Effects of First Thinning on Growth and Stem Form of Teak Plantations in Thailand

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Abstract

The effects of first thinning on growth and stem form of teak stands were examined in Uttaradit Province, Northern Thailand. In this study, a randomized complete block design with 3 replications was used, and thinning from below (low thinning) was applied as the first thinning. The thinning treatments were as follows: removal of basal area at the levels of 0% (unthinned), 30% (moderate), and 50% (heavy). The measurement period after thinning was 4 years. The results of the study revealed that heavy thinning provided the largest mean basal area and mean stem volume of individual trees in the stands compared with the other treatments. The total stand volume increase in production per rai (0.16 ha) was largest in moderate thinning plots and differed significantly from unthinned plots, but did not differ significantly from heavy thinning plots. The moderate and heavy thinning intensities reduced the annual stand volume increase by 23% and 64%, respectively, related to the mean stand volume increase of thinned stands before thinning was executed, whereas those in unthinned plots reduced by almost 99%.

Part of the total stand volume production of unthinned plots was lost through natural mortality. In the thinned plots, natural mortality was considerably lower compared with the unthinned plots. The mean diameter at breast height (DBH) increment of all trees as well as the mean DBH increment of the dominant trees was enhanced with increasing thinning intensity, but there was no significant difference among the thinned and unthinned plots. However, the mean DBH increment of all trees in unthinned plots was as much as those in moderate thinning plots. In contrast, total height increment of all trees and the dominant trees were not affected by thinning intensity. Live-crown ratio, slenderness ratio, and absolute form factor of the trees in the stand were affected by different thinning intensities. Live-crown ratio increased with greater thinning intensity. On the other hand, slenderness ratio decreased with greater thinning intensity. The absolute form factor was smallest in unthinned plots, and different thinning intensities had clear effects on the absolute form factor. Thus, thinning intensity resulted in improved growth and yield of stands after thinning as well as individual tree size and tended to have positive effects on stem form.

Keywords: Thinning intensity, Mean volume increment, Stand volume increment, Live-crown ratio, Slenderness ratio, Absolute form factor

Introduction

Teak (*Tectona grandis* L.f.) is the most important indigenous tree species of Thailand. It is considered by forestry industries as a species of high commercial value. The growth rate of teak is greater at sites with annual rainfall between 1,250 mm and 3,750 mm, associated with a 3- to 5-month drought periods, minimum temperatures between 13 °C and 17 °C, and maximum temperatures between 39 °C and 43 °C (Pandey et al. 2000).

Control of stand density by thinning has been the major tool in regulating tree growth and improving timber quality. Although thinning from below may increase the merchantable volume of a stand, usually it does not increase the total volume increment per unit area (e.g. Hasenauer et al. 1997; Zeide 2001). Many studies have revealed that the stand volume increment of various tree species does not decline with decreasing stand density (e.g. Hamilton 1981; Horne et al. 1986). This indicated that thinning from below (or low thinning) redistributes the increment of individual trees from smaller trees to larger ones, and the smaller number of trees is able to produce the same volume increment per unit area.

Thinning practice also affects wood properties such as heartwood proportion, wood density, and stem form. Stem form is defined as the rate of taper of a stem. Taper is the decrease in diameter of a stem of a tree or of a log from the base upwards. The potential change in stem form as a result of thinning is important with regard to volume and the product recovery prediction. Most variation in stem form may be traced to the change in size and distribution of the live crown on the stem and to the length of the branch-free bole (Larson 1963).

The objective of this study was to relate thinning intensity of the first thinning operation with diameter, height, volume increment, and stem form on the basis of permanent long-term experiments with thinning from below in a teak plantation in Thailand. This study provided us with the opportunity to investigate total stem volume production, thinning removal as well as changes in stem form, during the whole rotation.

Materials and methods

Study site

The thinning trial was established in a private teak plantation in Tha Sao District, Mueang Sub-District, Uttaradit Province, on a site with a tropical monsoon climate and mountainous region in Northern Thailand. The average annual temperature was approximately 27.7 °C with minor daily and annual fluctuations. The annual precipitation was 1,432.6 mm, with 6 dry months. The study site was located at an altitude of 105 m a.s.l., at 17° 41’25.5” N, and 100° 17’52.8” E.

In an area originally cleared for agricultural crops, a 47 rai (a rai is the local measurement unit used in Thailand and 1 rai equals 1,600 m^2 or 0.16 ha) *T. grandis* plantation was established in May 2005, with initial spacing of 2×4 m (200 trees per rai). The first thinning was conducted in May 2011, when the teak plantation was 6 years old. The pure teak stand presented canopy closure but severe competition was not evident. The stand basal area was around 1.90 m^2 rai^{-1} (11.88 m^2 ha^{-1}). There was no other silvicultural interventions such as pruning applied to the plantation prior to thinning.

Experimental design and treatments

The experimental design consisted of randomized complete blocks, with three treatments and three replicates. Prior to thinning, each treatment consisted of 200 trees (including dead trees) in square blocks of 1,600 m^2 (20×10 trees under a spacing of 2×4 m) or 1 rai, excluding buffer zones consisting of two lines of trees, each of them thinned according to the corresponding treatment they were bordering (Fig. 1).

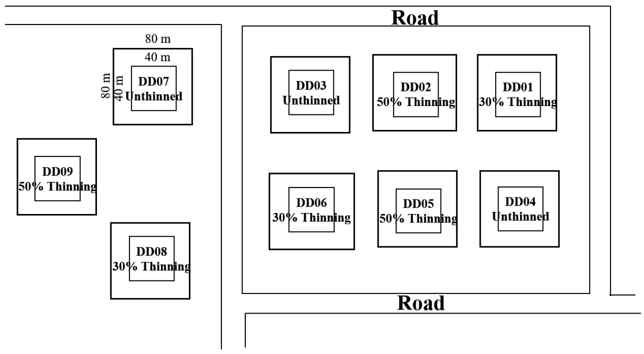

Fig. 1. Layout of experimental plots.

