RESPONSE OF UNMANAGED *ACACIA MANGIUM* PLANTATIONS TO DELAYED THINNING IN NORTH-EAST THAILAND

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Received July 2008

KAMO K, VACHARANGKURA T, TIYANON S, VIRIYABUNCHA C, THAINGAM R & SAKAI M. 2009. Response of unmanaged *Acacia mangium* plantations to delayed thinning in north-east Thailand. The effects of delayed thinning on the survival and growth of residual trees in 14-year-old unmanaged *Acacia mangium* stands in north-eastern Thailand were studied for 8.3 years. Two types of row-thinning were used: alternate-row thinning and every-third-row thinning plus selective thinning of the remaining two rows. Both types reduced mortality of residual trees to less than 26% of that in the unthinned stand. Both types also increased stand and individual stem volume compared with the unthinned stand. The stimulation of volume increment occurred with 1.2 years of thinning but lasted for only about 3 years. Trees of all sizes responded, although increased volume increment was greatest for larger trees. During the 8.3 years, alternate-row and third-row plus low thinning increased total stand volume increment by 5.8 and 4.2 times above that of the unthinned stand. Both thinning regimes also promoted greater production of merchantable wood volume. Of the two thinning methods, alternate-row thinning was superior to third-row plus low thinning in terms of total stand volume increment and merchantable volume production. Our results indicated that previously unmanaged stands of *A. mangium* were still capable of responding to thinning with increased volume growth even when the treatment was delayed 10 years, beyond the time normally recommended for the species.

Keywords: Fast-growing species, intensive row-thinning, volume increment, unmanaged stand

KAMO K, VACHARANGKURA T, TIYANON S, VIRIYABUNCHA C, THAINGAM R & SAKAI M. 2009. Respons ladang *Acacia mangium* tak terurus kepada penjarangan tertunda di timur laut negara Thai. Dirian *Acacia mangium* tak terurus berusia 14 tahun di timur laut negara Thai dikaji selama 8.3 tahun. Kajian tertumpu kepada kesan penjarangan tertunda terhadap kemandirian dan pertumbuhan pokok-pokok yang tinggal. Dua jenis penjarangan digunakan: penjarangan baris selang dan penjarangan baris ketiga + penjarangan terpilih pada dua baris yang lain. Kedua-dua jenis penjarangan mengurangkan kematian pokok yang tinggal kepada kurang daripada 26% nilai dirian yang tidak dijarangkan. Tambahan isi padu berlaku 1.2 tahun selepas penjarangan tetapi cuma selama 3 tahun sahaja. Pokok pelbagai saiz menunjukkan tambahan isi padu tetapi tambahannya lebih tinggi dalam pokok besar. Selama 8.3 tahun, jumlah pertambahan isi padu dirian bagi penjarangan baris selang dan penjarangan baris ketiga + pokok-pokok kelas kecil masing-masing 5.8 kali dan 4.2 kali lebih tinggi daripada isi padu dirian tak dijarang. Kedua-dua jenis penjarangan menghasilkan isi padu kayu niaga yang lebih tinggi. Penjarangan baris selang lebih baik daripada penjarangan baris ketiga + pokok-pokok kelas kecil dari segi tambahan jumlah isi padu dirian dan penghasilan isi padu kayu niaga. Keputusan menunjukkan bahawa *A. mangium* tak terurus masih menunjukkan gerak balas kepada penjarangan dan mampu menghasilkan pertambahan isi padu walaupun penjarangan terlewat 10 tahun iaitu tempoh yang disarankan untuk spesies tersebut.

INTRODUCTION

Thailand, like many tropical countries, has suffered serious forest deforestation, with only 25% of forest remaining in 2000. Preventing further deforestation and restoring forest ecosystems are urgent tasks in maintaining the biosphere and enhancing forest resources. During the Research and Training in Re-afforestation Project of Thailand (Royal Forest Department) and Japan (Japan International Cooperation Agency) period (1981–1994), various kinds of tree plantations, consisting of mainly fast-growing exotic species were established on degraded land of the Sakaerat Field Station, which is located in north-eastern Thailand. The forested areas totalled 2500 ha. However, stands have been left untended since their establishment. Plantations need to be conscientiously managed to enhance stand quality and promote wood production. Tending operations such as thinning are typically used to increase production of usable-sized trees (Zeide 2001). Thinning could also provide an intermediate financial return from the removed trees (Evans & Turnbull 2004). In fast-growing exotic species plantations, thinning is unnecessary for biomass production, whereas producing large-diameter timber with higher quality usually necessitates at least one thinning (Lamprecht 1989).

Many reforestation projects in South-East Asia had given priority to planting of forests but did not pay much attention to tending the stands after establishment, thereby leaving them unmanaged for long periods. *Acacia mangium*, which is planted widely in South-East Asia, has the potential to produce both pulpwood and lumber (Groome 1991). However, to produce large-volume trees suitable for plywood (Kato 1999), thinning is required.

