GROWTH RESPONSE AND YIELD OF PLANTATION-GROWN TEAK *(TECTONA GRANDIS)* AFTER LOW THINNING TREATMENTS AT PAGOH, PENINSULAR MALAYSIA

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ZUHAIDI YAHYA A, AMIR SAAIFFUDIN K & HASHIM MN. 2011. Growth response and yield of plantation-grown teak (*Tectona grandis*) after low thinning treatments at Pagoh, Peninsular Malaysia. The aim of the study was to evaluate the effects of thinning intensity on the growth and yield of teak (*Tectona grandis*). The thinning was established in a humid tropical teak plantation in southern Peninsular Malaysia. An assessment on the total periodic diameter (PI_D) increment showed that there were significant differences between treatments ($p \leq 0.001$). The total PI_D increments were 2.7 cm in treatment thinned down to 200 stems ha^{-1} (T2), 2.1 cm in 300 stems ha^{-1} (T3), 1.6 cm in 400 stems ha^{-1} (T4) and 0.6 cm in unthinned control (T1). True diameter increments of treatments T1, T2, T3 and T4 were 0.6, 1.9, 1.6 and 1.0 cm respectively ($p \leq 0.001$). The calculated total volume increments (PI_v) were 12.47 m^3 ha^{-1} in T1, 21.73 m^3 ha^{-1} in T2, 19.66 m^3 ha^{-1} in T3 and 14.02 m^3 ha^{-1} in T4. As expected the PI_v was lowest in the unthinned control treatment despite having a high number of remaining trees. The results showed that thinning regime down to 200 stems ha^{-1} was an appropriate stocking density for stand diameter and volume growth.

Keywords: Periodic annual diameter increment, true diameter growth, final crop stocking

ZUHAIDI YAHYA A, AMIR SAAIFFUDIN K & HASHIM MN. 2011. Pertumbuhan serta hasil pokok jati (*Tectona grandis*) selepas penjarangan impak rendah di Pagoh, Semenanjung Malaysia. Tujuan kajian adalah untuk menilai kesan tahap penjarangan terhadap pertumbuhan dan hasil dirian jati (*Tectona grandis*). Kajian penjarangan ini dijalankan di dirian jati yang terletak di selatan Semenanjung Malaysia. Penilaian terhadap jumlah pertambahan diameter berkala (PI_D) menunjukkan perbezaan yang signifikan antara rawatan ($p \leq 0.001$). Jumlah PI_D ialah 2.7 cm untuk kepadatan 200 pokok ha^{-1} (T2), 2.1 cm untuk 300 pokok ha^{-1} (T3), 1.6 cm untuk 400 pokok ha^{-1} (T4) dan 0.6 cm untuk kawalan (T1). Peningkatan diameter sebenar bagi T1, T2, T3 dan T4 masing-masing ialah 0.6 cm, 1.9 cm, 1.6 cm dan 1.0 cm ($p \leq 0.001$). Jumlah pertambahan isi padu (PI_V) ialah 12.47 m^3 ha^{-1} dalam T1, 21.73 m^3 ha^{-1} dalam T2, 19.66 m^3 ha^{-1} dalam T3 dan 14.02 m^3 ha^{-1} dalam T4. Seperti yang dijangkakan, PI_V daripada rawatan kawalan adalah yang terendah walaupun mempunyai jumlah pokok akhir yang tinggi. Keputusan ini menunjukkan bahawa kepadatan dirian akhir sebanyak 200 pokok ha^{-1} bersesuaian untuk pertambahan diameter dan isi padu. Secara keseluruhan, jati bertindak balas dengan baik terhadap rawatan penjarangan.

INTRODUCTION

Teak (*Tectona grandis*) belongs to the family Verbenaceae and is predominantly tropical and subtropical. The genus is represented by three species, viz. *T. grandis*, *T. hamiltona* and *T. philippinesis*. Its natural distribution is in South-East Asia, spreading from India, Myanmar, Thailand to the Philippines. The area under teak plantations in Asia has been reported to be around 94% of the total world teak plantations (5.7 mil ha); India has the greatest area with 3.2 mil ha and Indonesia and Laos have over 800 000 and 70 000 ha respectively (Manmohan & Dugaya 2010). Myanmar and Thailand have 14 and 6 mil ha of mixed deciduous teak forests respectively.