Thinning from below or low thinning (defined as the thinning method that favors the tallest trees in the stand by removal the lower crown classes) with different thinning intensities was applied in each treatment based on the percentage of the stand basal area prior to thinning. The trees removed in each treatment were also selected based on crown class, i.e. dominant, co-dominant, intermediate, and suppressed and also based on characteristics of tree, e.g. no defects, some defects, weak, and standing dead. All trees in each thinned stand was divided into five classes and the trees in the fifth class (or the lowest class, i.e. consisting of weak trees, dead trees, and fallen trees) were selected before the others until the target basal area removal in each treatment was reached. The thinning treatments were removal of initial basal area at rates of 0% (unthinned or control), 30% (moderate), and 50% (heavy).

Measurements

Prior to thinning, the experimental plots were measured, and they were measured again just after thinning was conducted. Following thinning, the tree sizes were measured and the surviving trees were surveyed in each plot every year. The measurement period was 4 years. At the time of the last measurement, the stand age was 10 years. All living trees in each treatment were numbered and marked at 1.3 m stem height for repeated annual measurements of stem diameter at breast height (DBH), total height (H), and height to crown base (Hb), using diameter tape and a measuring pole. A digital hypsometer was used when tree height was more than 15 m.

Two years after thinning, the stem diameter of 10 randomly selected trees per treatment (unthinned, 30% thinning, and 50% thinning) was measured, using an electronic BAF-scope/dendrometer (CRITERION RD 1000). The diameter of a standing tree at target points along the stem and total height of the tree were measured and recorded. The data was used to construct an allometric equation for calculating the individual stem volume of trees in each treatment.

Basal area and volume were calculated for each tree, and stand total basal area and total volume were calculated by summing the values of all trees in the measurement plot, and then these values were converted to 1 rai (1,600 m^2 or 0.16 ha). The stem volume of each tree was calculated at the thinning time, just after thinning, and 1 year after thinning from the stem volume equation for this species presented by Vacharangkura et.al. (2010):

$$V = 0.00009734\ DBH^{1.99583}\ H^{0.64695}$$

Where V is the over bark volume (m^3), DBH is the diameter at breast height over bark (cm) and H is the tree total height (m).

Because thinning affected stem form (shape) of any tree in the stands, different stem volume equations were calculated for each stand with the different treatments. The nonlinear model used to calculate individual stem volume was:

$$V = a\,(DBH^2H)^b$$

Where a and b are constants. Mean basal area and mean stem volume of each treatment were calculated to examine tree size. Annual increment was calculated as the difference between successive measurements divided by the number of years between the measurements. Dominant trees were based on 100 trees by diameter (DBH) of the largest trees per hectare (16 trees per rai). Total volume production and stand volume increment were calculated to examine the effects of the thinning operation.

In order to evaluate the effect of thinning on stem form, the three parameters were applied to investigate the attributes of trees in each treatment at the time before and after thinning was performed. These parameters were:

(1) Live-crown ratio (ratio between crown height and total height (H-Hb)/H)
(2) Slenderness ratio (H/DBH ratio)
(3) Absolute form factor (defined as the ratio of the volume of a tree or its part to the volume of a cylinder having the same length and cross section as the tree).

These parameters were calculated for each tree before and after thinning, and then the average in each treatment was used to examine the effect of thinning on stem form.

Statistical analysis

The effects of thinning intensity on tree size, individual growth rate, and growth rate of stand were analyzed. ANOVA was applied to examine statistical significant of the differences among treatment. The mean difference comparison using Tukey's HSD was performed to compare the means among treatments.

Results

Effects of the thinning on tree size

ANOVA showed that there was no significant difference among treatments in terms of mean DBH, mean height, stand basal area, or stand volume. This means that the plantation had a homogeneous structure even though there were slight differences in stand density in the heavy thinning plots compared with the moderate thinning and unthinned plots (Table 1).

Just after thinning, mean DBH was not significantly different between the thinned plots, but the thinned plots were different from the unthinned plots. There was no significant difference among treatments in term of mean height. Stand basal area differed significantly in all treatments. There was no significant differences in stand volume in the moderate thinning and heavy thinning plots, but the both thinning type plots were significantly different from the unthinned plots. The density of trees differed significantly because of the difference of thinning intensities (Table 1).

By the final measurement, at 4 years after thinning, the differences in stand density among the treatments had changed. There were no significant differences in stand density among treatments because mortality was high in the unthinned plots owing to severe competition. Mean diameters of the residual stands increased significantly in thinned plots and differed significantly from unthinned plots. On the other hand, there was no significant difference in mean height among treatments. Stand basal area was highest in the unthinned plots (2.02 m^2 rai^{-1}) but was not significantly different from plots that had received moderate thinning. There was no significant difference in stand basal area in all thinned plots. Four years after thinning, stand volume had increased in all of the thinned plots but decreased in unthinned plots. There was no significant difference in stand volume among the treatments (Table 1).

The corresponding basal area and stem volume development of trees in the stands from the time of thinning to 4 years after thinning are presented in Fig. 2 and Fig. 3, respectively. The mean basal area in heavy thinning plots was the largest year by year after thinning. At the age of 10 years (4 years after thinning), the mean basal area in heavy thinning plots differed statistically from those in moderate thinning plots and unthinned plots. There was no significant difference in mean basal area between moderate thinning plots and unthinned plots.

