43 ± 0.04 cm year^{-1}). The P_{obs} already falls below the mean annual diameter increment indicating that growth of the species had passed the culmination point of the mean annual increment. Two of the six plots (2 and 6) had significantly higher P_{obs} than the remaining plots. Both of these plots had lower stand densities (161 and 184 stem ha^{-1} respectively) and maintained the highest diameter increments throughout the observation period. The occurrence of a prolonged drought in 1997 did not effect these plots much. Plot 5 with the highest stocking had the lowest rate for P_{obs} at 0.21 ± 0.02 cm year^{-1}. Assuming all trees P_{obs} > 50 cm were harvested in 2000, the potential yield ranged from 61.3 to 425.8 m^3 ha^{-1}.

Key words: Periodic annual diameter increment - Bukit Lagong Forest Reserve - stand density - drought

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AHMAD ZUHAIDI, Y., VAN GARDINGEN, P. R. & GRACE, J. 2003. Pertumbuhan dan potensi hasil balak *Dryobalanops aromatica* yang ditanam di ladang di Semenanjung Malaysia. Kajian ini bertujuan untuk mengetahui kadar pertumbuhan dirian *Dryobalanops aromatica* (kapur) yang telah mencapai umur antara 50 hingga 70 tahun, potensi hasil balak serta faktor-faktor yang mempengaruhi pertumbuhan pokok di kawasan penyelidikan hutan simpan Bukit Lagong, Institut Penyelidikan Perhutanan Malaysia (FRIM). Pertumbuhan pokok dinilai dari segi tambahan diameter tahunan berkala selama empat tahun bermula dari tahun 1997 hingga tahun 2000 dengan enam petak kajian bersaiz antara 0.21 hingga 0.96 hektar. Keputusan kajian ini mendapati bahawa tambahan diameter tahunan berkala yang dicerap (P_{obs}) mempunyai perbezaan bererti antara petak dan tahun diukur, dengan purata P_{obs} sebanyak 0.28 ± 0.01 cm tahun^{-1} (julat antara 0.21 ± 0.02 hingga 0.43 ± 0.04 tahun^{-1}). Akan tetapi, P_{obs} adalah lebih rendah daripada kadar purata pertumbuhan tahunan. Ini menunjukkan bahawa pertumbuhan pokok ini telah melepasi tahap pertumbuhan maksimum. Dua daripada enam petak kajian (2 dan 6) mempunyai nilai P_{obs} yang lebih tinggi secara bererti berbanding petak lain. Kedua-dua petak ini mempunyai ketumpatan dirian yang rendah (masing-masing 161 dan 184 pokok hektar^{-1}) dan mempunyai tambahan diameter tahunan yang tinggi sepanjang kajian. Musim kemarau yang panjang pada tahun 1997 tidak mempengaruhi kadar pertumbuhan pokok di dalam petak berkenaan. Petak 5 mempunyai ketumpatan tertinggi tetapi mempunyai kadar P_{obs} yang paling rendah iaitu 0.21 ± 0.02 cm tahun^{-1}. Jika semua pokok yang mempunyai diameter > 50 cm ditebang, jangkaan hasil pengeluaran kayu balak pada tahun 2000 adalah antara 61.3 hingga 425.8 m^3 hektar^{-1}.

Introduction

The study of growth and yield of forest stands is a central issue in forestry research and management. In recent years, much emphasis has been placed on the growth and yield of mixed tropical forest (Lieberman & Lieberman 1987, Vanclay 1989, Yong 1990, Alder 1995, Ong & Kleine 1995, Silva *et al.* 1995, Kohler & Huth 1998) and subtropical forests (Rautiainen *et al.* 2001). However, a full understanding of the growth and yield of plantation-grown indigenous tropical species such as *Dryobalanops aromatica* is still lacking. Currently in Malaysia, there are few studies on the growth and yield of *D. aromatica*, which are restricted to naturally regenerated *Dryobalanops* species (Chiew & Garcia 1989, Primack *et al.* 1989, Abd. Rahman *et al.* 1992). Thus, this study was initiated after recognising the importance of growth and yield studies of plantation-grown dipterocarp species for future forest management decisions, coupled with a general paucity of knowledge on the growth and potential yield of the species planted under plantation conditions. *Dryobalanops aromatica* is regarded as the most promising indigenous species for forest plantation in Peninsular Malaysia (Afzal-Ata 1985, Abd. Rahman *et al.* 1992, Appanah & Weinland 1993) and future reforestation works with this species will cover a wide spectrum of land areas including flat, undulating and even sloping topography. The study provides an opportunity to generate growth and potential yield of the species and baseline information for future planting of *D. aromatica* under plantation conditions. This paper focuses on the analysis of the growth and estimates of potential yield of *D. aromatica* recorded between 1997 and 2000.

Materials and methods

Study area

The study area is situated in Selangor in the western part of Peninsular Malaysia at latitude 3° 14' N and longitude 101° 38' E (Amir Husni *et al.* 1997). Located just north of the equator, the area has a humid climate with average daily temperature ranging from 27 to 32 °C. The annual rainfall is between 1900 and 2050 mm indicating that the area receives precipitation at the lower range of rainfall expected in the humid tropics (Wyatt-Smith 1963, Ismail 1964). The study sites are located at an elevation between 90 and 130 m asl on the lower slopes of the Lagong range, Bukit Lagong Forest Reserve, Selangor, Peninsular Malaysia (Amir Husni *et al.* 1997). Most of the areas were formerly cultivated as vegetable gardens and later overgrown with *Imperata cylindrica* (Landon 1948).

The terrain is undulating. Boulders are common on ridges and in some cases on steep slopes. The parent material is granite and the soil texture ranges from lateritic, sandy loam to sandy soils. The soil is a reddish loam with underlying rock and granite belonging to the Palaeudult series, locally known as Rengam (Wyatt-Smith 1963).

Experimental plot and historical description

Study plots of 0.96, 0.64, 0.49, 0.48, 0.21 and 0.25 ha of *D. aromatica* were established in August 1996 and January 1997 in blocks located within the Bukit Lagong Forest Reserve. The plot size was smaller than the recommended size of one hectare (Alder & Synnott 1992) but unavoidable as the selection of plot was based on remaining areas of planted *D. aromatica.* These areas vary in sizes from 0.3 to 1.0 ha and are scattered within the reserve. Located within the same area, all the study plots have similar soil type and climate.

