EFFECT OF THINNING ON GROWTH AND WOOD PRODUCTION OF NATURALLY REGENERATED 8-YEAR-OLD *ACACIA MANGIUM* WILLD. PLANTATION ON ABANDONED MINING AREA, SOUTHERN THAILAND

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ABSTRACT

Thinning is an important practice for promoting growth and maintaining forest plantation for wood production from the remaining trees. In this study, thinning was carried out in a naturally regenerated 8-year-old *Acacia mangium* plot in the Phangnga Forestry Research Station. Three thinning schemes, with 175 (T_1), 300 (T_2) and 600 (T_3) remaining trees/ha, were compared with the control (no thinning) of 831 trees/ha. The diameter at breast height (DBH) and height (H) of the trees were measured. The differences in growth, current annual increment (CAI), aboveground biomass, and stem volume (V) were analyzed. We observed that the thinning of *A. mangium* increased the growth rate, with the DBH being clearly affected by thinning. CAI_{DBH} increased significantly, with the DBH class of thinned *A. mangium* plots also improving after thinning. The stem volume and aboveground biomass of T_3 plot was similar to the control plot after thinning. In addition, the number of large saw logs was the highest in T3 plot. The large saw logs can be used for multi-utilization and have a high value. These results suggest that thinning can promote stem growth, and increase the proportion of large saw logs in naturally regenerated *A. mangium* stands.

Keywords: abandoned mining area, aboveground biomass, *Acacia mangium*, growth, merchantable volume, thinning

INTRODUCTION

Acacia mangium Willd. is a fast-growing multipurpose tree species and is usually found in tropical plantations (Hegde *et al.* 2013). It has been widely planted for soil improvement of degraded lands (Martpalakorn 1990, Majid *et al.* 1998), as it is a nitrogen fixing tree and can supply nutrients back into the forest floor via litter decomposition processes (Fisher & Binkley 2000). *A. mangium* has thus been widely planted in Southeast Asia in commercial plantations (Nambiar & Harwood 2014). A density of approximately 1,100 stem/ha or a spacing of 3 m x 3 m is commonly used while planting *A. mangium*. A high density is usually recommended for trees grown in short-rotation periods (Saharjo 2006), with the rotation for *A. mangium* being between 5-8 years to be used in wood chip and pulp production (Huong *et al.* 2020b). On the other hand, older large trees, usually around 15-year-old, are used in furniture making and to obtain sawn wood (Yahya 1993).

Thinning is a silviculture practice to increase tree growth and stem volume of the remaining trees (Yahya *et al.* 2011; Beadle *et al.* 2013), as well as to improve the stem form and wood quality (Pérez & Kanninen 2005). It is commonly practiced in fast-growing trees species such as *Eucalyptus*, *A. auriculiformis*, and *Acacia* hybrid (Hung *et al.* 2019; Huong *et al.* 2020a). As a management practice in a plantation, thinning is used to reduce the number of trees in a stand, so as to increase the crown space between the remaining trees, to reduce the crown and root competition, and to increase growth. In addition,

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thinning can help to control pests and diseases, which in turn can increase the earned incomes before the final harvest (Onyekwelu *et al.* 2011). However, as a downside, the stem volume and aboveground biomass of thinned plantation can decrease.

Past mining activity has had an extreme impact on the soil quality and has severely affected the adjoining ecosystems through the loss of soil structure and nutrient depletion (Thaiutsa & Rungruangsilp 1990; Maiti 2013). The Phangnga Forestry Research Station is located on one such abandoned mining area. The reclamation of mining area was undertaken by planting *A. mangium*, given its growth and high aboveground biomass compared to other fast-growing or native tree species (Martpalakorn 1990). Additionally, *A. mangium* has reportedly been recommended to rehabilitate degraded lands with a high survival rate (Majid *et al.* 1998) to restore the soil properties, forest structure, and nutrient cycling (Wongprom *et al.* 2020; Wongprom *et al.* 2022; Staporn *et al.* 2022).

