RESPONSE OF A CLONAL TEAK PLANTATION TO THINNING AND PRUNING IN JAVA, INDONESIA

Budiadi[1, 3, *], Widiyatno[1] & H Ishii[2]

[1]Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta, 55281 Indonesia
[2]Graduate School of Agricultural Science, Kobe University, Kobe, 657-8501 Japan
[3]Laboratory of Silviculture and Agroforestry, Faculty of Forestry, Universitas Gadjah Mada, Jl. Agro No. 1, Bulaksumur, Yogyakarta 55281, Indonesia

*budiadi@ugm.ac.id

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Over the last decade, there has been a shortage of teak (*Tectona grandis*) timber supply in Indonesia, which cannot be fulfilled by the current rate of production. Genetic improvement has produced two promising clones, but the performance of the clones in degraded lands, where most new plantations are established, is still to be tested. The study shows initial results from a pilot forest of the clones established on degraded limestone soil in Java Island, where various thinning (0, 25 and 50% of trees) and pruning (⅓, ½ and ⅔ of the crown) treatments were applied four years after planting. Light levels inside the stands increased with increasing levels of thinning and pruning. Diameter growth increased with thinning intensity, especially in the first year, whereas the effect of pruning was undetectable after three years. Although standing stock in the thinned stands did not recover to pre-thinning levels in three years, cumulative production (standing stock plus harvested timber) was highest for the heaviest thinning treatment. Initial high growth rate after thinning could not be maintained due to poor soil condition. Fast growth may have induced canopy closure and crown competition among the residual trees. The results suggest that, in clonal teak plantations on degraded soils, short-rotation commercial thinning could maintain growth rates and provide income for the tree growers.

Keywords: Clonal forest, stand management, degraded land, competition

INTRODUCTION

Teak (*Tectona grandis*) is one of the most important tropical trees in Indonesian forestry. Despite vast plantation area, production rates are insufficient to meet the high demand for teak timber and there is a deficit of more than 2 million m^3 $year^{-1}$ (Iskak 2005). This deficit is predicted to continue due to low productivity of teak plantations, especially in Java, where production rates are lower than 3 m^3 ha^{-1} $year^{-1}$ (Pandey & Brown 2000). In order to meet the timber demand, silvicultural techniques need to be improved to increase productivity by selecting the best teak clones among the available genetic resources and by establishing better stand-level management protocols (Hadiyan 2008).

In Java, teak tree improvement has been continuously conducted by Perum Perhutani, the forest enterprise, and Faculty of Forestry in Gadjah Mada University since 1983, by selecting 680 mother trees from different sites in Indonesia. Two superior clones, namely, clone numbers 97 and 110 were selected from the mother trees and planted in various sites in Java in 2003 (Naiem 2012). In a productive site, the production rate was more than 200 m^3 ha^{-1} in a 20-year rotation (Iskak 2005, Hadiyan 2008, Budiadi et al. 2012).

While genetic improvement is important for productive plantation management, intensive silviculture, including site and stand manipulation should also be implemented. In many regions of Java, the soil is composed of volcanic ash. The parent material in south-central Java is limestone which is low in nutrient content. Historically, maximum teak production occurred in Gunung Kidul district in south-central Java during colonialism era (1700 to 1930s). However, due to over exploitation and clear cutting, erosion of the topsoil exposed the limestone bedrock. Since 1964, reforestation activity was started to examine the adaptability of several tree species to the degraded site (Soeseno & Setyo 1985, Pramoedibyo et al. 2004). Teak is one of the most adaptive species to the limestone-dominated sites (Pandey & Brown 2000).

Starting from 2004, pilot plantations of clonal teak was established in Wanagama Teaching Forest of Gadjah Mada University. Initial growth rates were high, but spacing of 6 m × 2 m resulted in canopy closure after three years and competition among trees led to reduced growth (Budiadi et al. 2012). Thinning and pruning are common silvicultural treatments for relieving competition to increase productivity, improve wood quality, encourage diameter growth and assist financial viability (Gerrand et al. 1997, Nyland 2002). The degree of response to thinning varies with stand age where generally, it appears that older stands respond more slowly to thinning than younger stands. Further, the residual stand after thinning is able to use additional growing space at an early age (Brown 1997, Ladrach 2004). The adequate timing and intensity of the silviculture treatments is important for sustaining productivity and should be based on stand growth rates (Krishnapillay 2000, Nyland 2002). For fast-growing teak, i.e. clonal teak plantation, initial thinning and pruning may need to be applied earlier and at shorter intervals than unimproved teak plantation to get the optimal growth and forest production at the end of the rotation.