In tropical tree plantations, thinning is usually conducted from a relatively early stage of stand development (Lamprecht 1989, Evans & Turnbull 2004). For example, Paudyal *et al.* (1991) recommend thinning to be carried out on four- to five-year-old *A. mangium* plantations in Peninsular Malaysia. However, many *A. mangium* stands in Sakaerat, which are 14 years old or more have already passed the age suitable for first thinning. Due to a lack of information, research was necessary to determine the effectiveness of late-rotation thinning in unmanaged *A. mangium* stands for optimizing timber production.

The objective of this experiment was to quantify the volume growth response to previously unmanaged stands of 14-year-old *A. mangium* to two different methods of thinning. One of the methods involved systematic removal of alternate rows of trees. Although it is easier to apply compared with selective thinning, it does not take into account individual tree quality (Evans & Turnbull 2004). The second method was a combination of systematic and selective thinning. Since many of the removed trees were large enough to be merchantable, the treatments were commercial thinnings and yielded financial return.

MATERIALS AND METHODS

Study site

The stand in which the experiment was conducted was located at the Royal Forest Department's Sakaerat Field Station (14°12' N, 101°50' E), in Nakhon Ratchasima province, northeastern Thailand. The mean annual temperature and mean annual rainfall are 26.3 °C and 1101 mm year^{-1} respectively. The area is characterized by a tropical monsoon climate with a rainy season from May till October and a dry season from November till April. The soils in Sakaerat are classified as ferric acrisols or red and yellow podzols (Yoshioka 1986).

Field methods

For comparison, an experimental site was selected in which each plot was as uniform as possible with regard to stand density and size of trees. Consequently, we identified three plots in which we randomly assigned one of the three treatments: (1) no trees removed, (2) alternate rows of trees removed and (3) every third row of trees removed and the remaining rows selectively thinned from below to remove the smallest, lowest quality individuals. We refer to the plots receiving these treatments as unthinned, row-thinned, and row-and-low-thinned plots. The last method was designed to improve on mechanical row-thinning, which generally results in a high proportion of low-quality, small trees in the residual stand. The proportion of basal area removed by thinning was approximately 50% for both treatments (Table 1).

We measured the diameter at breast height (dbh) and total height of residual trees at irregular intervals of 1.2, 2.1, 2.9, 6.8 and 8.3 years after thinning. Mortality was also determined during these intervals. Stem volumes and merchantable-size stem volumes were estimated using Equation 1.

$$V = 0.00017358\ (D^2H)^{0.82739} \qquad (1)$$

where V (m^3) equals the stem volume (including bark), and D^2H equals the square of the dbh (cm) multiplied by tree height (m). Equation 1 was obtained from felled sample trees of *A. mangium* in the Sakaerat plantation. D^2H in Equation 1 was the parameter that was found

Table 1 Stand characteristics of *Acacia mangium* stands before and after thinning

Parameter	Row-thinned[a]	Row-and-low-thinned[b]	Unthinned
Plot size (m^2)	2184	3276	2184
Initial spacing (m × m)	2 × 3	2 × 3	2 × 3
Stand age[c]	14	14	14
Before thinning			
No. of trees ha^{-1}	783	784	801
Mean dbh (cm)	19.1	19.3	19.0
Mean height (m)	20.7	19.3	19.9
Basal area (m^2 ha^{-1})	24.2	25.6	24.5
After thinning			
No. of trees ha^{-1}	394	342	801
Mean dbh (cm)	19.1	21.0	19.0
Mean height (m)	21.0	20.7	19.9
Basal area (m^2 ha^{-1})	12.2	12.4	24.5
Proportion removed			
No. of trees (%)	49.7	56.4	0
Basal area (%)	50.0	51.6	0

[a]Removal of every other row of trees, [b]removal of every third row of trees combined with selective low thinning in residual rows, [c]at the time of thinning

to provide the best estimate of stem volume in monospecific stands, irrespective of growing conditions (Oohata 1991).

Data analysis

Mortality

The difference in mortality, at 8.3 years after thinning, between the thinned and unthinned plots were analysed using the Newman-Keuls test ($p < 0.05$).

The mortality at 8.3 years after thinning was examined for the initial size classes in the thinned and unthinned plots. The initial three size classes: small (dbh < 16 cm), medium (16 cm ≤ dbh < 26 cm) and large (26 cm ≥ dbh) were determined by trisecting the overall range of dbh in row-thinned, row-and-low-thinned and unthinned plots. The binary variable (dead/alive) was tested against initial size classes within treatment (row-thinned, row-and-low-thinned, and unthinned) using the Newman-Keuls test.

Stand volume

The Richards function, regarded as being an accurate empirical model for plant growth (Hunt 1982, Osumi & Ishikawa 1983), was applied to the stand volume after treatment. The Richards function was expressed as $V = a(1-be^{-ct})^{1/d}$, where V is stand wood volume (m^3), a, b, c and d are coefficients, t is elapsed time since thinning (years), and e is the natural logarithm.