Seeds of *A. mangium* can accumulate in the soil and forest floor (Saharjo 2006), with the seedlings being highly dense after clear-cutting. A high tree density can result in the reduction of growth rate and yield, accompanied by high mortality due to competition. *A. mangium* plantations mainly focus on producing wood with a short-rotation period but the management of *A. mangium* for the production of large saw logs has been rarely studied. Timber production from natural forests is expected to decline, and as such, *A. mangium* plantations can play an important role in maintaining the commercial supply of wood. Thinning is recommended for trees used in timber and sawn wood production, with larger trees having the potential to increase the income earned (Onyekwelu *et al.* 2011).

The objectives of this study were to identify the effects of thinning on the growth and wood production of a naturally regenerated *A. mangium* plantation on an abandoned mining area. Thinning was applied to stands which were established through natural regeneration after clear-cutting of the *A. mangium* plantation. These results can be used to manage *A. mangium* stand in the Phangnga Forestry Research Station and other such degraded sites located in southern Thailand.

MATERIALS AND METHODS

Study site

The plantation is located on an abandoned area, previously under tin mining, at the Phangnga Forestry Research Station (8° 46' 5" N, 98° 16' 7" E), Takuapa district, Phangnga province, in southern Thailand (Fig. 1). Tin mining was done through the gravel pumping method. The post tin mining land forms could be mainly divided into sand, clay, and gravel areas. The soil nutrients and organic matter levels after tin mining were very low and the soil pH was strongly acidic (Anunsiriwat 1986). However, soil nutrients and organic matter content of this area were improved after the establishment of *A. mangium*, especially the topsoil level. The soil properties of this area are shown in Table 1 (Wachrinrat *et al.* 2002). The area receives an annual rainfall of 3,566 mm, with the rainy season spanning from April to October and dry season occurring during the months from November to March. The mean temperature was around 27.1°C and relative humidity around 83% (Wachrinrat *et al.* 2002).

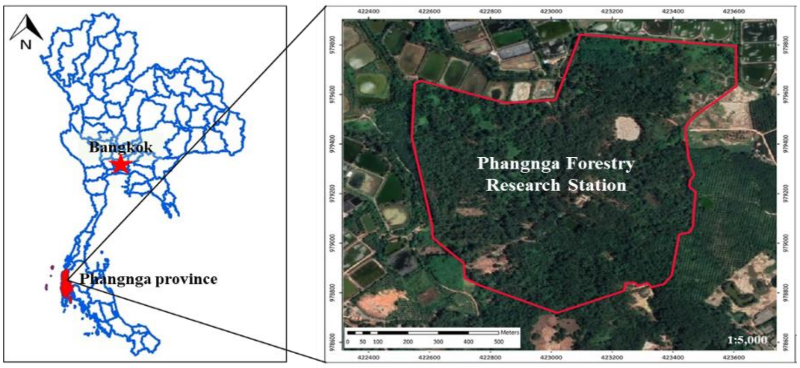

Figure 1 Location of the study sites in Phangnga province, southern Thailand

Table 1 Soil properties of *A. mangium* plantation in clay area at Phangnga Forestry Research Station

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Soil texture	pH	OM (%)	Avai. P (ppm)	Exchangeable bases (ppm)		
								K	Ca	Mg
0-7	10.40	30.72	58.88	clay	5.0	3.84	1.01	62.2	153.44	54.44
7-32	0.40	24.72	74.88	clay	4.9	0.91	0.03	38.4	11.68	67.34

Note: OM = organic matter, Avai. P = available phosphorus, K = potassium, Ca = calcium, Mg = magnesium.

In 1987, *A. mangium* was planted at a spacing of 4 m x 4 m, to reclaim the clayey soil (Wachrinrat *et al.* 2002). However, a clear cutting of *A. mangium* plantation was done for wood utilization when the trees were 14-year-old. After the area was cleared by cutting, the site was prepared by burning the branches and other parts of the trees. *A. mangium* seedlings were then allowed to naturally regenerate in the area and this resulted in a high density stand.