Plot 1

Plot 1 was established in block 9 A and has an elevation of 100 to 113 m asl and also an eastern aspect with slight to gentle slope. There had been vegetable cultivation prior to 1927 on what was almost certainly old mining land (Landon 1948). The soil was light and sandy except in patches with thick growth of ferns (*Gleichenis* spp.). In 1927, the block was planted in lines at 3.6 m apart with small seedlings of *Pterocarpus peltocarpum, Swietenia macrophylla* and *Artocarpus elasticus.*

The seedlings were planted to provide shade and to create an environment suitable for the establishment of *D. aromatica* seeds and seedlings. When the initial planting proved unsuccessful, seedlings of *P. indicus* were planted to fill the spaces left vacant by the dead shade trees. *Dryobalanops aromatica* seeds were planted in 1935 at an interval of 1.8 × 0.3 m. During the Japanese occupation period (1944–1945) all the *D. aromatica* trees, poles and saplings, except those with poor form were cut for construction of temporary quarters for the Japanese army. Towards the end of October 1947, bamboo tubes, stumps and wrenched seedlings of *D. aromatica* were re-planted together with few seedlings of *Balanocarpus hemii* at a spacing of 3.0 × 1.5 m (Anonymous 1947a, Landon 1948). Eight weeding and climber cutting treatments were carried out between 1948 and 1964. Thinning was carried out 13 years after planting, i.e. in 1960 with the removal of 451 trees. The majority of the removals (85%) were from the lower diameter classes (2.4 to 10.0 cm), leaving the larger trees to form the crop trees.

Plot 2

Plot 2 was established in block 30 E. The former vegetation in this plot consisted of secondary forest with heavy infestation of stem palms. Prior to planting, undergrowth was cut back and lines cleared leaving the ground lightly shaded by secondary forest canopy. The *D. aromatica* stand was established in October 1939 (Anonymous 1939), with the planting of 600 seedlings from seed sown in January the same year. The seedlings were planted at a spacing of 1.8 × 1.8 m in lines cleared at a width of 0.5 m. The seedlings experienced wet season in November followed by an intense drought lasting for 20 days in December 1939. Weeding was carried out in December 1940. Thinning was conducted on 10 May 1959 when the stand age was 20 years old with the removal of 47 trees. A total of 60% of trees removed had a diameter < 14.0 cm.

Plot 3

This plot is located in block 8 T. This block was formerly cultivated-vegetable gardens and in some parts were covered with secondary forests and stem palms. Parallel lines were cut throughout at 3.3 m interval, widened to 1.5 m and cleared. On 10 January 1933 (Anonymous 1933), 362 seedlings of *D. aromatica*, germinated from seed sown in April the previous year, were transferred from the nursery in small bamboo tubes to the plot. In November 1940, a total of 285 saplings of *D. aromatica* survived. However, no record of the removals and thinning were available.

Plot 4

The plot is located in block 12 C. The former vegetation in this block consisted of light secondary forest forming a complete cover with some parts overgrown with stem palms. The *D. aromatica* stand was established in January 1927 (Anonymous 1926), with the planting of 521 seedlings from seed sown in August 1926. Seedlings were planted along parallel lines cut throughout at 3.6 × 3.6 m intervals (772 seedlings ha^{-1}). Two thinnings were carried out in 1934 and 1940 at stand ages of eight and 14 years old respectively. However, there were no records of the number of stems removed. Two additional thinnings were carried out in 1953 and 1956 with the removal of 64 and 114 trees ha^{-1} at stand ages of 27 and 30 years old respectively. The first recorded diameter and height measurements in this block were carried out in 1949. This was followed by a series of diameter and height measurements in 1953, 1956, 1957, 1960, 1962, 1969 and 1978.

Plot 5

The plot is located in block 8 P. The *D. aromatica* stand within the block was established on 7 May 1947 from seed sown on 8 January 1947 (Anonymous 1947b). A total of 1060 seedlings were line-planted at 1.8 × 1.8 m spacing (3086 seedlings ha^{-1}). The former vegetation was mainly old secondary forest, vegetable gardens, palms and ferns (*Dicranopteris* spp.). Heavy thinning was carried out in November 1960 with the removal of 181 trees with diameter classes between 2.5 and 20 cm.

Plot 6

The plot is located in block 12 C 1. The former vegetation in this block consisted of light secondary forest forming a complete cover with some parts overgrown with stem palms. The *D. aromatica* stand was established in January 1927 (Anonymous 1926) from seeds sown in August 1926. Seedlings were planted along parallel lines cut throughout at 3.6 × 3.6 m interval (770 seedlings ha^{-1}). Thinnings were carried out in 1953 and in 1956 at stand ages of 27 and 30 years old respectively; however, no further records were available.

Diameter measurement

The diameter at breast height (dbh) was measured for all individuals with dbh > 10 cm. Measurements were taken from the uphill sides of trees and saplings that were standing erect, and from the insides of lean for leaning trees and saplings. For trees with deformations at 1.3 m, measurements were made at a sound point on the stem above the abnormality. For buttressed trees (about 10 trees altogether), a point of measurement was selected approximately 0.5 m above the convergence of the buttress (Husch *et al.* 1982). The point of measurement was permanently marked on the tree with a painted band. Measurement was made exactly along the top line of this band. Diameter measurements of trees were recorded using a metal metric diameter tape graduated in centimeters. During measurement, loose bark, climbers and epiphytes were lifted above the measuring tape. Trees were measured in the same sequence each year in August 1997, 1998, 1999 and 2000 as control for any seasonal effect on growth.

Total tree height and crown point height measurement

Total tree heights (H) and crown point heights (h) were measured for a sample of 30 trees in each plot as in Alder and Synnott (1992), and also over the whole range of height-diameter values (Kleine & Weinland 1991). The total height of a tree is the distance along the axis of the tree stem from the ground to the tip of the last branch of the crown (Husch *et al.* 1982). The highest point of the crown was measured vertically from the ground level at the centre of the stem to the tip of the crown.

Crown point height is the distance along the axis of the tree stem from ground level to the first branch forming the crown (Husch *et al.* 1982). The clear bole height, also called the crown point height, is the height from the base of tree to the first branch forming the crown, excluding small epicormic shoots. Crown length was calculated as the difference between total height and crown point height. The distance from the point of measurement to the tree trunk was recorded and then corrected for slope.

Tree height was determined by measuring the angle (in per cent) subtended to the top and base of the tree. Similarly, crown point of the tree was determined by measuring the angle subtended to the crown point and base of the tree. On sloping ground, when the base of the tree was below the eye level, both of the readings obtained were added. The tree height or crown point height is the product of the multiplication between corrected distance (j') and the sum of the percentage readings as in Equation 1 (Anonymous 1995).

$$H = \frac{j'(x+z)}{100} \qquad (1)$$

where

H = tree height (m),
j' = corrected distance (m),
x = angle subtended to the top of tree (%), and
z = angle subtended to the base of stem (%).