The study evaluated the changes in stand structure and growth rate of a clonal teak plantation, 3 years after thinning and pruning treatments (stand age = 4.5 to 7.5 years), in order to present technical options for sustainable management of teak on degraded forestlands in Java.

MATERIALS AND METHODS

The thinning and pruning trial was established on a clonal teak plantation in Wanagama Teaching Forest (7°54' S, 110°31' E) in Java, Indonesia. The annual rainfall in Wanagama is 1,700 mm with 5 months of dry season, thus classified as type C category which is rather wet (Q value = 33.3 to 60%) (Schmidt & Ferguson 1951). The soil surface is composed of limestone, generally suitable for teak. Shallow topsoil dominates the site, and the depth varies from 10 to 40 cm, with soil order of lithosol (entisol). In some spots the rocky limestone is exposed above the soil surface (Figure 1). The clonal teak plantation was established using selected clones (number 97 and 110) that were bulk planted with 6 m × 2 m initial spacing in December 2004 in compartment 13 of the Wanagama Teaching Forest.

Most of the plantation was established using taungya or 'tumpangsari' agroforestry system,

Figure 1 Soil condition at research site in compartment 13 of Wanagama Teaching Forest showing shallow organic layer on limestone

similar to other forest plantations in dense populated areas of Java (Gajaseni 1997, Budiadi et al. 2005). The farmers cultivate crops between the tree-rows during the first three years after planting. The trees were initially fertilised with cattle dung, 3 kg tree^{-1}. To maintain seasonal crop growth, the farmers usually fertilise the crops with cattle dung in various amounts, but this practice has been shown to have little or no effect on tree growth (Budiadi et al. 2006). In this study, agroforestry practices and the level of fertilisation were similar among the plots. Artificial thinning and pruning treatments were applied during the early dry season in April 2009 (4.5 years after planting) and monitoring was conducted until March 2012. A factorial randomised block design was employed to measure response of combined thinning and pruning treatments (Figure 2). Three blocks, as replicates, were established in the plantation and treatment was applied to 30 sample trees of three rows.

1. Thinning treatments: 0 (control, T_0), 25 of trees (moderate thinning, T_1) and 50% (heavy thinning, T_2).Thinning rates were based on the number of trees in each plot. The thinned trees were selected systematically (systematic thinning) to realise spatial evenness of the retained trees (Figure 3).
2. Pruning treatments: ⅓ of crown height (low pruning, P_1), ½ of crown height (P_2) and ⅔ of crown height (high pruning, P_3).

Plastic dendrometers were attached at breast height (1.3 m above ground level) to measure diameter at breast height (dbh) of the stems. Volume (V, m^3) of individual trees were calculated using the following formula (Perez & Kanninen 2003, Perez 2008):

$$V = (-0.0884 + 0.0297*dbh)^2 \quad (1)$$

where dbh = diameter at breast height. Light intensity was measured immediately after