Methods

The experiment plots were located in an 8-year-old naturally regenerated *A. mangium* plantation. We observed that the crown cover of *A. mangium* stand was closed leading to a strong crown competition, which meant that thinning was needed for plantation management. A randomized completely block design (RCBD) with three replications was used in a plot of size 20 m x 20 m. Three different thinning schemes were used and included 175 (T_1), 300 (T_2), and 600 (T_3) remaining trees per ha which were compared with a control of 831 trees/ha. A low thinning method was used in T_1, T_2, and T_3 plots. The low thinning scheme was used to remove the suppressed and poor crown trees (Hawley 1947). In this study, any small and irregular trees were removed in the thinned plots. In addition, a good stem form of the co-dominant and intermediate trees in the T_1, T_2, and T_3 plots were also removed to determine the spacing and tree density.

The diameter at breast height (DBH) and height (H) of remaining trees were measured for a period of three years. The DBH and H of each treatment was calculated as a mean among replications (n = 3). The current annual increment (CAI) of H and DBH were calculated using the equations:

$$CAI_{DBH} = (DBH_2 - DBH_1)/\ t_2 - t_1$$
$$CAI_H = (H_2 - H_1)/\ t_2 - t_1$$

Where:

H_1 = tree heights (m) at times t_1
H_2 = tree heights (m) at times t_2t
DBH_1 = diameters (cm) at times t_1
DBH_2 = diameters (cm) at times t_2
t_1 = beginning times of each period
t_2 = ending times of each period.

Allometric equations of the 11-year-old *A. mangium* trees were developed to estimate the aboveground biomass and stem volume, as the estimation equation previously reported for woodchip was for trees within an age bracket of 4-5 years in Thailand (Peawsa-ad & Viriyabuncha 2002). In this study, trees sampled from seven different DBH classes (8.4 to 34.9 cm DBH) were cut and separated as logs according to their respective heights binned under 0-0.3 m, 0.3-1.3 m, 1.3-2.3 m, etc., i.e., at every 1.0 m increment from the bottom to top. The tree height and diameter of the logs were measured. The fresh weights of stem, branch, and leaf components were determined in the field and representative samples were taken from each tree to determine the dry weight. The stem, branch and leaf samples were oven-dried at 80°C for 48 h to obtain a constant weight.

The aboveground biomass, i.e., stem (W_S in kg), branches (W_B in kg), and leaf (W_L in kg), of *A. mangium* was estimated using the allometric equations derived using destructive sampling as follows:

$$W_S = 0.0199*(DBH^2*H)^{0.9828}, \quad (R^2 = 0.98)$$
$$W_B = 0.0001*(DBH^2*H)^{1.3345}, \quad (R^2 = 0.99)$$
$$W_L = 0.0009*(DBH^2*H)^{0.9773}, \quad (R^2 = 0.94)$$
$$W_T = W_S + W_B + W_L,$$

Where:

W_T = total aboveground biomass
DBH = diameter at breast height (cm)
H = total height (m)

The volume of each log was calculated using the Smalian's formula:

$$V = (BA_1+BA_2)/2 \times L$$

Where:

V = log volume (m^3)
BA_1 = upper cross section area of the log
BA_2 = lower cross section area of the log
L = length of the log

The total stem volume (V_T) and merchantable volume (V_M) was estimated using the equation derived from destructive sampling. The merchantable volume was set at a top end diameter > 10.0 cm, as determined by the local wood sawmill;

$$V_T = 0.0395*(DBH) - 0.3369,\ (R^2= 0.98)$$
$$V_M = 0.0403*(DBH) - 0.4030.\ (R^2= 0.98)$$

Allometric equations for DBH and stem-log types were developed from seven representative trees (with DBH between 8.4 to 34.9 cm). Sawlog types were categorized as either small (V_{SSL}; diameter of log (D) $10.0 < D \leq 15.0$ cm and as a percentage of merchantable volume), medium (V_{MSL}; $15.0 < D \leq 20.0$ cm), or large (V_{LSL}; $D > 20.0$ cm). V_{SSL} and V_{LSL} were determined by establishing the respective allometric equations. V_{MSL} was determined as the difference between the merchantable volume (100%) and the sum of V_{SSL} and V_{LSL}. The sum of V_{SSL}, V_{MSL}, and V_{LSL} was equal to V_M.