The angles to the top of tree, crown point and base of stem were recorded using an optical clinometer (Model PM-5 / 400 PC, Suunto Company, Helsinki, Finland). From measurements taken for 30 individual trees per plot, height and crown point curves were fitted for each plot by employing the method of least squares using the quadratic function (Loetsch *et al.* 1973, Kleine & Weinland 1991) (Equations 2 and 3). The function was fitted using the SAS Version 8 software package.

$$\ln(H) = \{\ln(\beta_0) + \ln(\beta_1) \times d\} + \{\ln(\beta_2) \times d^2\} \qquad (2)$$

$$\ln(h) = \{\ln(\beta_0) + \ln(\beta_1) \times d\} + \{\ln(\beta_2) \times d^2\} \qquad (3)$$

where

H = dependent variable; height,
h = dependent variable; crown point height,
β_0, β_1 and β_2 = intercept and regression coefficients, and
d = independent variable; dbh.

Basal area

Basal area is defined as the cross-sectional area of planes cutting the stem of a tree to the longitudinal axis of the stem taken at breast height (Husch *et al.* 1982). The basal area per tree was obtained using Equation 4 (Loetsch *et al.* 1973).

$$g = \frac{\{(d^2 \pi) + 4\}}{10\,000} \qquad (4)$$

where

g = basal area per tree (m^2),
d = dbh (cm), and
π = 3.1416.

The basal area (G) was obtained by the sum of individual basal area corrected for the size of each individual plot.

Stem and stand volume

Currently there is no available double-entry volume table for *D. aromatica*; as such the stem volume was calculated using Equation 5 (Afzal-Ata *et al.* 1985, Abd. Rahman *et al.* 1996, Ahmad Zuhaidi & Gardingen 1999).

$$v = g \times h \times c \qquad (5)$$

where

v = volume per tree (m^3), and
c = an assumed constant factor of 0.65 for crown point height.

The volume (V) was obtained by the sum of individual stem volume corrected for the size of each individual plot.

Observed periodic annual diameter increment

The observed periodic annual diameter increment was obtained using Equation 6. Difference between diameters measured at the beginning and at the end of the period was determined and divided by the number of days in the period and multiplied by 365.

$$P_{obs} = \frac{d_{t+k} - d_t}{k} \times 365 \qquad (6)$$

where

P_{obs} = observed periodic annual diameter increment (cm $year^{-1}$),
d_{t+k} = diameter at end of growth period (cm),
d_t = diameter at beginning of growth period (cm), and
k = length of growth period (days).

Mean annual diameter increment (M_d) of a tree is the total accumulated diameter values of the tree divided by its age (number of days) (Evans 1982).

The overall periodic annual diameter increment, mean periodic annual diameter increment between the years of measurements and mean annual increment were determined using SAS/STAT 1989 PROC Summary.

Correlation

The correlation coefficient (*r*) values between the observed periodic annual diameter increments against the stand parameters (for instance the stem number, *N*) were calculated as in Freese (1984). Besides *r*, partial correlation coefficients were also calculated (Freese 1984).

Analysis of data

Statistical analysis of differences between plots was analysed using SAS/STAT 1989 repeated analysis of variance. A repeated measure analysis was employed to analyse the interaction between years of measurement and plots. SAS/STAT 1989 PROC GLM was used since four diameter measurements were obtained on the same trees from 1997 to 2000. Duncan's multiple range test (DMRT)was used to determine differences between means.

Results and discussion

Overall stand growth

Table 1 shows the details of the stand in the six plots initially measured at the beginning of the study in 1997. After more than 50 years, the maximum achieved mean dbh of Plots 2, 3, 4 and 6 had reached more than 70 cm (Table 1). Plots 2 and 6 showed low stand density regimes after thinning treatments in the early 1950's, while Plots 3 and 4, reached standing ages of 64 and 71 years respectively. The calculated mean annual diameter increment was between 0.54 and 0.80 cm year^{-1}. Similar growth rates were reported by Abd. Rahman *et al.* (1996) and Afzal-Ata *et al.* (1985). This indicated that the stands had passed the culmination point of the mean annual increment and were approaching rotation age and close to limiting growth. Plot 5 had the lowest mean diameter among all plots (Table 1). In terms of basal area ha^{-1}, all plots had similar values ranging from 30.2 to 38.2 m^2 ha^{-1}. Plot 5 also had the highest stand density at 557 stems ha^{-1} followed by Plot 1 with 321 stem ha^{-1}. Higher stand density is the most possible reason for the low mean diameter in Plot 5. This achieved mean diameter is further explained by the relatively high rate of annual mortality in this plot at 2.6%, which is indicative of high between-tree competition. Stands with high density have smaller mean diameter than similar stands with wider spacing as in thinned stands (Kleine & Weinland 1991). Plots 2 and 6, which had the lowest remaining stems at 161 and 184 stems ha^{-1} respectively, achieved the highest mean dbh at 45.7 and 49.3 cm respectively. Low densities with wide spacing of even-aged stands in Plots 2 and 6 (161 and 184 stems ha^{-1} respectively) showed consistent increases in dbh.

Table 1 Standing stock of the *Dryobalanops aromatica* plots for trees ≥ 10 cm dbh at Bukit Forest Lagong Reserve, Selangor, Peninsular Malaysia in 1997

Plot	Age (year)	N (ha^{-1})	d (cm)	h (m)	d_{max} (cm)	G (m^2 ha^{-1})	V (m^3 ha^{-1})
1	50	321	32.6 ± 0.9	22.3 ± 0.2	68.4	32.5	465.1
2	57	161	45.7 ± 1.9	20.8 ± 0.5	91.4	30.2	409.0
3	64	318	36.2 ± 1.0	21.1 ± 0.4	73.3	37.4	527.0
4	71	258	40.3 ± 1.5	24.7 ± 0.6	80.7	38.7	647.4
5	51	557	27.8 ± 0.9	25.6 ± 0.3	58.7	38.2	615.8
6	71	184	49.3 ± 1.5	28.6 ± 0.2	73.2	36.7	627.1

Note: N: number of stems, d: mean diameter, h: mean crown point height, d_{max}: maximum achievable diameter, G: basal area ha^{-1}, V: volume ha^{-1} (up to crown point height)
Means ± 1 SE

Data from this study revealed a calculated total volume 409.0 to 647.4 m^3 ha^{-1}. Similar calculated total volume was reported for stands of *Shorea platyclados* and *Shorea parvifolia* (553 and 436 m^3 ha^{-1} respectively) within Bukit Lagong Forest Reserve in Peninsular Malaysia (Ahmad Zuhaidi *et al.* 1995).