There is no natural teak stand in Malaysia but the tree has been widely planted as plantation species in various parts of Peninsular Malaysia especially in the northern states of Perlis and Kedah (Hashim & Mohd Noor 2002). It is also widely planted in the eastern and northern parts of Sabah, East Malaysia (Mohd Fauzi 2004). Despite active participation by local investors, the general lack of knowledge on the silvicultural regime for the final crop density of teak is still common in Malaysia, even though the

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concept of thinning regime in teak stands is well documented in many tropical countries, mainly in Central America. Thinning in teak stands has positive effect on stem form, producing trees with desired diameter size and height (Pérez & Kanninen 2005). Thinning at an early age is important to increase foliage biomass and sustain rapid diameter growth (Kanninen et al. 2004). Thus, this study was carried out to provide baseline information and to facilitate the development of a silvicultural regime for teak and, at the same time, compliment additional data on thinning effects in South-East Asia.

MATERIALS AND METHODS

Site

The study was conducted at both sides of the KM 133.6 Pagoh–Yong Peng Projek Lebuhraya Utara Selatan (PLUS) expressway (102° 14' E and 3° 25' N) in Johore, Peninsular Malaysia. This expressway is part of the north–south expressway managed by PLUS Expressway Berhad. The study area has 10-year-old *Tectona grandis* stand and its temperature ranges from 27 to 32 °C. The annual rainfall is between 1800 and 2050 mm, indicating the middle range of rainfall in humid tropics. The research area is located at about 80 m above sea level and the terrain is level. The sites had a mixed combination of different soil types with top soils removed at three of the sites during construction of the highway. Organic compost (6 kg) was applied in the hole during planting and 300 g NPK yellow (12:12:17:2) was applied twice annually from year one till four. The stand was planted at an initial spacing of 2.4 × 2.4 m (1736 trees ha^{-1}). Old records have shown removal of dead and diseased trees but details of the trees removed are not available. Upon commencement of the study, trees had reached a small pole size of about 12–16 cm diameter. The stand was distinctly monolayered with canopy closed. Generally, foliage was dense. The stands contained a high proportion of forked trees which were badly formed (crooked). Basal damage was high and trees were suppressed particularly in the lower diameter class.

Methods

The study comprised eight 0.16-ha plots (40 × 40 m) with four treatments and two replicates in a randomised complete block design. The total area is 1.48 ha. Each of the plot was separated by a 10-m wide buffer zone. The treatments were as follows:

(1) T1: unthinned control
(2) T2: thinning down to 200 stems ha^{-1}
(3) T3: thinning down to 300 stems ha^{-1}
(4) T4: thinning down to 400 stems ha^{-1}

All sites had their top soils removed except for T2. Initial measurements of the plots were conducted in December 2007 when trees were 10 years old. This was followed by low thinning treatments in March 2008. Subsequent measurements were conducted in August 2008, March 2009 and finally in September 2009. Diameter (dg) measurements of all trees were taken using Richter diameter tape. The total tree height and clear bole measurements were recorded using a Vertex Hagloff digital hypsometer. The equation used for calculating height of trees was developed using height–growth function (Curtis 1967).

$$\text{Height (hg)} = a + b \log(dg) \qquad (1)$$

where a is the intercept and b, the coefficient. The coefficient of determination was generally high at 0.643. The hg was calculated from the height curves.