This result indicated that thinning promoted larger stem diameter in the stands, and heavier thinning intensity tended to encourage larger stem diameter of trees. The corresponding mean stem volume of the stands was significantly different among treatments by 1 year after thinning. From 2 year after thinning, the mean stem volume in both moderate and heavy thinning plots were not significantly different, but they were significantly different from the unthinned plots. The results clearly demonstrated that thinning promoted larger tree size.

Effects of thinning on tree growth

The arithmetic mean annual DBH increments of all trees in heavy thinning plots were the largest, followed by those in unthinned plots and moderate thinning plots (Fig. 4). The differences among thinning intensities were not statistically significant in all treatments. The mean diameter increment was also calculated for the dominant

Table 1. Stand characteristics of Den Dan plantation before, just after and 4 years after thinning

	Treatment								
Before thinning	Moderate			Heavy			Unthinned		
Stand density (tree ha^{-1})	195	(±1.00)	a	193	(±1.00)	b	196	(±0.58)	a
Mean DBH (cm)	10.15	(±1.06)	a	10.33	(±0.81)	a	9.99	(±1.00)	a
Mean height (m)	10.94	(±1.31)	a	11.01	(±1.00)	a	10.44	(±1.44)	a
Stand BA^2 (m rai^{-1})	1.63	(±0.30)	a	1.68	(±0.23)	a	1.6	(±0.30)	a
Stand volume (m^3 rai^{-1})	9.64	(±2.38)	a	9.94	(±1.79)	a	9.25	(±2.35)	a
Just after thinning									
Stand density (tree ha^{-1})	123	(±8.98)	c	81	(±4.04)	b	196	(±0.58)	a
Mean DBH (cm)	11.58	(±0.58)	a	12.17	(±0.34)	a	10.82	(±0.87)	b
Mean height (m)	12.45	(±0.48)	a	12.54	(±0.24)	a	11.17	(±1.32)	a
Stand BA^2 (m rai^{-1})	1.33	(±0.21)	b	0.93	(±0.12)	c	1.88	(±0.28)	a
Stand volume (m^3 rai^{-1})	8.40	(±1.49)	b	5.95	(±0.78)	b	11.30	(±2.40)	a
4 years after thinning									
Stand density (tree ha^{-1})	120	(±11.01)	a	79	(±6.11)	a	174	(±5.86)	a
Mean DBH (cm)	13.16	(±0.70)	b	14.50	(±0.18)	a	12.49	(±0.45)	b
Mean height (m)	13.42	(±0.89)	a	13.95	(±0.11)	a	12.83	(±0.37)	a
Stand BA^2 (m rai^{-1})	1.62	(±0.26)	ab	1.31	(±0.11)	b	2.02	(±0.17)	a
Stand volume (m^3 rai^{-1})	14.19	(±3.28)	a	8.91	(±0.72)	a	10.15	(±1.01)	a
Thinning ratio									
No. of trees (%)		36.91			58.20			0.00	
BA (%)		30.32			50.77			0.00	

Remarks: BA = basal area

Treatments marked with the different letters are significantly different ($p < 0.05$); standard deviation in parentheses.

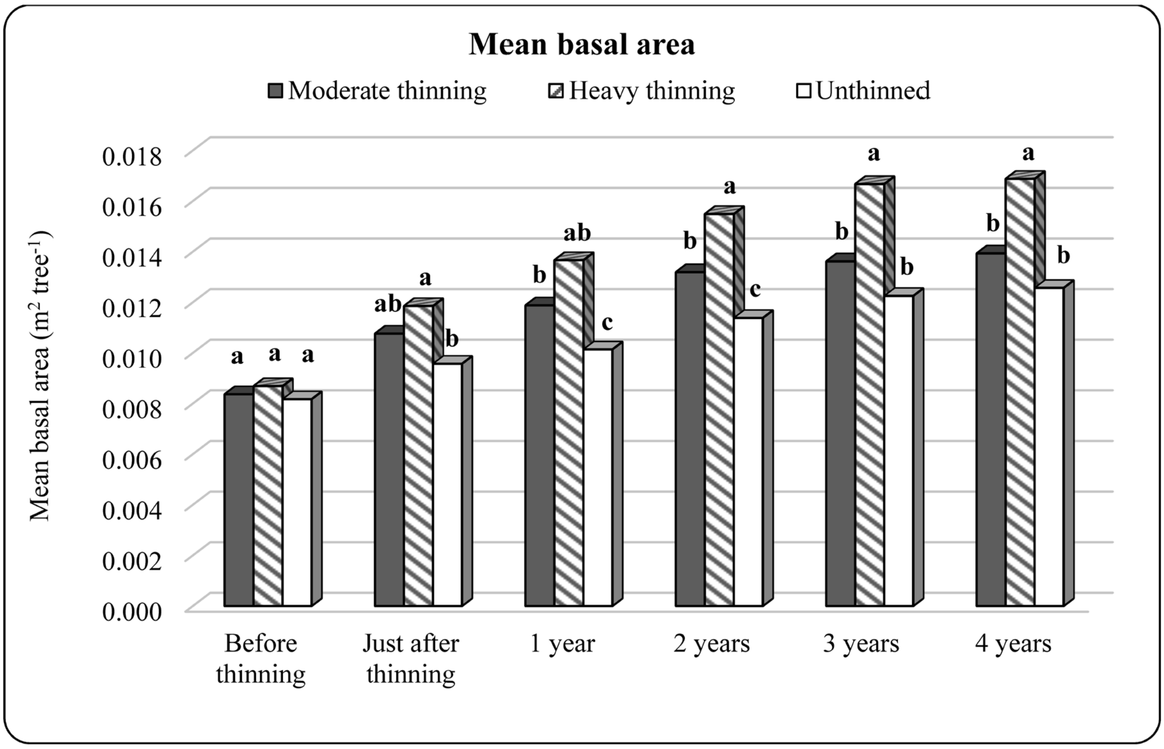

Fig. 2. Mean basal area 4-year after thinning. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA test. The treatments marked with the different letters are significantly different ($p< 0.05$).