Periodic and mean annual diameter increments

The periodic annual diameter increments during the period 1997 to 2000 ranged from 0.21 to 0.42 cm $year^{-1}$ (Table 2). Ranking based on DMRT showed that periodic annual diameter increment in Plots 2 and 6 were significantly higher than the other plots and significantly different between Plots 1, 3, 4 and 5 at $p < 0.05$. These periodic annual diameter increments are similar to the values attained by the naturally regenerated *Dryobalanops* species in the unlogged lowland dipterocarp forests of Kuamut Forest Reserve, Sabah, East Malaysia and Sungei Menyala Forest Reserve, Peninsular Malaysia (Manokaran & Kochummen 1987, Chiew & Garcia 1989, Yong 1990). Nicolas *et al.* (1998) reported an overall periodic annual diameter increment growth of 0.3 cm $year^{-1}$ for dipterocarps in mixed dipterocarp forests of East Kalimantan while Nicholson (1965) found higher overall growth rate of 0.48 cm $year^{-1}$ in North Bornean forests.

Table 2 Observed periodic annual diameter increment (P_{obs}) for the period 1997 to 2000 and mean annual increment (M_d) of plantation-grown *Dryobalanops aromatica* for trees ≥ 10 cm dbh

Plot	P_{obs}* (cm $year^{-1}$)	M_d* (cm $year^{-1}$)
1	0.28 ± 0.01b	0.64 ± 0.01c
2	0.41 ± 0.03a	0.80 ± 0.01a
3	0.25 ± 0.02bc	0.57 ± 0.01d
4	0.24 ± 0.02bc	0.56 ± 0.01d
5	0.21 ± 0.02c	0.54 ± 0.01d
6	0.43 ± 0.04a	0.69 ± 0.02b
Mean	0.28 ± 0.01	0.61 ± 0.01

*Values in each column with the same letter are not significantly different at $p < 0.05$.
Means ± 1 SE

After three years, assessment on the growth performance of each stand was carried out based on the periodic annual increment between plots and years of measurement. Results of the analysis (Table 3) using repeated analysis of variance showed that there were significant difference between plots ($p < 0.0001$), years ($p < 0.05$) and interaction between plots and time ($p < 0.0001$). The periodic annual diameter increment for interval 1 (1997 to 1998) in Plots 1, 3 and 4 was lower than the periodic annual diameter increment in interval 2 (1998 to 1999) and interval 3 (1999 to 2000) (Figure 1). The periodic annual diameter increment for 1997 (0.2 cm) was significantly different and lower than the periodic annual diameter increment in 1998 and 1999 (0.3 cm). The reason for the lower value in 1997 was the prolonged dry weather, haze and smoke in Peninsular Malaysia including areas in Bukit Lagong Forest Reserve. This was caused by the effects of El Niño from the Sumatran forest fires in 1997 between January and end of May (Khandekar *et al.* 2000). The effects of the prolonged drought and haze were more distinct in Plots 1, 3 and 4 for interval 1 compared with intervals 2 and 3. However, Plot 5 had the lowest increment for all intervals. Increased aridity, drought and haze can reduce growth rates and photosynthetically active radiation and cause permanent wilt for some trees (Yoneda *et al.* 2000, Aiba & Kitayama 2002).

Plots 2 and 6 did not show any significant trend in the periodic annual diameter increment between all intervals. Nevertheless, the results showed that the periodic annual diameter increments in Plots 2 and 6 were significantly higher than Plots 1, 3, 4 and 5 ($p < 0.05$) due to better resistance to drought. Plots 2 and 6 had the lowest number of trees ha^{-1} and most of the trees were of larger size class and thus, were less affected by the drought. Subsequently, the calculated mean annual diameter increment was between 0.54 and 0.80 cm year^{-1} (Table 2). Ranking based on DMRT showed that mean annual diameter increments in Plots 1, 2 and 6 were significantly different at $p < 0.05$ with Plot 2 having the highest value. The mean annual diameter increments in Plots 2 and 6 were also significantly higher as both plots had the highest mean dbh with low stand density and thus experienced reduced effect from tree competition. The achieved mean annual diameter in the remaining plots were significantly lower in the ranking of Plot 1 > 3 > 4 > 5 with Plot 5 having the highest stand density.

Table 3 Repeated analysis of variance between subject effects (plots) and within subject effects (years of measurement)

Source	Degree of freedom	Sum of square	Mean of square	F	Pr > F
Plot	5	8.72	1.74	6.42	< 0.0001
Error	813	220.91	0.27		
Total	815	229.63			
Time	2	1.16	0.58	5.12	0.0061
Time*plot	10	5.44	0.54	4.82	< 0.0001
Error	1626	183.59	0.11		
Total	1638	190.19			