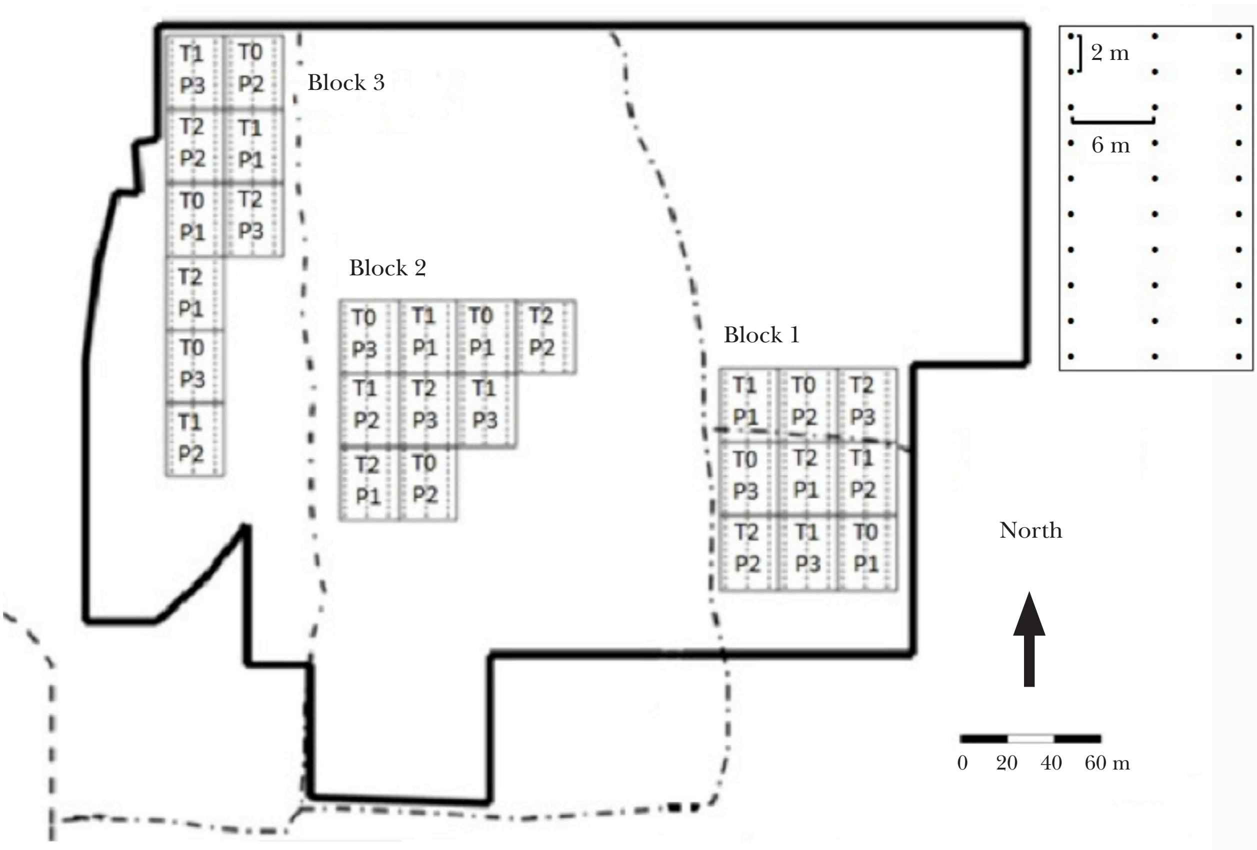

Figure 2 Research design of silvicultural treatments to improve stand growth of clonal teak plantation in Wanagama Teaching Forest, Java, Indonesia; T_0, T_1, and T_2 = 0, 25 and 50% intensity of trees, respectively; P_1, P_2, and P_3 = ⅓, ½, and ⅔ of the crown pruning intensity, respectively, solid lines = borderline of clonal teak plantation area; break lines = pathways along the study site; plantation pattern = 6 m × 2 m

thinning and pruning in different locations inside the stand, at the same time, under uniform cloudy conditions, using two light meters. The relative light intensity was calculated as the percentage of light recorded relative open area outside the stand. The measurements were replicated five times for each plot.Vertical projection of the idividual tree crown was delineated from the radial length of the crown in North, South, East and West sides in addition to crown depth of the trees. Individual crown area was visualised using a three-dimensional spatial model with SExI-FS software (Harja & Vincent 2008). Dbh (cm) and height (m) measurements were made 6 months, 1 year and 3 years after treatment. Data were analysed using a two-way ANOVA to test the effect of thinning and pruning treatments on relative light intensity and stand productivity (dbh, basal area (BA), current annual increment (CAI), stand volume and volume gain after treatments). Tukey's test was employed for multiple comparisons among treatment means. All the analyses were performed with Statistical Analysis System Institute 9.0 for Window.

RESULTS

Three years after thinning, the level of canopy closure was similar in all stands (Figure 3). Individual crown area, however, was larger for T_2 than T_0 and T_1. Both thinning and pruning significantly increased light intensity in the stands immediately after treatment, but the effect of thinning ($F = 647.20$, $p < 0.0001$) was greater than that of pruning ($F = 13.49$, $p = 0.0004$) (Figure 4, Table 1). Pruning had the greatest effect in T_1 where light intensity increased by more than two fold, whereas in T_2 there was no effect of pruning on light intensity.