The basal area (g) was calculated for each tree while the basal area ha^{-1} (G) was obtained by totalling the individual values and converting the results into a ha^{-1} value using the area factor (1:0.16), i.e.

$$g = \tfrac{1}{4}(\pi \times dg^2)/10\,000 \qquad (2)$$

$$G = \sum g_i \times 1/0.16 \qquad (3)$$

With reduction factor = 0.6 to allow for stem taper, the volume per tree (v) was calculated as in equation 4:

$$v = g \times hg \times 0.6 \qquad (4)$$

The volume per ha (V) is the total sum of individual tree volumes converted to ha^{-1}. The annual increment (I) is the difference between the growth value at the end of the one year period (e.g. for standing volume at stand age t, V_{t+1}) and growth at the beginning of that year (V_t).

$$I = V_{t+1} - V_t \qquad (5)$$

The periodic annual increment for volume (PI_v) was calculated by dividing the annual increment by the number of years or the fraction of a year.

$$PI_v = (V_{t+k} - V_t)/k \quad (6)$$

where V_{t+k} = standing volume at the end of observation period k and k = length of growth period. For stand diameter, periodic diameter increment PI_D was calculated as:

$$PI_D = (D_{t+k} - D_t)/k \quad (7)$$

where D_{t+k} = standing diameter at the end of observation period k and D_t = standing diameter at the beginning of observation period k.

The mean annual increment refers to the total production of the stand at the time of study, including removals of the past. The periodic increment was calculated by dividing the mean increment by stand age. For volume,

$$MAI_t = (V_t + \sum R)/t \quad (8)$$

where MAI_t = mean annual increment at stand age t and $\sum R$ = total removals up to stand age t.

Analysis of data

Statistical analysis of differences between treatments was analysed using SAS/STAT 1989 PROC GLM (Generalised Linear Model). Duncan's multiple range tests was used to determine differences between means.

RESULTS AND DISCUSSION

Stand and stock tables for the four treatments at the beginning of the study (i.e. before thinning) and at 5, 12 and 18 months after thinning in March 2008 are given in Tables 1–4. In each treatment, the calculated stand parameters and increments for the stand diameter, basal area and volume are also presented. Throughout the 21-month-observation period (i.e. from initial measurement in December 2008), the total PI_D increased by 0.6 cm, 2.7, 2.1 and 1.6 cm in T1, T2, T3 and T4 respectively (Tables 1–4). The thinning interventions caused distinct and significant differences ($p \leq 0.001$, Table 5) in the diameter increment.

From Tables 1–4, T2 (18.7 cm) has higher initial dg in comparison with T3 (16.8 cm), T4 (15.9 cm) and T1 (13.8 cm). This may be attributed to soil conditions in T2, i.e. the area

Table 1 Unthinned control (T1)

Measurement	N (stems ha^{-1})	hg (m)	dg (cm)	G (m^2 ha^{-1})	V (m^3 ha^{-1})	MAI (m^3 ha^{-1} $year^{-1}$)
December 2007	883	13.31	13.8	13.29	106.13	10.61
Removal	0	0	0	0	0	
Remaining	883	13.31	13.8	13.29	106.13	
August 2008	883	13.38	13.9	13.43	107.92	10.79
Removal	19	12.48	12.7	0.24	1.8	
Remaining	864	13.38	13.9	13.19	106.12	
March 2009	864	13.52	14.1	13.43	108.94	9.84
Removal	32	9.70	9.6	0.23	1.34	
Remaining	832	13.59	14.2	13.20	107.60	
September 2009	832	13.87	14.6	14.00	117.25	10.24
API			0.6	1.18	14.42	
TPI			0.6	1.04	12.47	

hg = total tree height, dg = diameter corresponding to mean basal area, G = basal area, V = volume, MAI = mean annual increment, API = apparent periodic diameter/basal area/volume increment, TPI = true periodic diameter/basal area/volume increment is the only site without soil cutting during the establishment phase. Thus, direct comparison of effects of thinning on the diameter growth may be misleading as initial diameters were not comparable. Theoretically, the growth after thinning consisted of a mixture of apparent (i.e. increased growth immediately after thinning operation) and true (i.e. in this study at 5, 12 and 18 months after the actual thinning) growths. To avoid mistakes caused by the mixture of apparent and true growths, results obtained from comparison of effects of thinning on apparent and true increments of the stands are separately presented (Tables 1–4).