The log components of each tree were estimated as a percentage of the merchantable volume ($V_M = 100\%$) according to the following equations:

$$V_{SSL} = 418.76e^{-0.137*(DBH)},\quad (R^2= 0.97)$$
$$V_{LSL} = 8.9603e^{0.0677*(DBH)},\quad (R^2= 0.77)$$
$$V_{MSL} = 100 - (V_{SSL} + V_{LSL})$$
$$V_M = V_{SSL} + V_{MSL} + V_{LSL},$$

where V_M is the merchantable volume (m^3).

Data Analysis

Growth performance, as indicated by DBH, H, CAI_{DBH} and CAI_H, the aboveground biomass of trees, stem volume, merchantable volume, and saw logs among the various treatments was compared using SPSS 16.0. A one-way analysis of variance (ANOVA) followed by Tukey HSD was used to determine the differences between means at a 5% probability level.

RESULTS AND DISCUSSION

Tree growth

Thinning had a positive influence on the growth of *A. mangium*, although the DBH and H were not found to be significantly different ($p > 0.05$) during the initial stages of development. The parameters measured during the initial stages of growth and development after thinning are listed in Table 2. After thinning for one year, the DBH and H of trees in the T_1 treatment increased rapidly compared with the control plot and were significantly different ($p < 0.05$). It has been previously reported that *A. mangium* grows well after an early thinning (Yahya 1993). Heavy thinning is an important factor influencing the DBH with its incremental change significantly and positively correlated with the thinning intensity (Mäkinen & Isomäki 2004; Juodvalkis *et al.* 2005). In this study, the small and suppressed trees were removed by thinning. This resulted in a structured stand, with a marked increase in measured DBH. The size distribution moved towards normality and then became positively skewed, and was affected by low intensity thinning. Larger DBH values were found in thinned plots, while trees with smaller DBH were frequently found in the unthinned plot (Fig. 2).

CAI_{DBH} was the highest in the T_1 plot, followed by T_2, T_3, and control, respectively. The density of *A. mangium* significantly influenced the CAI_{DBH} after thinning during the first and second years, but no significant difference was observed in the third year. CAI_{DBH} of trees in the thinned plots peaked during the second year. However, CAI_{DBH} tended to decrease and was not significantly different among treatments after thinning for three years. A rapid reduction in CAI_{DBH} from 2.47 cm/cm/yr to 1.03 cm/cm/yr under thinning for 1-3 years in the T_1 plot indicates a strong competition between the remaining trees. A dense *A. mangium* canopy was observed after thinning for three years. A crown competition within the stand led to the death of small and suppressed trees. A high relative mortality rate of 21.98% was observed in the unthinned plot.

CAI_H was significantly different after the thinning for one year, but was not significantly different after thinning for 2-3 years. This indicates that the increase in height was affected by thinning only during the early period. We observed that the thinning intensity only slightly affected the increase in height and is similar to results reported previously for many plantations (Wanthongchai & Sahunalu 2002; Mäkinen & Isomäki 2004; Cicek *et al.* 2013; Rytter 2013).