Although it was the dry season, dbh growth slightly increased in the thinned stands six months after treatment ($F = 4.65$; $p < 0.025$, Figure 5, Table 2, Table 3) and the increase in DBH growth was positively correlated with thinning intensity. DBH growth continued to increase after 1 year, but after 3 years, DBH growth was lower than the initial year. However, the cumulative effect of increased DBH growth was reflected in a significant difference in mean DBH among thinning treatments after three

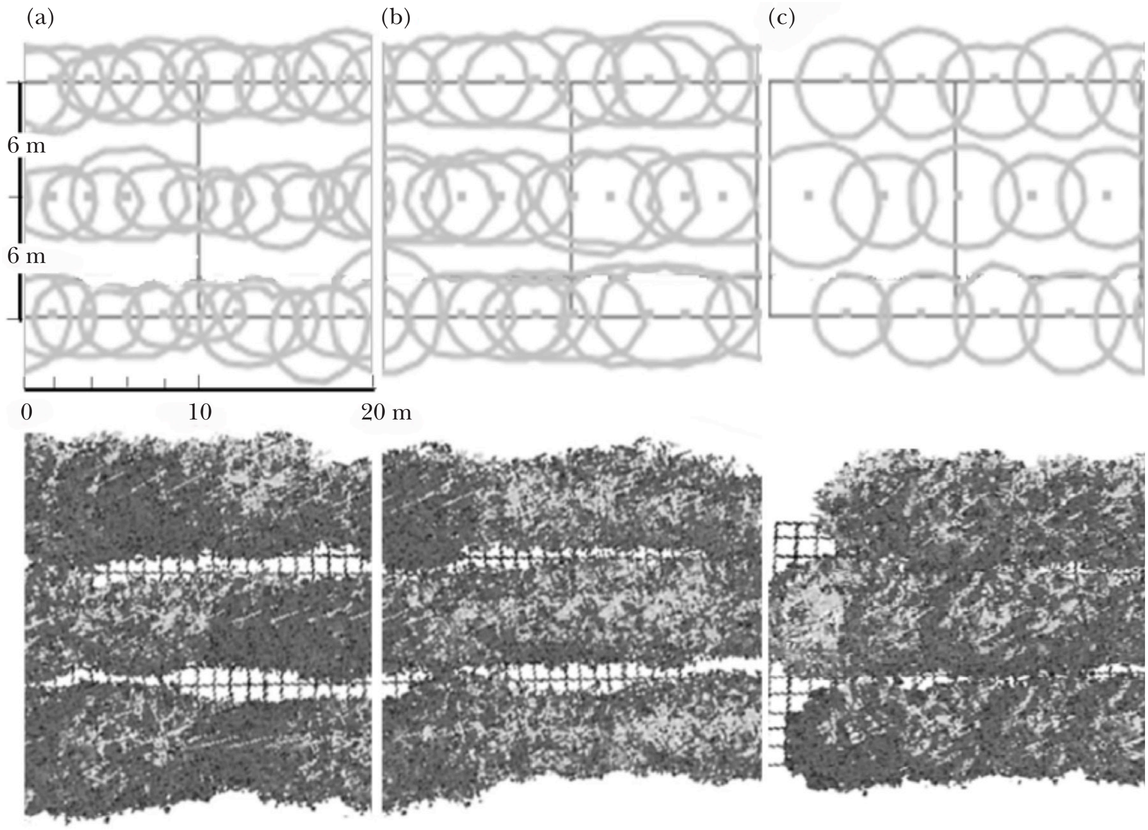

Figure 3 Crown projections of the clonal teak stands 3 years after thinning in Wanagama Teaching Forest, Java, Indonesia; thinning intensities = (a) 0%, (b) 25% and (c) 50% of trees