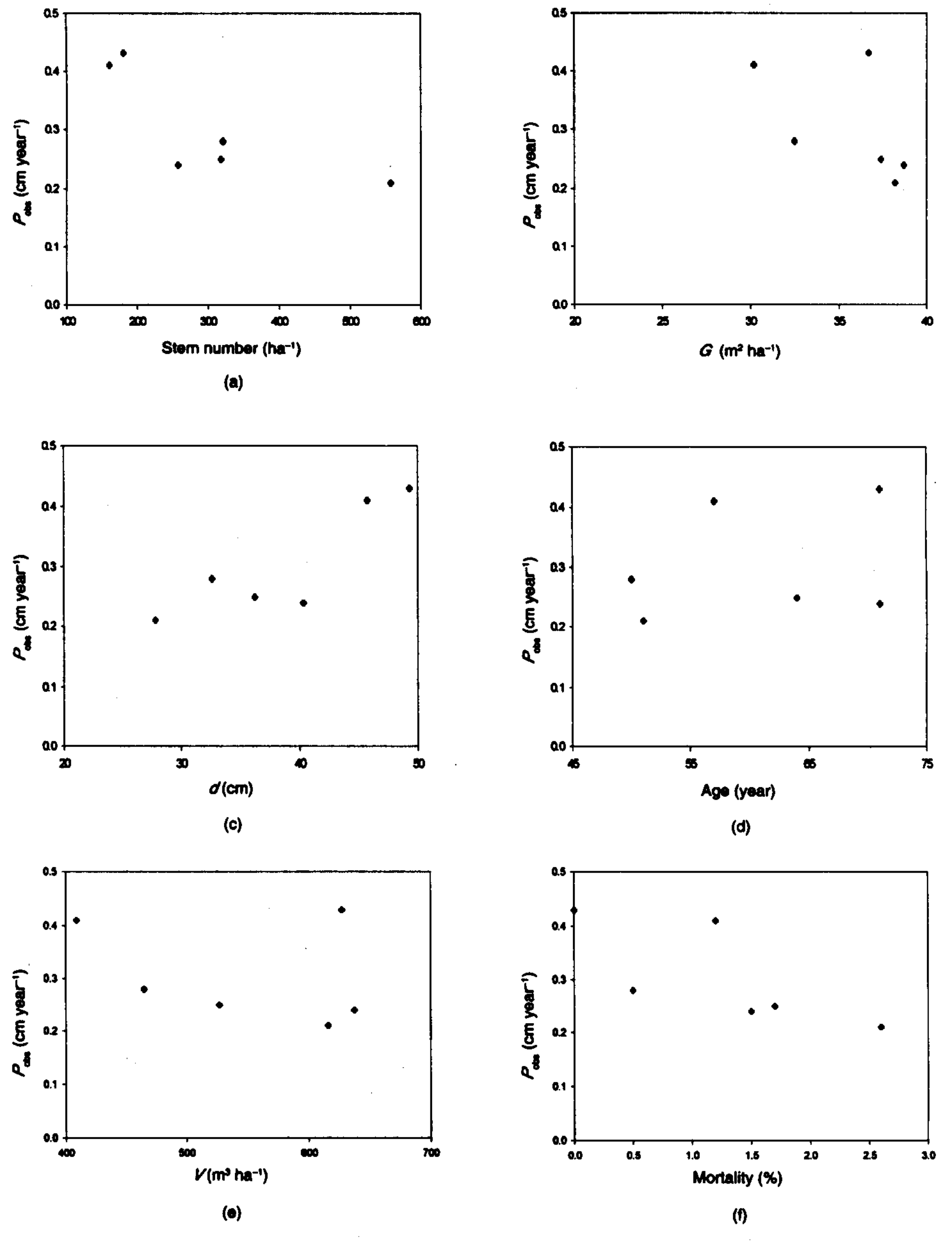


Figure 1 Graphical representations of the relationship between periodic annual diameter increment (P_{obs}) against number of stems ha^{-1}, basal area ha^{-1}, mean diameter, age, volume ha^{-1} and mortality rate

Despite all the differences in the response among all plots, no significant trend was observed in Plot 5. Generally, periodic annual diameter increments for all plots were lower in the first period but increased at the later period of observation. Figure 1 shows the pattern for periodic annual diameter increment from 1997 to 1998, 1998 to 1999 and 1999 to 2000.

Basal area, volume ha^{-1} and mortality rate for trees ≥ 10 cm dbh

Plots 2 and 6 also had the highest increase in basal area ha^{-1} at 0.46 and 0.67 m^2 ha^{-1} year^{-1} respectively (Table 4) compared with the periodic annual basal area increments in Plots 1, 3, 4 and 5. Higher periodic annual basal area increment was due to the large size class trees ≥ 50 cm dbh. Plot 6 had the highest increase in periodic annual volume increment at 14.4 m^3 ha^{-1} year^{-1} followed by Plots 4, 1, 2, 5 and 3. Plot 5 showed the lowest change in basal area with 0.05 m^2 ha^{-1} year^{-1} as a result of the lowest periodic annual diameter increment during the observation period but a moderate volume increment (6.2 m^3 ha^{-1} year^{-1}). This can be explained by the comparatively large increase in crown point height (Table 4) in this plot. The trees in Plot 5 were growing under high stand density and intensive competition; thus the canopy lifted more and, as a result, the crown point increased. The total remaining trees reduced from 321 to 316 trees ha^{-1} (Plot 1), 161 to 155 trees ha^{-1} (Plot 2), 316 to 300 trees ha^{-1} (Plot 3), 258 to 246 trees ha^{-1} (Plot 4) and 557 to 509 trees ha^{-1} (Plot 5). This gave annual mortality rates ranging from 0.5 to 2.6% over the whole observation period between 1997 and 2000 (Table 4).

Table 4 Annual change in the basal area ha^{-1} (P_G), crown point height (P_h) and volume ha^{-1} (P_V) of plots and the estimated mortality rate from of 1997 to 2000

Plot	P_G (m^2 ha^{-1} year^{-1})	P_h (m year^{-1})	P_V (m^3 ha^{-1} year^{-1})	Mortality rate (% year^{-1})
1	0.19	0.24	9.1	0.5
2	0.46	0.18	6.9	1.2
3	0.27	0.02	2.8	1.7
4	0.41	0.40	10.8	1.5
5	0.05	0.37	6.2	2.6
6	0.67	0.16	14.4	0.0
Mean + SE	0.34 ± 0.09	0.23 ± 0.06	8.4 ± 1.6	1.2 ± 0.4

Correlation and partial correlation

Table 5 shows the correlation and partial correlation coefficient values of the periodic annual diameter increment against stand parameters. These relationships were further illustrated using graphical relationship as shown in Figure 2. Analysis of the results on the achieved periodic annual diameter against the stand parameters showed negative coefficient of correlation (Figures 2(a), (b), (e) and (f)). Negative correlation coefficient was found between periodic annual diameter increment and stem number ha^{-1} ($r = -0.79$), basal area ha^{-1} ($r = -0.56$), volume ha^{-1} ($r = -0.31$) and mortality rate ($r = -0.73$). This indicates an association with the larger values of periodic annual diameter increment with reduced stem number ha^{-1}, basal area ha^{-1}, volume ha^{-1} and mortality rate. These results show that

Table 5 Correlation and partial correlation coefficients between periodic annual diameter increments against stand parameters

Parameter	r	$r_{12.3}$	$r_{13.2}$	$r_{23.1}$
N	- 0.79	- 0.44	- 0.18	0.03
G	- 0.56			
V	- 0.31			
d	0.87			
Age	0.28			
Mortality	- 0.73			
Mortality / N	0.74			
Mortality / G	0.77			
Mortality / d	- 0.66			

Note: $r_{12.3}$ = partial coefficient of correlation between P_{obs} and N, holding G constant,
$r_{13.2}$ = partial coefficient of correlation between P_{obs} and G, holding N constant,
$r_{23.1}$ = partial coefficient of correlation between N_{obs} and G, holding P_{obs} constant,
N = number of stems ha^{-1}, G = basal area diameter, V = volume ha^{-1} (up to crown point height), d = mean diameter