Volume increment

Cumulative stand volume increment (CI), current periodic stand volume increment (CPSI) mean annual volume increment (MAI) and current periodic volume increment (CPI) were calculated as follows:

$$CI = V_i - V_o$$
$$CPSI = (V_e - V_s) / (t_e - t_s)$$
$$MAI = (v_i - v_0) / (t_i - t_o) \text{ and}$$
$$CPI = (v_e - v_s) / (t_e - t_s)$$

where V is stand volume (m^3 ha^{-1}), v is stem volume (m^3), t is time in year, i is measurement made at some time after treatment, o is the measurement made at time of treatment, e is the end of the measurement period and s is the start of the measurement period.

The difference in stem volume increment for the thinned and unthinned plots in the initial three size classes [small (dbh < 16 cm), medium (16 cm ≤ dbh < 26 cm) and large (26 cm ≥ dbh)] were analysed using the Newman-Keuls test ($p < 0.05$).

Merchantable wood

For producing lumber, trees grown in a plantation need to exceed a certain size. In the *A. mangium* plantations, trees with dbh at least 24 cm are needed to produce three poles with 20 cm in diameter and 2 m length for sawn wood (Kato 1999). Trees with dbh exceeding 24 cm were regarded as being able to produce merchantable wood. For comparing the merchantable wood production between the plots, the merchantable wood volume at each measurement time was normalized at 100 just after thinning.

Applicability of results

This experiment was conducted without replication. The results, therefore, would not make landscape-scale comparison between treatments.

RESULTS

Stand density and mortality

Stand density decreased more in the unthinned plot than in the two thinned plots after thinning (Figure 1). The mortality of trees at 8.3 years after thinning was significantly smaller in the row-and-low-thinned (9%) and row-thinned plots (7%) than in the unthinned plot (34%). There was no significant difference in mortality between the two thinned plots. Thinning markedly reduced the stand density to 50 and 44% of pre-thinning level in the row-thinned and row-and-low-thinned plots respectively. Although stand density trajectories for thinned plots were shallow following treatment, the trajectory for the unthinned plot declined steeply and was converging on those for thinned plots after 8.3 years (Figure 1).

Mortality at 8.3 years after treatment was affected by initial size of residual trees in unthinned plot but not in the thinned plots (Figure 2). Smaller trees showed significantly higher mortality (63%) than medium (24%) and large (0%) trees in the unthinned plot. The mortality of small trees in the unthinned plot was also higher than the thinned plots (13%). In the two thinned plots, mortality was low in each size class. There is no significant difference between these size classes.

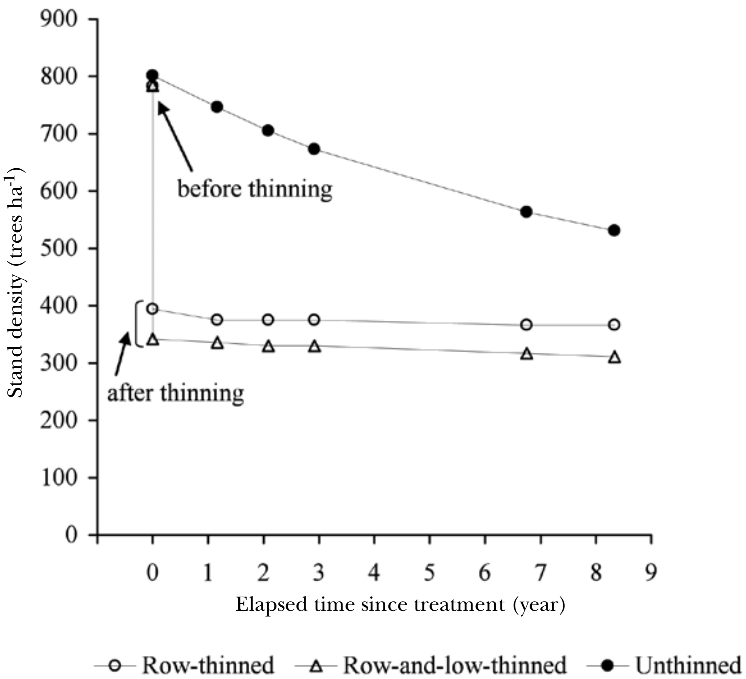

Figure 1 Effects of thinning treatments and elapsed time since treatment on stand density in an *Acacia mangium* plantation

Stem volume

Accumulation of stand volume was accelerated in the thinning plots. Stand volume was similar in the two thinned plots for the first 3 years after thinning but tended to be larger in the row-thinned plot afterwards. On the other hand, stand volume increased slightly in the unthinned plot during the 8.3 years' research period (Figure 3). The growth equations obtained using the Richards function for the thinned and unthinned plots are as follows:

$V = 204(1\text{-}0.8650e^{-0.1657t})^{1/3.8320}$ ($r^2 = 0.9994$) for row-thinned plot (2)

$V = 169(1\text{-}0.0076e^{-0.6317t})^{1/0.0209}$ ($r^2 = 0.9938$) for row-and-low-thinned plot (3)

$V = 252(1+54858802e^{-5.3210t})^{-1/341.4292}$ ($r^2 = 0.9867$) for unthinned plot (4)

The constants 204, 169 and 252 in the equations show the asymptote for maximum stand volume when the row-thinned, row-and-low-thinned and unthinned plots ultimately reached after thinning and in unthinned conditions respectively. Since the asymptote values of stand volume in the thinned plots were smaller than that of the unthinned plot, the stand volume in the thinned plots could not reach the stand volume in the unthinned plot, even when extrapolating the growth curve of stand volume beyond 8.3 years. The stand volume before thinning in both thinned plots is also not likely to be reached after a considerable elapse of time because the asymptote of stand volume was smaller than the stand volume before thinning in the thinned plots (240 m^3 ha^{-1}).