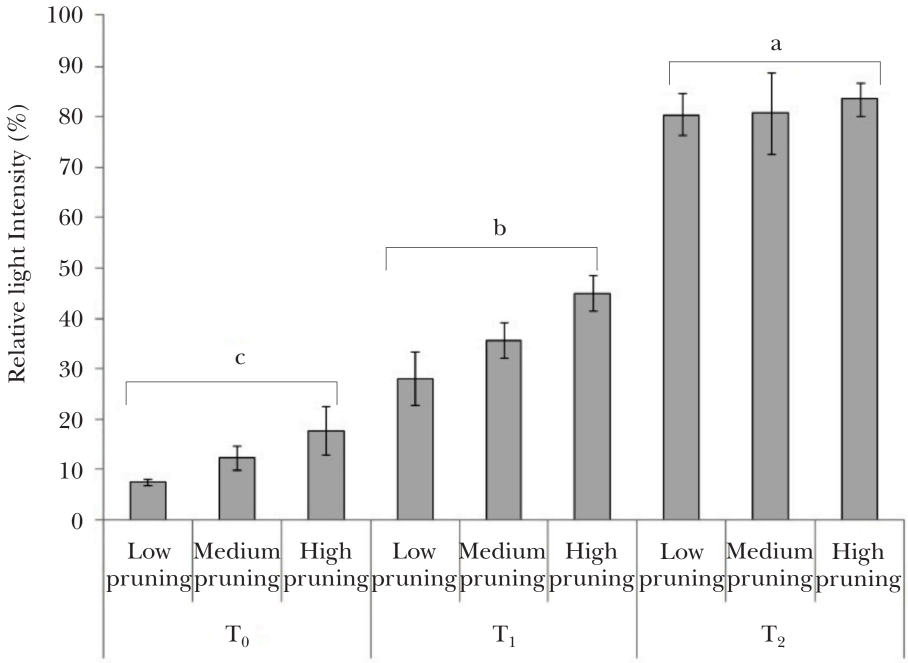

Figure 4 Changes in relative light intensity immediately after thinning and pruning treatments within the clonal teak stand in Wanagama Teaching Forest, Java, Indonesia; error bars indicate one standard deviation; thinning and pruning significantly affected RLI, but there was no interaction among the two treatments ($p > 0.05$); letters (a, b, c) indicate significant differences RLI among the thinning treatments ($p < 0.05$)

Table 1 Treatment effects on relative light intensity of clonal teak stand in Wanagama Teaching Forest in Java, Indonesia

Source of variance	df	MSE	F	p
Block	2	37.8	2.21	0.1419
Thinning	2	11054.6	647.20	< 0.0001
Pruning	2	230.5	13.49	0.0004
Thinning and pruning	4	36.6	2.14	0.1223

df = degrees of freedom, MSE = mean squared error

years ($F = 14.28$, $p = 0.0003$). Although initially, there was some effect of pruning on DBH growth ($F = 0.12$, $p = 0.889$ and $F = 0.11$, $p = 0.897$ for 6 months and 1 year after treatment, respectively), after 3 years, the effect of pruning on DBH growth was no longer observed ($F = 0.05$; $p = 0.95$), nor was the interaction between thinning and pruning significant ($F = 0.27$, $p = 0.892$).

Basal area at 3 years after thinning in T_0, T_1 and T_2 were 1.69, 1.42 and 1.13 $m^2\ ha^{-1}$, respectively. As a result, the standing volume in T_2 remained lower than those of T_1 and T_0, even after 3 years ($F = 13.66$, $p = < 0.0003$) (Figure 6, Table 4, Table 5). However, accounting for the volume of trees removed, T_2 had the greatest volume gain, although it was not significantly different at 3 years after the treatment ($F = 1.26$, $p = 0.31$). Meanwhile, the effect of pruning was not significantly different among treatments on both stand volume ($F = 0.03$, $p = 0.97$) and volume gain after 3 years ($F = 0.42$, $p = 0.66$).

DISCUSSION

Despite poor soil conditions, thinning stimulated diameter growth of the clonal teak trees in this study. Since teak is a light demanding tree that does not grow well in dense stands (Pandey & Brown 2000), increasing the light intensity is important for stimulating growth of old, overstocked stands, older than 5 years where crown competition may inhibit tree growth