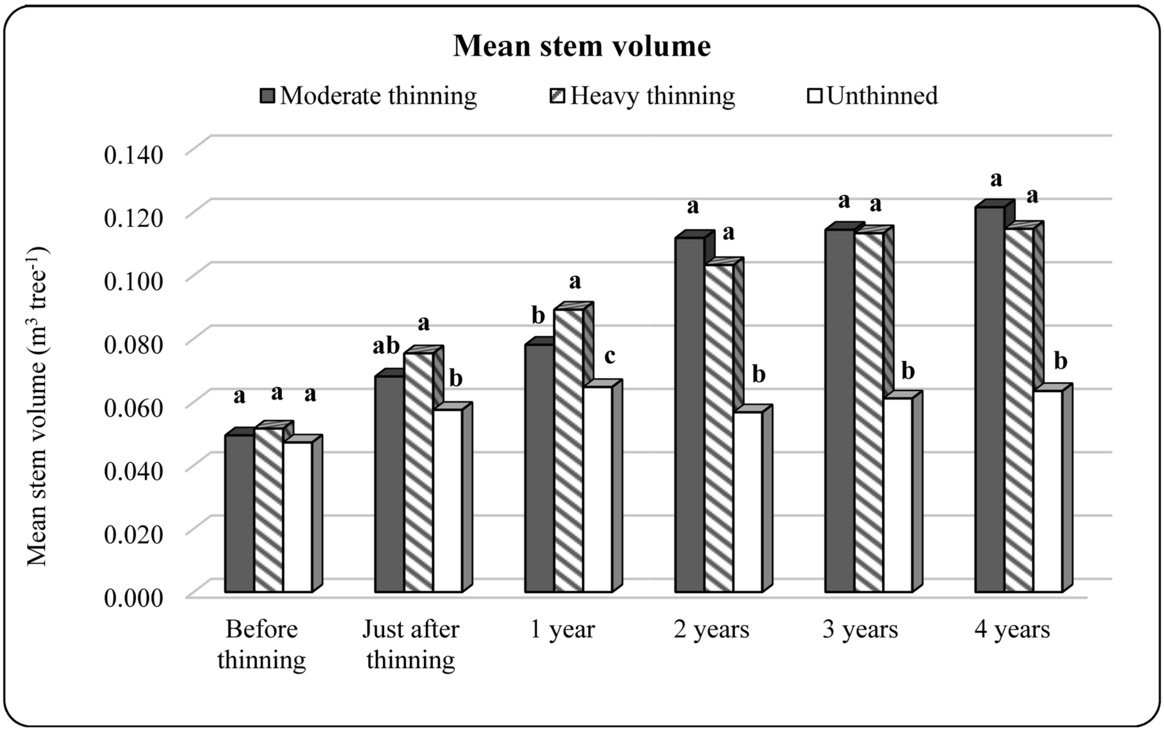

Fig. 3. Mean stem volume 4-year after thinning. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA test. The treatments marked with the different letters are significantly different ($p< 0.05$).

trees (defined as 16 largest tree by DBH per rai). The mean annual increment of the dominant trees was the largest in heavy thinning plots, followed by those in moderate thinning plots and unthinned plots. The test of mean annual increment of dominant trees revealed the same result as for all the trees. This result indicated that thinning intensity had no clear effect on annual DBH increment of the dominant trees in the residual stands (Fig. 4).

In case of mean height of all trees and mean annual height increment of the dominant trees, the results were aligned with the results in mean annual DBH increment presented above. The mean annual height increment of all trees and dominant trees were largest in the unthinned plots, followed by the heavy thinning plots and then the moderate thinning plots. The heavy thinning plots seemed to show a greater annual height increment of all trees and the dominant trees, but there was no significant differences (Fig. 5).

Effects of thinning on stand growth

The volume production of the residual stands calculated from the year of thinning was only examined in the fourth year after thinning, and the data are presented in Table 2. Total volume production in each stand consisted of the volume of thinned trees, volume of dead trees, and current volume production. The total volume of production was the summation of these three parts. The total volume of production in moderate thinning plots was the largest (17.95 m^2 rai^{-1}), followed by the heavy thinning plots and then the unthinned plots. The numbers and volume of dead trees in unthinned plots were much larger than those

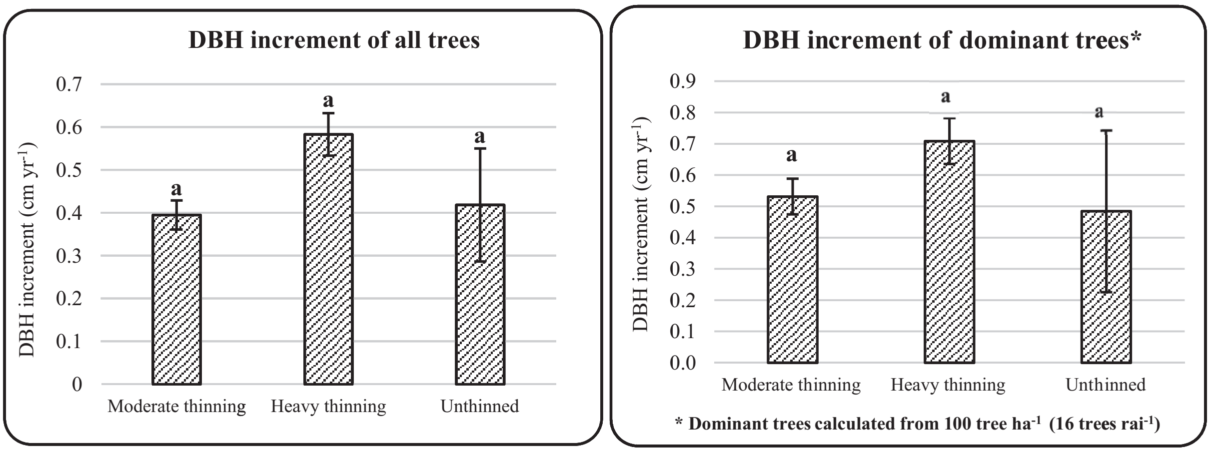

Fig. 4. Mean annual DBH increment of all trees and dominant trees. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA test. The treatments marked with the different letters are significantly different ($p < 0.05$).