Table 2 Thinning down to 200 stems ha^{-1} (T2)

Measurement	N (stems ha^{-1})	hg (m)	dg (cm)	G (m^2 ha^{-1})	V (m^3 ha^{-1})	MAI (m^3 ha^{-1} $year^{-1}$)
December 2007	818	16.33	18.7	22.41	219.51	21.95
Removal	608	15.72	17.6	14.75	139.12	
Remaining	210	17.76	21.6	7.66	80.39	
August 2008	210	18.08	22.3	8.17	88.62	21.36
Removal	0	0	0	0	0	
Remaining	210	18.08	22.3	8.17	88.62	
March 2009	210	18.3	22.8	8.57	94.13	20.73
Removal	6	15.50	17.2	0.14	1.30	
Remaining	204	18.34	22.9	8.43	92.83	
September 2009	204	18.93	24.3	9.49	108.05	21.15
API			2.7	1.97	29.26	
TPI			1.9	1.46	21.73	

hg = total tree height, dg = mean diameter corresponding to mean basal area, G = basal area, V = volume, MAI = mean annual increment, API = apparent periodic diameter/basal area/volume increment, TPI = true periodic diameter/basal area/volume increment

Table 3 Thinning down to 300 stems ha^{-1} (T3)

Measurement	N (stems ha^{-1})	hg (m)	dg (cm)	G (m^2 ha^{-1})	V (m^3 ha^{-1})	MAI (m^3 ha^{-1} $year^{-1}$)
December 2007	885	15.26	16.8	19.71	181.08	18.11
Removal	554	14.90	16.2	11.4	101.92	
Remaining	331	15.89	18.6	8.31	85.81	
August 2008	331	16.59	19.2	9.57	95.26	18.50
Removal	0	0	0	0	0	
Remaining	331	16.59	19.2	9.57	95.26	
March 2009	331	16.64	19.3	9.67	96.77	17.66
Removal	8	18.77	23.9	0.36	4.05	
Remaining	323	16.59	19.2	9.31	92.72	
September 2009	323	17.24	20.5	10.7	110.87	18.45
API			2.1	2.75	29.11	
TPI			1.4	1.49	19.66	

hg = total tree height, dg = diameter corresponding to mean basal area, G = basal area, V = volume, MAI = mean annual increment, API = apparent periodic diameter/basal area/volume increment, TPI = true periodic diameter/basal area/volume increment

Thus, the calculated true dg increments of T1, T2, T3 and T4 were 0.6, 1.9, 1.4 and 1.0 cm respectively. From the Duncan's multiple range test, it was observed that mean dg before thinning, true dg and total dg increment were significantly different between treatments at $p < 0.01$ with T2 having the highest true dg increment (Table 6).

The periodic volume increment (apparent or true) depends on the dg increment and number of stems ha^{-1}. As expected, the true volume increment was lowest in the unthinned control treatment despite having a high number of remaining trees. The values obtained were 12.47 m^3 ha^{-1} in T1, 21.73 m^3 ha^{-1} in T2, 19.66 m^3 ha^{-1} in T3 and 14.02 m^3 ha^{-1} in T4. Results obtained from this study agreed with findings from other studies of thinning treatments, in that diameter of teak stands increased with increased spacing after thinning (Ola-Adams 1990, Kanninen et al. 2004). Heavily-thinned teak stands with wide spacing are able to produce higher diameter increment and consequently increased size of logs due to higher turnover rate of the crown as new leaves quickly adapt to the better environment (e.g. Malimbwi et al. 1992, Kanninen et al. 2004, Kamo et al. 2009). The results of this study also showed that thinning down to 200 stems ha^{-1}

Table 4 Thinning down to 400 stems ha^{-1} (T4)