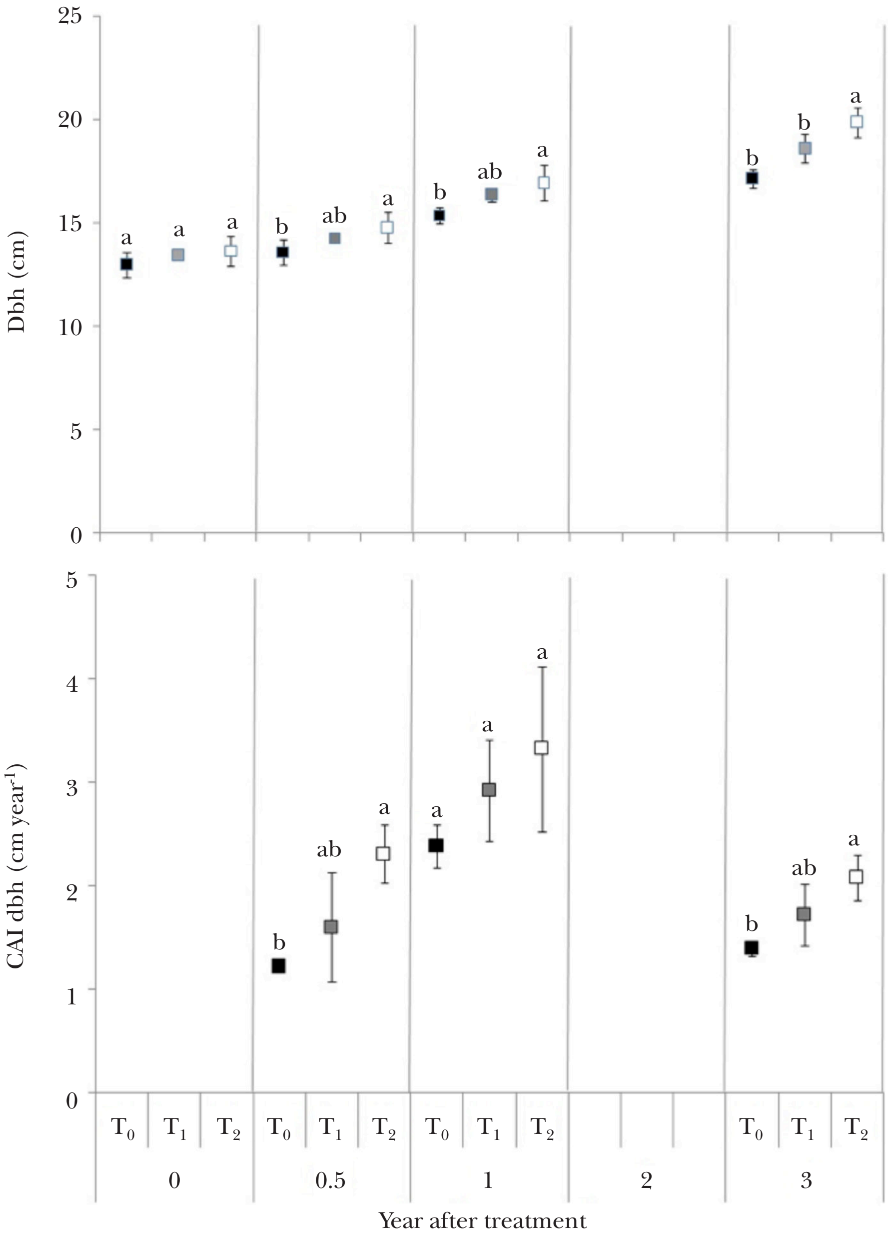

Figure 5 Diameter at breast height (dbh) and current annual increment (CAI) of dbh after thinning treatment of clonal teak plantation in Wanagama Teaching Forest, Java, Indonesia; error bars indicate one standard deviation; within each year, thinning treatments labeled with the same letter are not significantly different (n = 3, $p > 0.05$); T_0, T_1 and T_2 = 0,25 and 50% intensity of tree respectively

Table 2 Treatment effects on diameter at breast height at 0, 0.5, 1 and 3 years after thinning of clonal teak stand in Wanagama Teaching Forest in Java, Indonesia

Source of variation	df	0		0.5		1		3	
		MSE	F	MSE	F	MSE	F	MSE	F
Block	2	1.41	1.28	1.10	1.25	0.71	0.60	1.57	1.25
Thinning	2	1.62	1.47	4.07	4.65*	6.29	5.28*	17.97	14.28**
Pruning	2	0.25	0.23	0.10	0.12	0.13	0.11	0.06	0.05
Thinning and pruning	4	1.30	1.18	0.78	0.89	0.21	0.18	0.34	0.27

df = degrees of freedom, MSE = mean squared error, * significant at $p < 0.05$, ** significant at $p < 0.01$

Table 3 Treatment effects on current annual increment at 0.5, 1 and 3 years after thinning of clonal teak stand in Wanagama Teaching Forest in Java, Indonesia

Source of variation	df	0.5		1		3	
		MSE	F	MSE	F	MSE	F
Block	2	0.38	1.11	0.92	1.23	0.19	1.64
Thinning	2	2.24	6.74*	1.54	2.07	0.98	8.43**
Pruning	2	0.19	0.56	0.28	0.37	0.06	0.48
Thinning & pruning	4	0.41	1.23	1.15	1.54	0.16	1.37

df = degrees of freedom, MSE = mean squared error, * significant at $p < 0.05$, ** significant at $p < 0.01$