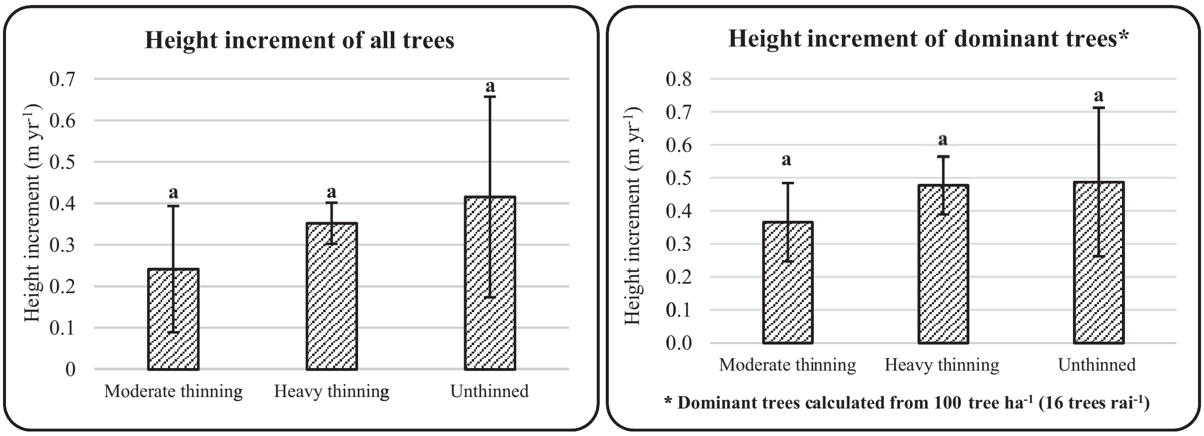

Fig. 5. Mean annual height increment of all trees and dominant trees. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA test. The treatments marked with the different letters are significantly different ($p < 0.05$).

in both thinned plots, because of severe competition in unthinned plots. The number and volume of dead trees was smallest in heavy thinning plots. This result may be caused the larger volume of production in heavy thinning plots than in unthinned plots. This result indicated that thinning prevented regular tree mortality.

The annual stand volume increment was larger in moderate thinning plots than those in heavy thinning plots, but there was no significant difference between the two thinning intensities. Compared with the unthinned plots, the annual stand volume increment in moderate thinning plots differed significantly. In contrast, annual stand volume increment in heavy thinning plots was not significantly different from the unthinned plots (Fig. 6).

The total stand volume production was largest in moderate thinning plots, followed by heavy thinning plots and then unthinned plots. The differences between the thinning intensities were not statistically significant. The total stand volume production in heavy thinning plots was not significantly different from that in the unthinned plots. These results were in accordance with the results of annual stand volume increment (Fig. 7).

Annual stand volume increments on the thinned and unthinned plots during the whole measurement period were also examined in relation to the mean volume increment of unthinned plots (Table 2). As expected, annual stand volume increment decreased with increasing thinning intensities. This result was in accordance with the result of current volume production (Table 3). The heavy thinning intensity decreased the annual stand volume increment by 64% compared with the mean volume increment of unthinned plots prior to thinning. The moderate thinning intensity decreased the annual stand volume increment by 23%, whereas unthinned plots showed a decrease in annual stand volume increment of almost 99%.

Effects of thinning on stem form

The effect of thinning on live-crown ratio was observed from the year thinning was performed to 4 years after thinning. The live-crown ratio in thinned stands was larger than those in unthinned plots from 1 year after thinning. Among thinned plots, the live-crown ratio in heavy thinning plots was larger than those in moderate thinning plots by 2 years after thinning and clearly differed from 3 years after thinning (Fig. 8).

On the other hand, the slenderness ratio (slenderness coefficient) in unthinned plots was larger than those in thinned plots from 1 year after thinning. The slenderness ratio in heavy thinning plots clearly showed lower values than those in the moderate thinning plots and unthinned plots, although the differences between the moderate thinning and unthinned plots were not clear (Fig. 8).

Absolute form factor clearly differed among treatments from 3 years after thinning. The form factor in moderate thinned plots yielded more cylindrical trees than those in heavy thinned plots and unthinned plots. The form factor of all thinned plots was larger than those of unthinned plots (Fig. 9).

The effects of thinning on the three parameters contributed to the quality of stem form by 4 years after thinning, and the results are presented in Table 4.

The ANOVA results indicated that there were significant differences in live-crown ratio among treatments. The live-crown ratio in heavy thinning plots was larger than those in moderate thinning and unthinned plots; however, there was no significant difference between heavy thinning plots and moderate thinning plots. Compared with the unthinned plots, but the live-crown ratio in moderate thinning plots was not significantly different.

In contrast, the ANOVA results clearly indicated that there was no significant difference in slenderness ratio among the treatments. The slenderness ratio in heavy thinning plots was markedly different from the others because the value was less than 100%, whereas the corresponding values were higher than 100% in the other treatments.

As shown in Table 4, the absolute form factor in moderate thinning plots was the largest, followed by those in heavy thinning plots and unthinned plots. The ANOVA results clearly showed that there were significant effects of thinning intensity on the absolute form factor.