Cumulative stand volume increment

Cumulative stand volume increment increased greater in the thinned plots than in the unthinned plot. In the thinned plots, the increment was conspicuously large for the first 3 years after thinning, and then tended to level off (Figure 4a). The decline in stand volume increment after 3 years was greater in the row-and-low-thinned plot than in the row-thinned plot. The unthinned plot showed a small stand volume increment for the first 3 years and then almost none. A little decline in CI in unthinned plot in the last 8 years was due to the death of some large trees. As a result, total stand volume increment 8.3 years after thinning was 5.8 and 4.2 times greater respectively in the row-thinned and row-and-low-thinned plots than in the unthinned plot.

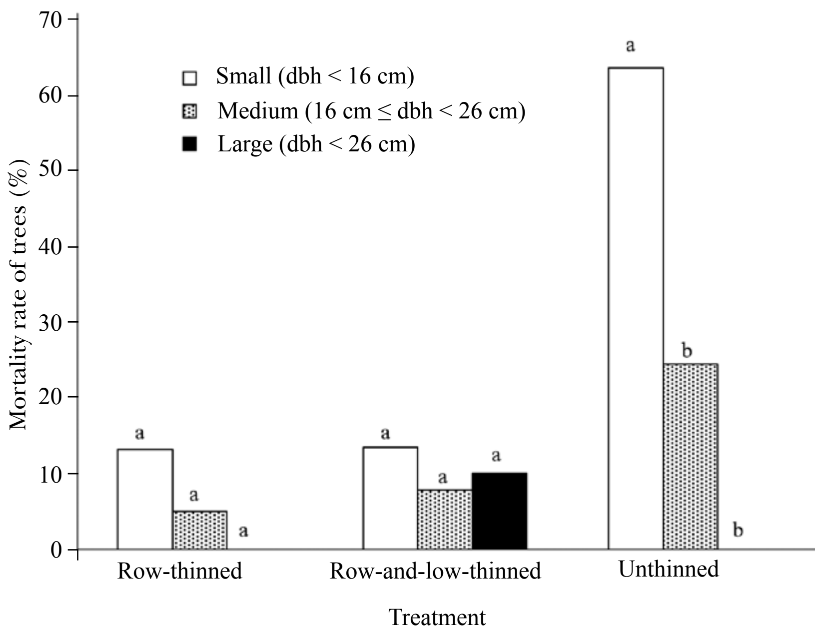

Figure 2 Effects of thinning treatment on mortality of small, medium and large size class *Acacia mangium* trees 8.3 years after thinning. Within a given treatment, bars with a common letter are not significantly different (Newman-Kuels test; $p < 0.05$).

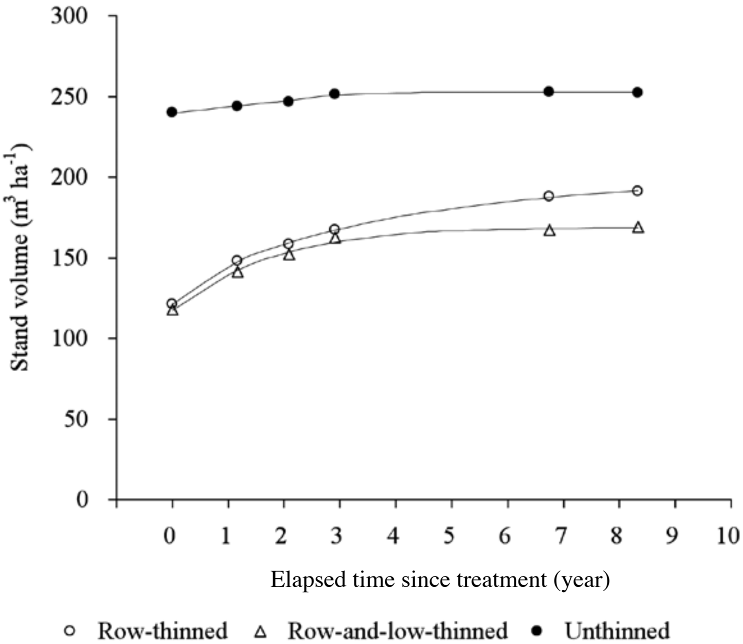

Figure 3 Effects of thinning treatments and elapsed time since treatment on stand volume of *Acacia mangium*