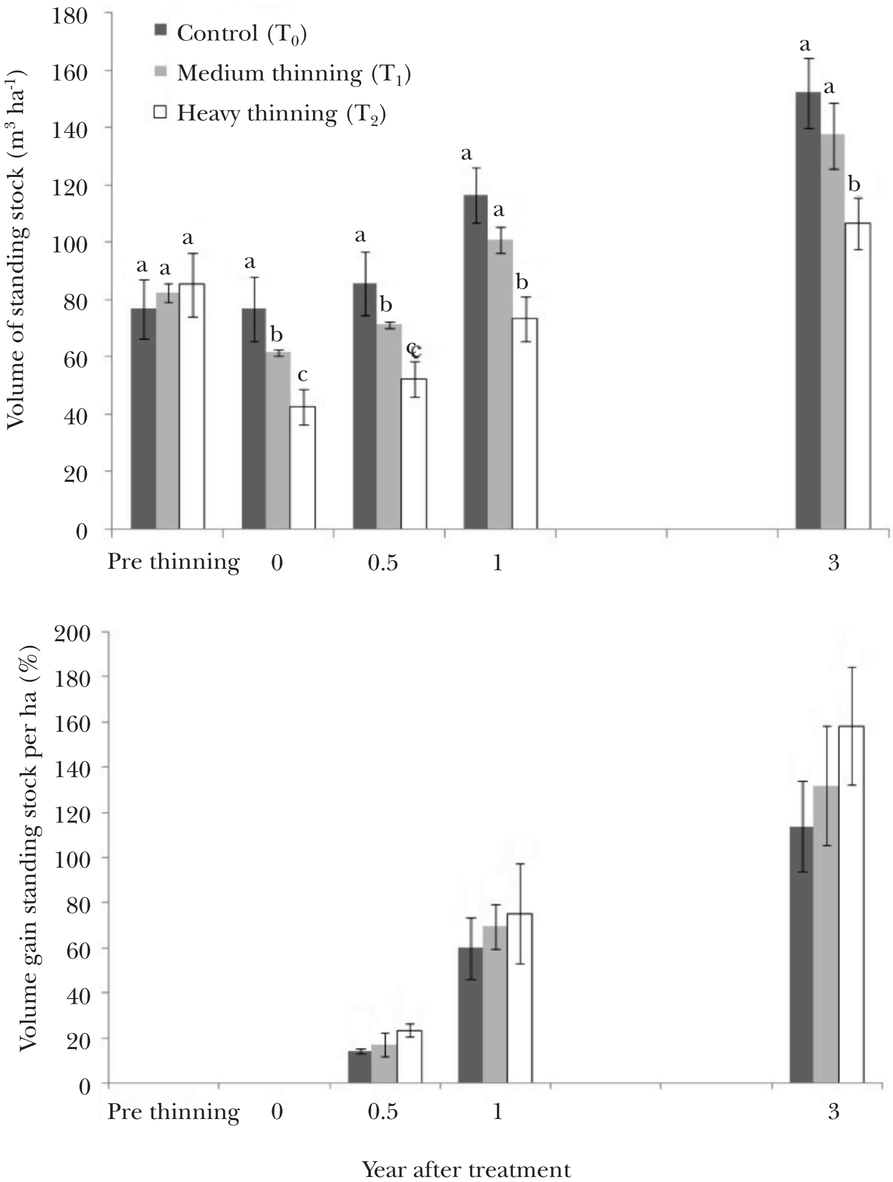

Figure 6 Standing stock and volume gain after thinning treatment of clonal teak stand in Wanagama Teaching Forest, Java, Indonesia; error bars indicate one standard deviation; within each year, thinning treatments had no significant effect on volume gain of standing stock (n = 3, p > 0.05)

Table 4 Treatment effects on stand volume at pre-thinning, 0, 0.5, 1 and 3 years after thinning of clonal teak stand in Wanagama Teaching Forest in Java, Indonesia

Source of variation	df	Pre-thinning		0.5		1		3	
		MSE	F	MSE	F	MSE	F	MSE	F
Block	2	446.81	1.71	211.64	1.86	170.80	0.84	542.61	1.64
Thinning	2	315.26	1.21	2335.92	20.55**	4139.78	20.26**	4523.78	13.66**
Pruning	2	79.26	0.30	42.37	0.37	39.98	0.20	9.46	0.03
Thinning and pruning	4	313.61	1.20	139.69	1.23	25.19	0.12	45.29	0.14

df = degrees of freedom, MSE = mean squared error, * significant at $p < 0.05$, ** significant at $p < 0.01$

Table 5 Treatment effects on volume gain 0.5, 1 and 3 years after thinning of clonal teak stand in Wanagama Teaching Forest in Java, Indonesia