Discussion

The plantation responded to the first thinning, and the largest diameter increment occurred after heavy thinning (Fig. 4). The results of this study were similar to the results of many other studies, especially in broad-leaved stands (e.g. Hibbs et al. 1995; Rytter 1995; Kerr 1996; Clatterbuck 2002; Meadows and Goelz 2002). The increase in diameter growth in response to thinning was associated with an increase in photosynthetic rate and water and nitrogen use efficiency among thinned trees (Wang et al. 1995).

Height increment was not affected by thinning intensity in moderate thinning or heavy thinning plots (Fig. 5). Similar results were found in young stand of teak in Costa Rica after the first thinning was performed at 4 years (Kanninen et al. 2004). It is well-known that stand

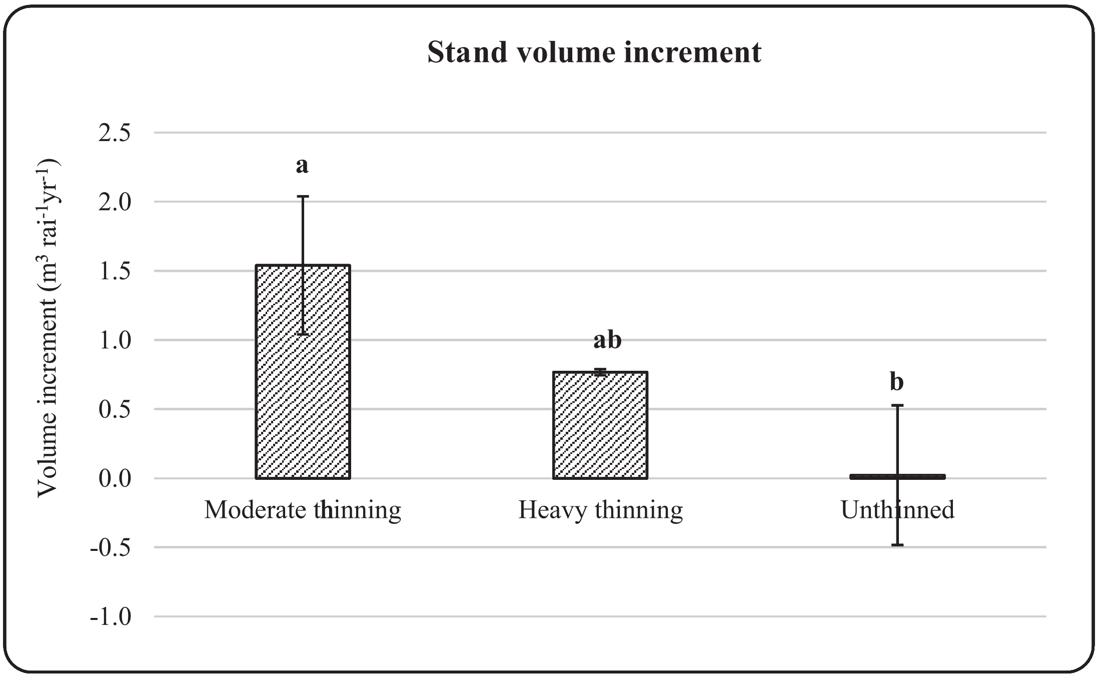

Fig. 6. Mean stand volume increment. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA test.

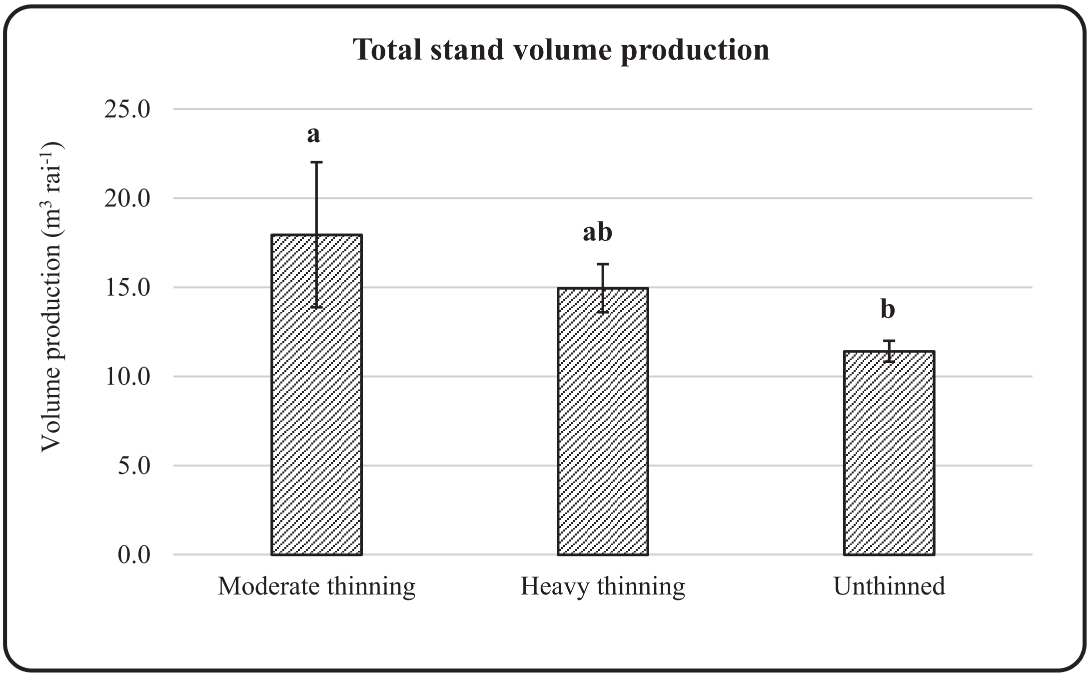

Fig. 7. Total stand volume production. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA test. The treatments marked with the different letters are significantly different (p< 0.05).