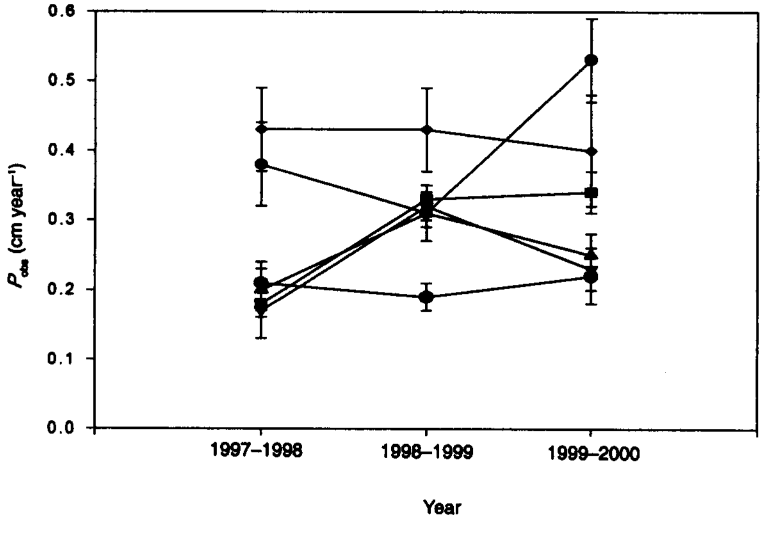


Figure 2 Observed periodic annual diameter increment (P_{obs}) for each study plot the averaged period as shown. (a) Plot 1 - ■, (b) Plot 2 - ●, (c) Plot 3 - ▲, (d) Plot 4 - ▼, (e) Plot 5 - ●, (f) Plot 6 - ◆. Means are reported ± 1 SE

lower stand density and bigger-size trees reduced the effect of drought stress on the periodic annual diameter increment. Negative correlation between periodic annual diameter increment and tree mortality was indicative of reduced mortality in trees of bigger size class growing under a lower stand density with lower levels of between-tree competition.

Positive correlation between periodic annual diameter increment and mean diameter ($r = 0.87$) and age ($r = 0.28$) (Figures 2(c) and (d)), indicates that larger values of periodic annual diameter increment were associated with low stand densities and larger values of tree size. Low correlation between periodic annual diameter increments and age indicates that age had little effect on the increment. Furthermore, the observation period was rather short ranging from 50 to 70 years. Similarly the correlations between mean mortality rate and stem number ha^{-1} ($r = 0.74$) and between mortality rate and basal area ha^{-1} ($r = 0.77$) were indicative of the effect of high between tree-competition that caused high mean mortality rate in the plots. A negative correlation ($r = -0.66$) between mortality rate and dbh shows that high mortality rate was associated with plots containing many trees having small diameter class.

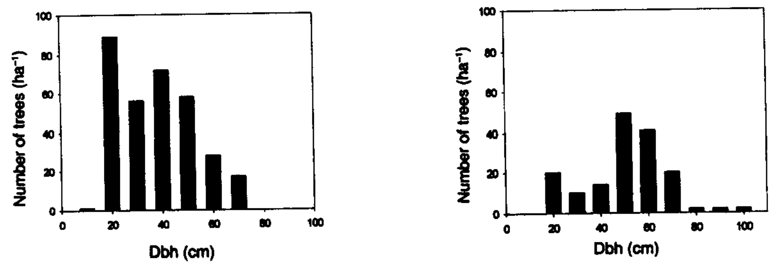
The partial coefficients of correlation were also calculated between the three variables, i.e. periodic annual diameter increment (P_{obs}), stem number ha^{-1} (N) and basal area ha^{-1} (G). This is to ascertain the true degree of association between P_{obs} and N, independent of G, which may be associated with them. The results showed that $r_{12.3}$, $r_{13.2}$ and $r_{23.1}$ were - 0.44, - 0.18 and 0.03 respectively which truly indicate the negative coefficient of correlation between P_{obs} and N, P_{obs} and G (holding G and N constant), and positive partial coefficient of correlation between N and G (holding P_{obs} constant).

Diameter class distribution

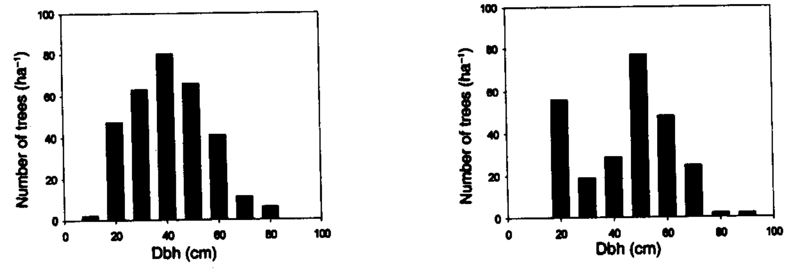
Figure 3 shows the summary of the diameter class distribution of all trees ≥ 10 cm for all study plots. The frequency distributions for Plots 1 to 5 show many trees of small-size classes. This is probably the reason for the presence of dual histogram peaks on the same graph. The greatest frequency for trees > 20 cm dbh was in Plot 5 at 119 trees ha^{-1}. Small-size classes comprised trees that were naturally regenerated within the plots from previous flowering and fruiting observed within the stands. However, there were no trees < 30 cm dbh in Plot 6.

Potential yield

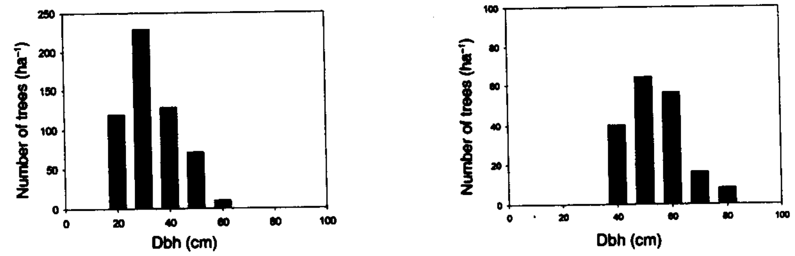
The potential yield, which refers to the utilisable timber volume, was calculated by assuming that stands harvested in 2000 removed all trees ≥ 50 cm dbh (Table 6). The calculated average potential yield ha^{-1} (trees ≥ 50 cm dbh) ranged from 61.3 to 404.8 m^3 ha^{-1}. Mean diameters in all plots were not significantly different at $p < 0.05$. The 95% confidence interval for potential yield per plot was 138 to 430 m^3 ha^{-1}. However, the potential yield in Plot 5 was significantly lower and lay outside the limit of 95% confidence interval and as such was significantly different compared with the other plots which all lay within the 95% confidence interval.