Source of variation	df	0.5		1		3	
		MSE	F	MSE	F	MSE	F
Block	2	40.07	0.61	454.41	0.44	1293.26	0.52
Thinning	2	146.68	2.22	229.86	0.22	3141.55	1.26
Pruning	2	44.32	0.67	658.25	0.64	1039.66	0.42
Thinning and pruning	4	81.32	1.23	1887.12	1.84	3826.54	1.53

df = degrees of freedom, MSE = mean squared error,* significant at $p < 0.05$, ** significant at $p < 0.01$

(Krishnapillay 2000). Thinning is a practical method for increasing light intensity to stimulate growth of the residual trees (Smith 1986, Nyland 2002). Diameter growth rates in the thinned stands of this study were higher than the average for teak plantations in Java and East Timor indicating that thinning improves productivity on poor soils (Krishnapillay 2000, Sousa et al. 2012). In this study, the heaviest thinning treatment resulted in the highest DBH growth of the residual individual tree during the three-year experiment. Kanninen et al. (2004) cited similar finding on the significant effect of different thinning intensity to DBH growth. However, the growth rates decreased markedly in the third year suggesting that fast growth response following thinning may have induced crown closure and competition among the residual trees. The results showed that heavy thinning treatment could positively influence growth of remaining trees, although the site was categorised as low nutrient content and shallow soils. Heavy thinning, however, may expose the soil surface, increasing erosion and nutrient leaching during rainy season, which could lead to severe land degradation at the site.

Furthermore, early thinning is a silviculture technique to reduce stagnation and loss of growth potential in clonal teak plantation. The results revealed that heavy thinning that removed 50% of initial trees, promoted dbh growth of residual stand for 3.3 ± 1.24 cm $year^{-1}$ within three years of monitoring. In a teak stand in Costa Rica, upon 60% thinning treatments at age 4 and 6 years, dbh of remaining trees increased 2.8 and 1.3 cm, respectively, while the first thinning of 10 years-old stand in Malaysia increased DBH for 1.6 ± 0.1 cm $year^{-1}$ (Kanninen et al. 2004, Yahya et al. 2011). In addition, Kanninen et al. (2004) found that timing of the thinning operation impacted the recovery of basal area (BA), for stand that was first thinned at 4 years was better than at 6 years after planting. This suggested that second thinning treatments may need to be applied earlier because the pattern of growth and yield of teak plantation would determine the thinning decision, including timing, frequency and intensity (Rance et al. 2013).

In contrast, to the positive effect of thinning on diameter growth, pruning effects were observed only for a short period and the results revealed that the differences of pruning intensity did not cause growth loss. Although pruning may improve wood quality by preventing knot formation (Krishnapillay 2000, Nyland 2002, Pramono et al. 2011), it may only have ephemeral effects on stem growth, especially for fast-growing trees like the clonal teak. The peak effect of pruning was found during the first years which declined to 40% of growth in the three years after. Similarly, in a teak plantation in Costa Rica, the pruning effect on stem growth was only observed in young stands less than 6.1 years old (Visquez & Perez 2005). On the other hand, early pruning increased wood quality without affecting tree growth or stand productivity, as well as increases labor efficiency for sawn on extension poles (Pèrez 2005, Ladrach 2009). This suggests that pruning has no direct effect on growth of teak but increased quality and stand management.

Although thinning reduces stand basal area and volume, if the harvested timber can be utilised (commercial thinning), it could improve long-term stand productivity (Smith 1986). In the heaviest thinning treatment, the clonal teak plantation produced 44.5 ± 10.1 m^3 ha^{-1} of small sized timber with average diameter of 13.63 ± 1.59 cm. In the local market, small teak wood is used as material for home furniture and firewood. Although gross price of small timber is only around ⅛ of mature, 20 year old trees in the local market (Pramono et al. 2011), commercial thinning could be a source of short-term income for the tree growers. For fast-growing teak, the first commercial thinning could be applied as early as 4 or 5 years after planting. As long as the value of timber is based on the size of dbh and clear bole length, thinning and pruning operation should lead to higher timber productivity for the final cut. Further research including assessment of wood quality and economic value are needed to evaluate the effectiveness of commercial thinning in clonal teak plantations.

CONCLUSIONS

Clonal teak initially grows faster than common teak even when planted on degraded soils. Timely intensive management is needed to maintain high growth rates of clonal teak. Canopy closure occurs within three years after planting, reducing stand growth and productivity. Heavy thinning is recommended along with ground treatment, such as terracing, to prevent erosion and nutrient loss during rainy season. Since the positive effect of thinning on growth rate is only sustained for less than 3 years, short-rotation commercial thinning could maintain growth rates and also provide income for the tree growers.

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