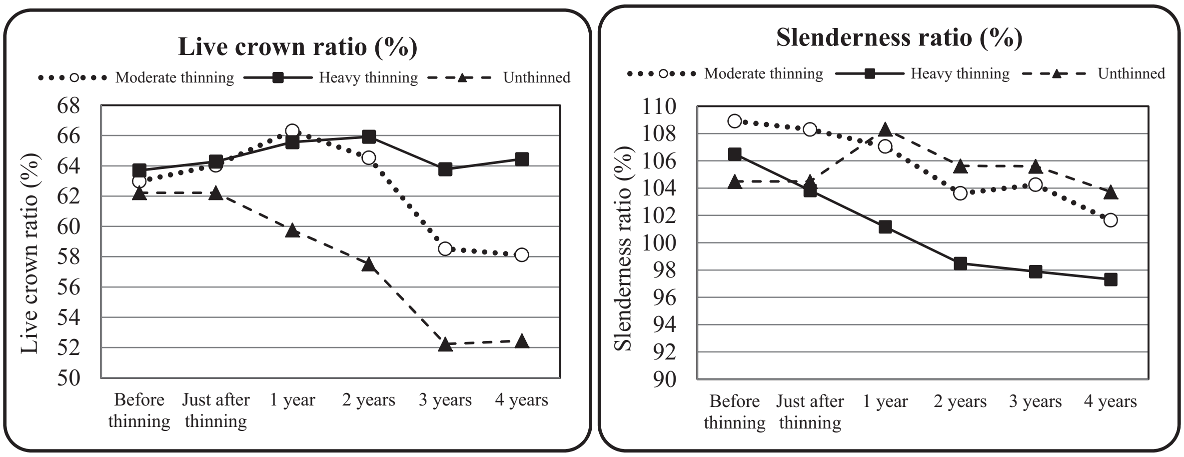

Fig. 8. Live-crown ratio and slenderness before and after thinning.

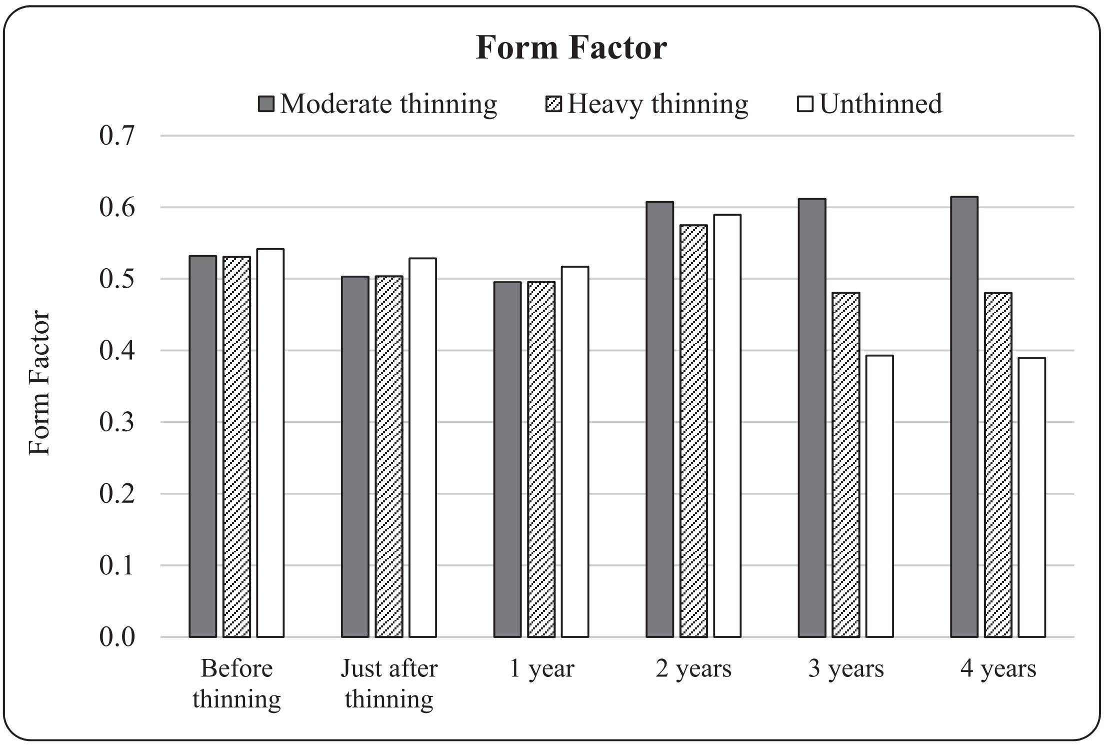

Fig. 9. Absolute form factor before and after thinning.

Table 2. Decrease in annual stand volume increment

Treatment	Annual stand volume increment (m^3 rai^{-1} $year^{-1}$)		
	Just after thinning	4 years after thinning	Decrease in volume increment (%)
Moderate thinning	1.96	1.54	−22.51
Heavy thinning	1.98	0.77	−64.30
Unthinned	1.89	0.02	−98.86

Table 3. Stand volume production (m^3) in stands with different thinning intensities

Treatment	Volume of thinned trees	Volume of dead trees	Current volume production	Total volume production	No. of dead trees
Moderate thinning	3.39	0.36	14.19	17.95	7.33
Heavy thinning	5.88	0.15	8.91	14.95	3.00
Unthinned	0.00	1.26	10.15	11.41	36.00

Table 4. Parameters of tree attributes associated with quality of stem form: 4 years after thinning

Treatment	Live-crown ratio (%)	Slenderness ratio (%)	Absolute form factor
Moderate thinning	58.11 (+3.96) ab	101.65 (+3.56) a	0.61 (+0.02) a
Heavy thinning	64.45 (+2.43) a	97.31 (+1.91) a	0.48 (+0.0005) b
Unthinned	52.45 (+5.60) b	103.73 (+1.71) a	0.39 (+0.005) c

density has significant effects on diameter growth, but not on height growth, except for very high and very low stand densities. Our study results concurred with this finding.