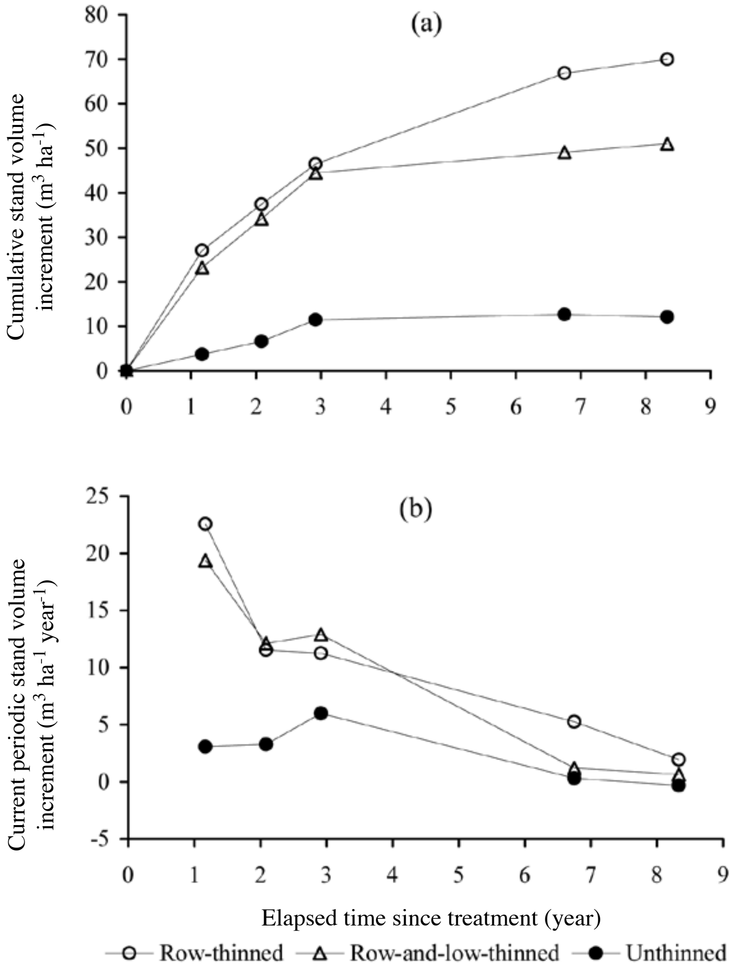

Figure 4 Effects of thinning treatment on (a) cumulative stand volume increment and (b) current periodic stand volume increment during 8.3-year period after thinning *Acacia mangium* stands

Current periodic stand volume increment

Current periodic stand volume increment for both thinned plots was greatest the first year after treatment at approximately 20 m^3 ha^{-1} $year^{-1}$ but declined thereafter (Figure 4b). The corresponding CPSI for the unthinned stand was less than 5 m^3 ha^{-1} $year^{-1}$, and it declined only slightly over the next 7 years. At the end of the study, there was little difference in CPSI betweeen treatments.

Current periodic individual tree volume increment

The mean current periodic volume increment of trees in the thinned plots was greatest in the first year after treatment, and decreased thereafter to lows that were < 0.01 m^3 $tree^{-1}$ $year^{-1}$ during the final measurement. In contrast, mean CPI for individual unthinned trees was consistently low throughout the study, never exceeding 0.02 m^3 $tree^{-1}$ $year^{-1}$.

The mean current periodic volume increment the first year after treatment (Figure 5a) and mean annual volume increment (MAI) 8.3 years after treatment (Figure 5b) were both affected by initial tree size. In general, both measures of growth were least for small trees and greatest for large trees, regardless of treatment. Within each size class, CPI for the first year and MAI for the 8.3-year period tended to be significantly larger for thinned than unthinned trees. In the two thinned plots, the CPI and MAI tended to be