(a) Plot 1 (b) Plot 2



(c) Plot 3 (d) Plot 4



(e) Plot 5 (f) Plot 6

Figure 3 Dbh class distribution (for trees ≥ 10 cm dbh) of plantation-grown *Dryobalanops aromatica* in Plots 1, 2, 3, 4, 5 and 6 in 1997 at Bukit Lagong Forest Reserve, Selangor, Peninsular Malaysia. The frequency scales for (e) differ from others because of the high total number of stems in this plot.

Table 6 Calculated potential yields of plantation grown *Dryobalanops aromatica*, at Bukit Lagong Forest Reserve in 2000

Plot	Age	d (cm)	N (ha^{-1})	G (m^2 ha^{-1})	V (m^3 ha^{-1})
1	53	58.4 ± 0.8a	51	13.8	203.8
2	60	59.7 ± 1.6a	88	25.2	355.5
3	67	58.5 ± 1.1a	66	17.9	252.8
4	74	59.8 ± 1.0a	87	24.8	425.8
5	54	55.7 ± 3.2a	14	3.5	61.3
6	74	59.8 ± 1.6a	92	22.1	404.8
Mean		59.1 ± 0.5	66 ± 12	17.9 ± 3.4	284.0 ± 56.8
95% CI of mean		57.8–60.4	35–97	9.2–26.6	138.0–430.0

Note: N: number of stems ha^{-1} > 50 cm, d: mean diameter of harvested trees, G: basal area ha^{-1}, V: volume ha^{-1} (up to crown point height). CI = confidence interval. Values in each row with the same letter are not significantly different at $p < 0.05$ as determined by DMRT. Means are reported ± 1 SE.

Conclusions

Results from this preliminary growth analysis indicate that:

(1) *Dryobalanops aromatica* can be categorised as relatively fast growing dipterocarp with the ability to produce marketable size logs (50–55 cm diameter) in a rotation length of 50 to 60 years. It can be noted that the potential yield is comparable with some other dipterocarps.

(2) This species showed relatively fast height and diameter growth with a mean annual height increment of 0.6 to 0.7 m year^{-1} and a mean annual diameter increment of 0.7 to 0.8 cm year^{-1} over the whole rotation period.

(3) At the current age, the periodic annual diameter increment at 0.3 cm year^{-1} already falls below the mean annual increment indicating that the culmination point of the mean annual increment had occurred earlier in the rotation.

(4) Statistical analysis showed that periodic annual diameter increments were significantly different between plots and years. Plots 2 and 6 were significantly different and had higher values than the other plots. The prolonged dry weather in 1997 had caused reduction in the periodic annual diameter increment in that year. Plots 2 and 6, with lower stand density, were less affected by the drought due to their significantly higher periodic annual diameter increments compared with the remaining plots.

The knowledge generated from this study provides the path for future direction for planting of *D. aromatica* and other high quality timber species in Peninsular Malaysia. It is important in the determination of overall growth and its increment, as well as size-class distribution of trees and poles of plantation-grown *D. aromatica* stands. The study generates reliable information on the volume of potential harvest at the end of the predetermined cutting cycle. However, the results of this study were only obtained from experimental plots within the Bukit Lagong Forest Reserve, Selangor, Peninsular Malaysia. The growth and potential yield may not represent the overall growth potential of *D. aromatica* if planted elsewhere within the country. It has to be emphasised that growth and potential yield may deviate for better or for worse depending on the silviculture regime and site quality, and so the results of this study are inconclusive. However, these results may have values in answering questions relating to future planting programmes, including potential growth and yield and approximate rotation length.

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References

ABD. RAHMAN K., ISMAIL, H., A. ZUHAIDI, Y. & SHAHRULZAMAN, I. 1992. *Dryobalanops aromatica*: a potential quality timber tree for large scale planting. Pp. 61–68 in Ahmad Said, S., Razali, A. K., Shahwahid, O., Faridah, H. & Hamami, S. (Eds.) *Proceedings of a National Seminar on Indigenous Species for Forest Plantations.* 23–24 April 1992. University Pertanian Malaysia, Serdang.

ABD. RAHMAN, K., SHAHRULZAMAN, I. & WEINLAND, G. 1996. Growth performance of a naturally regenerated stand of *Dryobalanops aromatica* Gaertn. f. 37 years after a low heavy thinning treatment. Pp. 347–355 in Edwards, D. S., Booth, N. E. & Choy, S. C. (Eds.) *Tropical Rainforest Research: Current issues.* Kluwer Academic Publishers, Netherlands.

AFZAL-ATA, M., NUR SUPARDI, M. N. & PATRICK, E. S. 1985. Local volume table for plantation *Dryobalanops aromatica* Gaertn. F. at Sungai Puteh Forest Reserve (Federal Territory). *Malayan Forester* 48: 276–287.

AFZAL-ATA, M. 1985. Stem form of *Dryobalanops aromatica* Gaertn. F. with special references to it potential for round-pole for overhead transmission lines. *Malayan Forester* 48: 137–147.

AHMAD ZUHAIDI, Y., & VAN GARDINGEN, P. R. 1999. Growth and yield of plantation grown *Dryobalanops aromatica*: 50 years after planting. *Journal of Tropical Forest Science* 11(1): 205–217.

AHMAD ZUHAIDI, Y., WEINLAND, G. & KOLLERT, W. 1995. Growth performance of three dipterocarp plantation stands. Pp. 136–151 in Konohira, K. (Ed.) *Proceedings of the International IUFRO Symposium on Growth and Yield of Tropical Forests.* 27 September–1 October 1994. Fuchu, Tokyo. Tokyo University of Agriculture & Technology, Tokyo.

AIBA, S. I. & KITAYAMA, K. 2002. Effects of the 1997–98 El Niño drought on rain forests of Mount Kinabalu, Borneo. *Journal of Tropical Ecology* 18(4): 215–230.

ALDER, D. 1995. *Growth Modelling for Mixed Tropical Forests.* Tropical Forestry Papers 30. Oxford Forestry Institute, Oxford. 231 pp.

ALDER, D. & SYNNOTT, T. J. 1992. *Permanent Sample Plot Techniques for Mixed Tropical Forest.* Tropical Forestry Papers 25. Oxford Forestry Institute, Oxford. 124 pp.