The results clearly demonstrated that the remaining trees can rapidly occupy the growing space released by the thinned trees, especially in the moderate thinning plots. The DBH and height increment of all trees as well as that of dominant trees clearly increased (Hamilton 1976), but there was no significant difference among thinned and unthinned stands. The differences in diameter increment, basal area, and volume in reaction to thinning can be explained by differences among tree species, sites, stand ages, tending practices, and thinning type and intensity. The results from our study support known information about the effects of thinning on stand production.

The total stand volume increment per unit area (per rai) did not vary much between the moderate thinning plots and heavy thinning plots, but there was significant difference from the unthinned plots (Fig. 7). The main reason was the dense unthinned stands consumed more carbon for respiration than thinned stands; thus, net production will be reduced in dense stands (Savill et al. 1997). However, stand volume increment in the heavy thinning plots did not differ significantly from the unthinned plots because a large number of trees were removed. The total stand volume production in the unthinned plots was the smallest compared with the thinned plots (Table 3) because part of the total stand volume production was lost owing to severe competition in the stand. Therefore, thinning prevents natural mortality. The results in this study revealed that increasing thinning intensity resulted in only a small reduction in total stand volume production (from 17.95 m^3 rai^{-1} in moderate thinning plots to 14.95 m^3 rai^{-1} in heavy thinning plots) (Fig. 7). However, the DBH increment of the remaining trees was clearly increased by thinning.

The results in this study revealed that thinning had a positive effect on stem form. Live-crown ratio in heavy thinning plots was largest and differed significantly from the unthinned plots (Fig. 8). It meant that heavy thinning expanded the crown size of trees. Because we know that the crown contains the foliage, which is the photosynthetic structure that provides carbohydrates for the growth and development of the whole tree (Larson 1963; Leites and Robinson 2004). The stem of a tree was strongly influence by its crown size and position (crown length, crown ratio, and crown height). This result was confirmed in our study, whereby the mean stem volume of an individual tree in the unthinned plots was the smallest compared with those in the thinned plots.

The slenderness ratios (or slenderness coefficients) of trees in the heavy thinning plots were larger than those in the moderate thinning and unthinned plots, even though the difference among treatments was not statistically significant (Fig. 8). The slenderness ratio has been widely used as an index of the stability of trees, especially the resistance of a tree to windthrow. The preferred slenderness ratio of a tree was lower than 100%. In this study, the slenderness ratio was lower than 100% (97.31%) only in the heavy thinning plots. It meant that the trees in heavy thinning stands may be at low risk for windthrow compared with the others. However, for teak species Pérez and Kanninan (2005) reported from their study in a young stand of a teak plantation, intensive thinning had a positive effect on the stem form, inducing the development of trees with the desired proportion of DBH and total height. Trees suffering high competition in the unthinned and medium thinning treatments will hardly reach a DBH/total height ratio (slenderness ratio) of 1:1. However, there have been no similar studies in teak plantations for comparison.

The absolute stem form factor was largest in the moderate thinning plots and differed significantly from the heavy thinning and unthinned plots. The unthinned plots had the smallest value (Table 4). The larger stem form factor provided a more cylindrical volume of a tree. The results of this study confirmed this; the mean stem volume of individual trees at 4 years after thinning in the moderate thinning plots was largest compared with the others. Pérez and Kanninen (2005) reported in young teak plantations in Costa Rica that moderate early thinning yielded trees that were more cylindrical in form (average form factor of 0.46) than late thinning and control (unthinned) average form factors (0.43 and 0.44, respectively). The results of our study in the heavy thinning plots provided a similar value of stem form factor found in early moderate thinning stands from their study.

Conclusion

The heavy thinning intensity (50% based on basal area) applied at the age 6 years gave the largest values in terms of mean DBH, mean height, mean basal area, and mean stem volume of individual trees, whereas the unthinned control showed the smallest values. The total height was not statistically different among treatments, although the mean height in the unthinned treatment was smaller than that of the other treatments. The current stand basal area and stand volume at 4 years after thinning was the largest with moderate thinning intensity, whereas those with the heavy thinning intensity were the smallest.

The results from this study indicated that the mean DBH increment of all trees, as well as the mean DBH of the dominant trees, increased with increasing intensity, but there was no significant difference among thinned and unthinned stands. The mean DBH increment of all trees in the unthinned stands was similar those in the moderate thinning stands. On the other hand, the height increment of all trees and of the dominant trees was not affected by thinning intensity.

The mean stand volume increment produced per rai was largest in the moderate thinning stands and differed significantly from the unthinned stands. However, it did not differ significantly from the heavy thinning stands. In the case of total stand volume production at 4 years after thinning, the results were in accordance with the results of the total stand volume increment.

The moderate and heavy thinning intensities reduced the stand volume increment by 23% and 64%, respectively, related to the mean stand volume increment of the unthinned stands, whereas the stand volume increment in the unthinned stand decreased by almost 99%. However, part of the total stand volume production of the unthinned stands was lost because of natural mortality.

Thinning intensity had effects on tree (stem) attributes that contributed to the quality of stem form. Live-crown ratio increased with increasing thinning intensity. On the other hand, the slenderness ratio decreased with increasing thinning intensity. The absolute form factor was clearly affected by thinning intensity. The form factor was significantly different among treatments, and unthinned stands gave the smallest form factor; therefore, thinning practice tended to have a positive effect on stem form even in a young stand of teak.

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