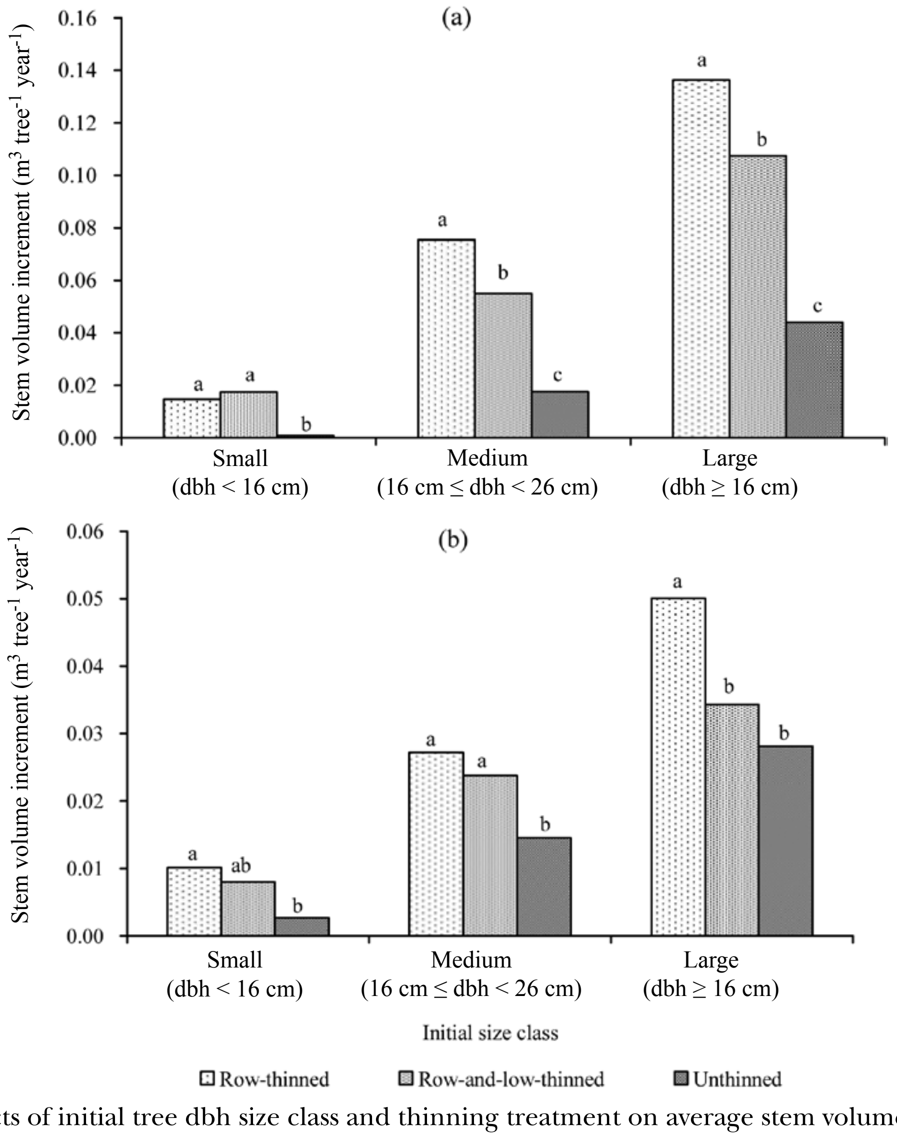

Figure 5 Effects of initial tree dbh size class and thinning treatment on average stem volume increment of individual trees (a) during the first year after thinning and (b) over 8.3 years of the study. Within a given size class, bars capped with a common letter are not significantly different (Newman-Kuels test; $p < 0.05$).

significantly larger for row-thinned plot than for row-and-low-thinned plot within the medium and large size classes.

Merchantable volume production

The merchantable wood production was also affected by thinning. The total volume of trees with dbh exceeding 24 cm increased in both the thinned and unthinned plots after thinning (Figure 6a). The rate of increase of merchantable volume was the largest in the row-thinned plot, followed by the row-and-low-thinned plot and least in the unthinned plot (Figure 6b). Although the rate of increase was higher in the thinned plots than the unthinned plot, the total volume of merchantable wood in the residual stands remained below that in the unthinned stand even after 8.3 years of growth due to there being fewer trees in the thinned plots. However, if we include the volume of merchantable wood removed during thinning, then the total volume of merchantable wood in thinned plots exceeds that in the unthinned plot (Figure 6a).

DISCUSSION

This study showed that a 14-year-old unmanaged *A. mangium* stand which had already passed the ordinary rotation period of 6 or 7 years for pulpwood production (Srivastava 1993) responded well to delayed thinning with respect to mortality and growth of residual trees.

Both the row-thinning and the row-and-low thinning strategies reduced the natural mortality of *A. mangium* stands (Figure 1) by decreasing the mortality rate of small trees (Figure 2). Considerably reduced natural mortality resulting from thinning has also been reported in other forest stands (Mäkinen & Isomäki 2004). In our study stands, intensive thinning (50.0 and 51.6%) appeared to have a beneficial effect on suppressed small trees (Figure 2) which otherwise would have died, resulting in decreased overall mortality in the thinned stands.

Thinning in the 14-year-old *A. mangium* stand also enhanced total stand volume increment for 8.3 years by a factor of 5.8 in the row-thinned plot and 4.2 in the row-and-low-thinned plot (Figure 4a). The unthinned stand showed a small total stand volume increment over the 8.3-year research period (Figure 4a), that is, at the age of 14 to 22 years. This appears to be due to age-related decline of stand growth (Kira & Shidei 1967, Ryan *et al.* 1997), since tropical fast-growing tree species (Kawahara *et al.* 1981, West 2006) including *A. mangium* in South-East Asia (Kamo & Jamalung 2005) show an early growth peak that subsequently declines. It has been reported that intensive selective thinning enhances stem volume increment in a 4-year-old *A. mangium* stand (Ahmad Zuhaidi & Mohd Noor 1997) and diameter growth in a 6-year-old *A. mangium* plantation (Miller & Hepburn 1991) in Malaysia. Our results showed that intensive row-thinning also greatly stimulated the stand and individual volume increments (Figures 4a, b and Figures 5a, b) in an unmanaged aged *A. mangium* stand which had possibly passed a growth peak and showed slow volume increment.