AMIR HUSNI, M. S., AHMAD ZUHAIDI, Y., MOHD NOOR, M., GHAZALI, H., SUHAIMI, W. C. & LOK, E. H. 1997. Growth and current stocking of plantation species of Bukit Hari and Bukit Lagong Forest Reserve, Selangor in relation to soil distribution pattern. 23 pp. (Unpublished)

ANONYMOUS. 1926. Field records block 12, Forest Research Institute Peninsular Malaysia. 2 pp. (Unpublished)

ANONYMOUS. 1933. Field records block 8 T, Forest Research Institute Peninsular Malaysia. 2 pp. (Unpublished)

ANONYMOUS. 1939. Field records block 30 E, Forest Research Institute Peninsular Malaysia. 2 pp. (Unpublished)

ANONYMOUS. 1947a. Field records block 9 A, Forest Research Institute Peninsular Malaysia. 2 pp. (Unpublished)

ANONYMOUS. 1947b. Field records block 8 P, Forest Research Institute Peninsular Malaysia. 2 pp. (Unpublished)

ANONYMOUS. 1995. *Optical Reading Clinometer PM5.* Suunto Company, Espoo, Helsinki. 2 pp.

APPANAH, S. & WEINLAND, G. 1993. *Planting Quality Timber Trees Peninsular Malaysia: A Review.* Malayan Forest Records No. 38. Forest Research Institute Malaysia, Kuala Lumpur. 221 pp.

CHIEW, K. Y. & GARCIA, A. 1989. Growth and yield studies in Yayasan Sabah forest concession area. Pp. 192–204 in Wan Razali, W. M., Chan, H. T. & Appanah, S. (Eds.) *Proceedings of the Seminar on Growth and Yield in Tropical Mixed Moist Forests.* Forest Research Institute Malaysia, Kuala Lumpur.

EVANS, J. 1982. *Plantation Forestry in the Tropics.* Clarendon Press, Oxford. 472 pp.

FREESE, F. 1984. *Statistics for Land Managers.* Paeony Press, Jedburgh, Scotland. 176 pp.

HUSCH, T. J., MILLER, C. I. & BEERS, T. W. 1982. *Forest Mensuration.* John Wiley & Sons, London. 402 pp.

ISMAIL, A. 1964. Enrichment planting in Selangor with particular reference to *Dryobalanops aromatica. Malayan Forester* 27: 3–17.

KHANDEKAR, M. L., MURTY, T. S., SCOTT, D. & BAIRD, W. 2000. The 1997 El Nino, Indonesian forest fires and the Malaysian smoke problem: A deadly combination of natural and man-made hazard. *Natural Hazard* 21: 131–144.

KLEINE, M. & WEINLAND, G. 1991. *Course on Forest Mensuration.* Malaysian-German Forestry Project No. 151. Forest Research Institute Malaysia, Kuala Lumpur. 85 pp.

KOHLER, P. & HUTH, A. 1998. The effects of tree species grouping in tropical rainforest modelling: simulations with the individual-based model FORMIND. *Ecological Modelling* 109: 301–321.

LANDON, F. H. 1948. Planting experiments with *Dryobalanops aromatica. Malayan Forester* 11: 146–153.

LIEBERMAN, D. & LIEBERMAN, M. 1987. Forest tree growth and dynamics at La Selva, Costa Rica (1969–1982). *Journal of Tropical Ecology* 3: 347–358.

LOETSCH, F., ZOHRER, F. & HALLER, K. E. 1973. Forest Inventory. BLV Verlagsgesellschaft Bern Wien, Munchen. 469 pp.

MANOKARAN, N. & KOCHUMMEN, K. M. 1987. Recruitment, growth and mortality of tree species in a lowland dipterocarp forest in Peninsular Malaysia. *Journal of Tropical Ecology* 3: 315–330.

NICHOLSON, D. 1965. Pp. 67–87 in *A Study of Virgin Forest Near Sandakan,* North Borneo. UNESCO, Paris.

NICOLAS, N. T., VINCENT, F., PLINIO, S., LOUIS, H. & BERTAULT, J. G. 1998. Growth and mortality patterns before and after logging. Pp. 181–216 in Bertault, J. G. & Kosasi, K. (Eds.) *Silvicultural Research in a Lowland Mixed Dipterocarp Forest of East Kalimantan, P. T. INHUTANI 1, Jakarta.* CIRAD - Foret, Ministry of Forestry Indonesia, Kalimantan.

ONG, R. C. & KLEINE, M. 1995. *DIPSIM: A Dipterocarp Forest Growth Simulation Model for Sabah.* Forest Department, Sabah, Kota Kinabalu. 94 pp.

PRIMACK, R. B., ERNEST, O. K. C., TAN, S. S. & LEE, H. S. 1989. Relative performance of dipterocarp trees in natural forest, managed forest, logged forest and plantations throughout Sarawak. Pp. 161–175 in Wan Razali W. M., Chan, H. T. & Appanah, S. (Eds.) *Proceedings of the Seminar on Growth and Yield in Tropical Mixed Moist Forests.* Forest Research Institute Malaysia, Kuala Lumpur.

RAUTIAINEN, O., PUKKALA T. & MIINA, J. 2001. Optimizing the management of even-aged *Shorea robusta* stands in southern Nepal using individual tree growth models. *Forest Ecology and Management* 126: 417–429.

SILVA, J. N. M., CARVALHO, J. O. P., LOPES, C. A., ALMEIDA, B. F., COSTA, D. H. M., OLIVEIRA, L. C., VANCLAY, J. K. & SKOVSGAARD, J. P. 1995. Growth and yield of a tropical rain forest in the Brazilian Amazon 13 years after logging. *Forest Ecology and Management* 71: 267–274.

VANCLAY, J. K. 1989. A stand growth model for yield production in rainforests: design, implementation and enhancements. Pp. 21–34 in Wan Razali W. M., Chan, H. T., Appanah, S. (Eds.) *Proceedings of the Seminar on Growth and Yield in Tropical Mixed Moist Forests.* Forest Research Institute Malaysia, Kuala Lumpur.

WYATT-SMITH, J. 1963. *Manual of Malayan Silviculture for Inland Forests.* Malayan Forest Records, No. 23. Forest Research Institute Malaysia, Kuala Lumpur. 150 pp.

YONEDA, T., NISHIMURA, M. & CHAIRUL, S. 2000. Impacts of dry weather in 1997 on a tropical rainforest ecosystem in West Sumatra, Indonesia. *Ecological Research* 15: 63–71.

YONG, T. K. 1990. *Growth and Yield of a Mixed Dipterocarp Forest in Peninsular Malaysia.* ASEAN Institute of Forest Management, Kuala Lumpur. 160 pp.