Measurement	N (stems ha^{-1})	hg (m)	dg (cm)	G (m^2 ha^{-1})	V (m^3 ha^{-1})	MAI (m^3 ha^{-1} year^{-1})
December 2007	997	14.71	15.9	19.68	173.58	17.58
Removal	606	14.40	15.4	11.34	97.98	
Remaining	391	15.08	16.5	8.34	75.60	
August 2008	391	15.44	17.1	9.01	83.74	17.05
Removal	0	0	0	0	0	
Remaining	391	15.44	17.1	9.01	83.74	
March 2009	391	15.55	17.3	9.18	86.00	16.35
Removal	0	0.00	0	0	0	
Remaining	391	15.55	17.3	9.18	86.00	
September 2009	391	16.00	18.1	10.11	97.76	16.66
API			1.6	1.77	22.16	
TPI			1.0	0.89	14.02	

hg = total tree height, dg = diameter corresponding to mean basal area, G = basal area, V = volume, MAI = mean annual increment, API = apparent periodic diameter/basal area/volume increment, TPI = true periodic diameter/basal area/volume increment

Table 5 Analysis of variance between subject effects (diameter (dg), true dg and total dg increments) and within subject effects (thinning treatments)

Source	Degree of freedom	Sum of squares	Mean of squares	F	pr > F
dg	4	4232.18	1058.04	83.29	0.0001
Error	1142	14 506.57	12.70		
Total	1146	18 738.75			
True dg	4	125.02	31.26	51.79	0.0001
Error	554	134.36	0.60		
Total	558	459.38			
Total dg	4	186.54	96.53	95.02	0.0001
Error	554	562.81	1.01		
Total	558	948.95			

Table 6 Diameter (dg) before thinning, true dg and total dg increment

Treatment	Mean dg before thinning	True dg (cm)	Total dg increment (cm)
T1	13.8 ± 0.3 d	0.6 ± 0.1 d	0.6 ± 0.1 d
T2	18.7 ± 0.4 a	1.9 ± 0.1 a	2.7 ± 0.2 a
T3	16.8 ± 0.3 b	1.4 ± 0.1 b	2.1 ± 0.2 b
T4	15.9 ± 0.2 c	1.0 ± 0.1 c	1.6 ± 0.1 c

Values in each column with the same letter are not significantly different at $p < 0.01$; means ± SE; T1, T2, T3 and T4 = unthinned, 200, 300 and 400 stems ha^{-1} respectively

(T2) was the expected final stocking regime until the end of rotation. Being established in an area that had the top soil removed during road construction, with the exception of T2, the teak stands in general produced an equivalent growth rate. It was reported that 25-year-old teak on poor lateritic soil only showed a growth rate of 8.05 m^3 ha^{-1} $year^{-1}$ (Hashim & Mohd Noor 2002). In Thailand, teak grown on very fertile and well maintained site had an average volume growth of 15 m^3 ha^{-1} $year^{-1}$ but poor plantations gave 6–8 m^3 ha^{-1} $year^{-1}$ of growth (Kijkar 1998). Based on the standing stock retained, the highest true volume increments obtained in this study were equivalent to 7.13, 12.42, 11.23 and 8.01 m^3 ha^{-1} $year^{-1}$. These values are slightly lower than the volume growth in Thailand.

Mean annual increment in T2, T3 and T4 increased from 20.73 to 21.15, 17.66 to 18.45 and 16.35 to 16.66 m^3 ha^{-1} $year^{-1}$ respectively. It can be expected that the mean annual volume increment over the whole rotation period will be above 20 m^3 ha^{-1} $year^{-1}$ in all treatments.

CONCLUSIONS

The preliminary results from this thinning trial showed that 10-year-old teak stands showed positive reactions to reduction in stand density and change of stand environment. By leaving other factors constant, teak with appropriate stocking density has higher growth rate compared with stand at close planting. Trees showed increased PI_D, which was highest for the heaviest thinning (200 stems ha^{-1}), followed by thinning down to 300 stems ha^{-1}, 400 stems ha^{-1} and unthinned control. Until new information is available, thinning down to 200 stems ha^{-1} seems an appropriate final stocking regime to be practised. However, interpretation of the results must be done with caution as the trial was conducted at a specific site. The growth may be uncertain if conducted elsewhere, but the results may be used in answering questions related to overall growth rate of the species.

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