We found that the current stand volume increment in the thinned plots was stimulated immediately after thinning (Figure 4b). In temperate tree plantations, stem growth is reported to be delayed immediately after thinning (Saito *et al.* 1967, West & Osler 1995, Hennessey *et al.* 2004). During the first year after thinning, the biomass of leaves and branches initially increased, but there was no significant increase in bole biomass in Japanese cedar plantations (Saito *et al.* 1967). The rapid response of stand volume increment to thinning in the thinned *A. mangium* stands is likely to be due to the higher turnover rate of *A. mangium* leaves (Kamo *et al.* 2008) than seen in temperate trees (Kikuzawa 2005). This would enable the new leaves to adapt quickly to the better light environment caused by thinning.

Stimulation of volume increment occurred in small trees as well as medium and large trees (Figures 5a, b). After selective thinning, dominant trees responded markedly but suppressed trees did not (Opie *et al.* 1978). However, in our thinned stand, all sizes of trees, including small trees, responded well to thinning (Figures 5a, b), indicating that even small trees were freed from light competition in the row-thinned stands.

However, growth response to thinning did not last long. The influence of thinning on current stand volume increment was strongest in the years following thinning and then lessened with time. Conspicuous stand volume increment was confined to approximately 3 years after thinning: the stand volume increment then declined to a

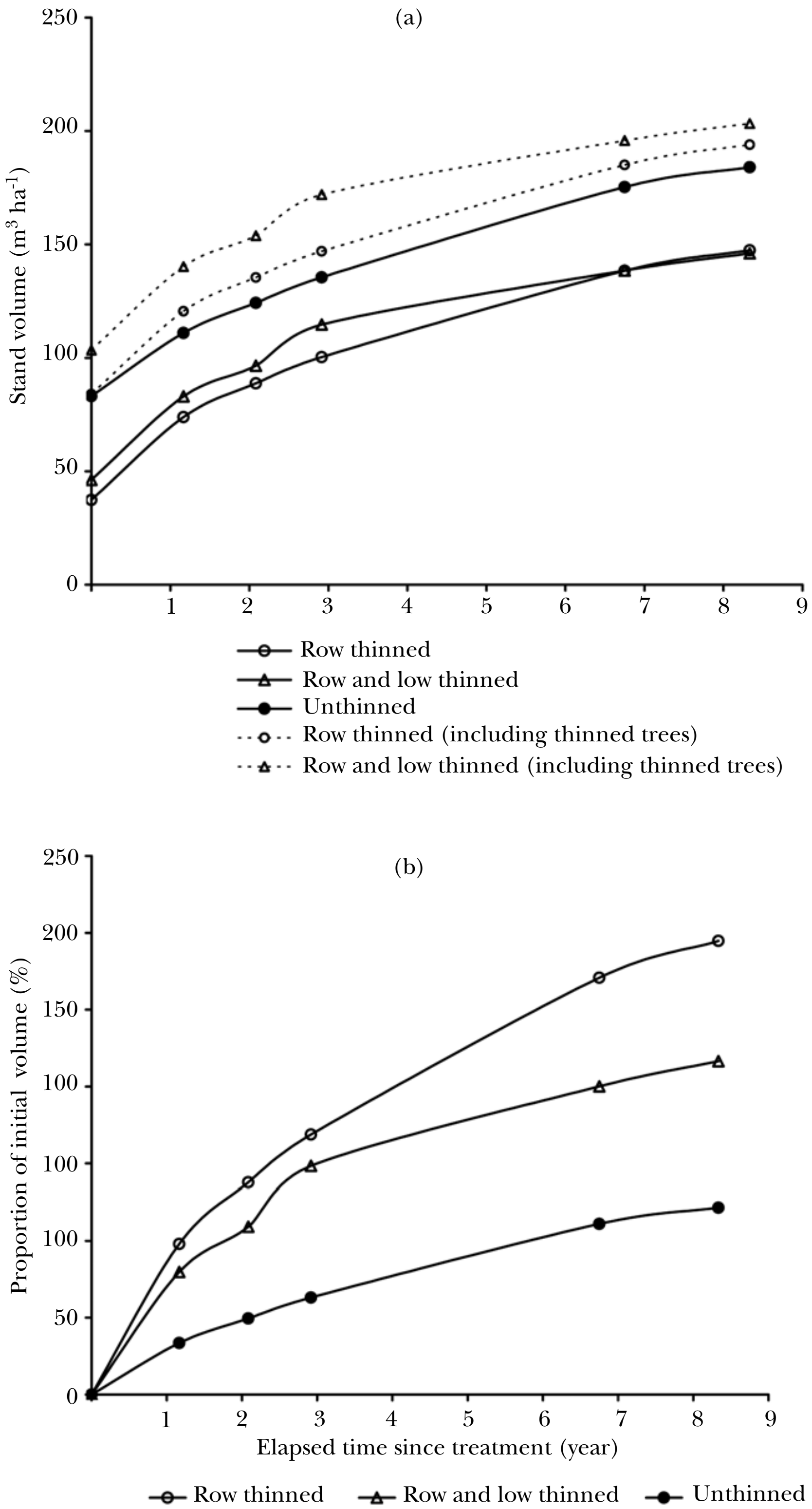

Figure 6 Change in the stand volume of merchantable wood as a function of thinning treatment and elapsed time since treatment: (a) volume in trees with a dbh ≥ 24cm and (b) normalized volume using the volume just after thinning as the starting point

similar level of the unthinned plot at 8.3 years after thinning (Figure 4b). This may have been due to not only increased canopy competition but also root competition after thinning. It has been reported that in pine plantations, trees in heavily thinned plots (86 and 56% of basal area removed) were free to grow unhindered for the first few years after thinning, but their roots quickly penetrated the available soil area and they were no longer competition-free at the end of 5 years (Zahner & Whitmore 1960). Measurement of soil moisture indicated that loss of soil moisture was greater in *A. mangium* stands than in open sites in Sakaerat (Sakai & Thaingam 1998). This fact suggests that root competition for water due to growth of roots can be one factor in reducing stand volume increment with time after thinning.

The stand volume in the thinned plots did not reach that in the unthinned plot and did not regain their previous volume in the 8.3 years following thinning (Figure 3). The growth curve for the thinned plots predicted that thinned stands would not regain the volume lost during thinning, even for a considerable time after 8.3 years. In pine plantations, even a lower thinning rate (29 and 42% removal of basal area) did not result in regaining of the volume lost during thinning for at least 12 years following thinning (Amateis *et al.* 1996). The limited period of accelerated growth of residual stands after thinning probably hinders the thinned stands from compensating for the loss of stand volume caused by thinning for a considerable time after thinning.

It was found that thinning has the benefit of producing merchantable large stems to be used for sawn wood. The thinned stands produced more merchantable stem volume than unthinned stands (Figures 6a, b), and the total volume of merchantable wood would be greater in the thinned plots than in the unthinned plot assuming that the merchantable stem volume of thinned trees was included (Figure 6a). This assumption appears to be justified, because thinning a large 14-year-old plantation is not precommercial: it constitutes commercial thinning for providing an intermediate income. Thus, even delayed thinning of unmanaged *A. mangium* stands can enhance the production of merchantable wood. This fulfils one of the purposes of thinning: to stimulate the production of larger, more valuable logs to be used for sawn wood production (West 2006).

Of the two thinning methods, row-thinning and selective thinning, low thinning is often thought to be less advantageous than selective thinning from below for wood production, since row-thinning retains a larger proportion of small slow-growing trees than does selective thinning from below (Cremer & Meredith 1976). However, our study in row-thinned stand, which has more small trees than row-and-low-thinned showed that row-thinning promoted greater production of stand volume and merchantable volume than did row-and-low thinning (Figures 4a and 6b), which is a combination of row-thinning and selective thinning from below. This may be due to the removal of every second row in the row-thinned plots. The zone of influence of row-thinning is largely confined to the rows immediately adjacent to those removed (Hamilton 1976). If the number of residual rows were to be increased, this would have a negative effect on stand growth, since trees inside the row could not be released. However, residual trees in alternate-row thinning were free from competition on two sides, while in row-and-low thinning, residual trees on one side were completely free from competition, but the trees on other side would experience competition from adjacent trees, since medium and large trees remained on other side. The advantage of removing every second row to promote stem volume increment was also reported in a trial of row-thinning and selective thinning of pine plantations (Baldwin *et al.* 1989). Further increasing the thinning ratio by removing more rows would promote the mean diameter growth of the residual rows, since mean dbh after thinning tended to be enhanced after increasing the thinning ratio (50, 75, 90%) in *A. mangium* stands (Miller & Hepburn 1991). However, the stand volume increment would fall with a further increased thinning ratio, since the number of residual trees would be greatly decreased. Also, overthinning may result in wind damage (Cremer *et al.* 1982). The Sakaerat area is subject to strong winds from December till January. Therefore, alternate-row thinning rather than row-and-low thinning, which needs intensive thinning work may be a better option for stimulating stand growth in aged unmanaged *A. mangium* stands. Although row-thinning is not as common in the tropics as in temperate plantations (Evans &

Turnbull 2004), it has the advantages of being easier, cheaper and less labour-intensive than selective thinning (Lemmien & Rudolph 1964, Evans & Turnbull 2004).

Normally, thinning should start early and be carried out at frequent intervals (Schönau & Coetzee 1989), and early thinning is recommended in tropical plantations (Craib 1934, Schönau & Coetzee 1989). This study suggests that single intensive row-thinning of late-stage unmanaged *A. mangium* can effectively enhance volume production.

ACKNOWLEDGEMENTS

We express our sincere gratitude to the late J Kongsangchai, of the Royal Forest Department, for his support in this study. We also thank P Sahunalu of Kasetsart University for giving us invaluable comments on the manuscript; P Vasuwanich, P Petmak, S Nimpila and B Duangsrisen of the Royal Forest Department for their kind assistance and to the personnel of the Sakaerat Field Station for helping us with our field work. This study was funded by the Japan International Co-operation Agency and the Royal Forest Department.

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