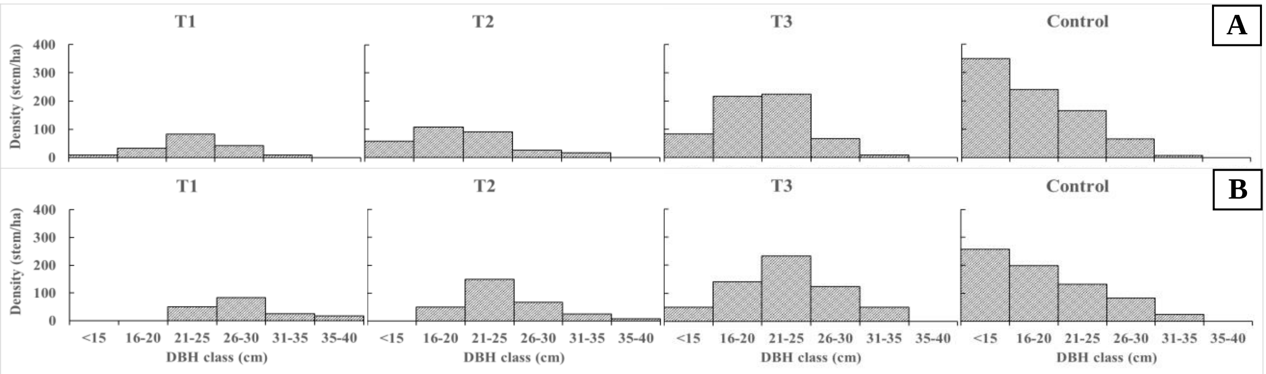

Figure 2 Distribution of DBH classes of the thinned *A. mangium* during the initial stages of development (A) and after three years of thinning (B) at the Phangnga Forestry Research Station

Table 2 Diameter at breast height (DBH), height (H), and current annual increment (CAI) of the thinned *A. mangium* plots after thinning for one, two, and three years at the Phangnga Forestry Research Station

Treatment	DBH (cm)	H (m)	CAI	
			DBH (cm)	H (m)
Before thinning				
T_1	21.94 ± 1.95	24.18 ± 0.53	-	-
T_2	19.91 ± 1.20	23.56 ± 0.76	-	-
T_3	19.47 ± 1.57	23.17 ± 0.71	-	-
control	17.24 ± 2.23	21.79 ± 2.59	-	-
F- value	2.58^{ns}	3.40^{ns}	-	-
After thinning for one year				
T_1	25.14 ± 1.96^{b}	26.22 ± 0.72^{b}	2.47 ± 0.26^{c}	1.20 ± 0.04^{c}
T_2	22.34 ± 1.16^{ab}	24.84 ± 0.47^{b}	1.80 ± 0.24^{b}	0.87 ± 0.13^{b}
T_3	21.22 ± 1.49^{ab}	24.38 ± 0.64^{b}	1.40 ± 0.27^{b}	0.67 ± 0.14^{b}
control	17.56 ± 3.03^{a}	22.29 ± 1.18^{a}	0.64 ± 0.25^{a}	0.54 ± 0.12^{a}
F- value	7.13^{*}	12.57^{**}	26.74^{**}	19.14^{**}
After thinning for two years				
T_1	27.65 ± 2.52^{c}	27.19 ± 1.00^{b}	2.51 ± 0.74^{c}	0.96 ± 0.33
T_2	24.30 ± 1.25^{bc}	25.69 ± 0.50^{b}	1.96 ± 0.13^{bc}	0.85 ± 0.10
T_3	22.85 ± 1.39^{b}	25.10 ± 0.56^{b}	1.63 ± 0.11^{b}	0.72 ± 0.10
control	18.33 ± 3.19^{a}	22.94 ± 1.74^{a}	0.77 ± 0.27^{a}	0.65 ± 0.62
F- value	8.98^{**}	8.15^{**}	9.90^{**}	0.47^{ns}
After thinning for three years				
T_1	28.65 ± 2.55^{b}	27.58 ± 0.99^{b}	1.03 ± 0.13	0.39 ± 0.10
T_2	25.28 ± 1.15^{b}	25.99 ± 0.40^{b}	0.98 ± 0.14	0.38 ± 0.15
T_3	23.71 ± 1.12^{ab}	25.48 ± 0.44^{ab}	0.86 ± 0.30	0.29 ± 0.14
control	18.93 ± 3.36^{a}	23.08 ± 1.70^{a}	0.60 ± 0.22	0.14 ± 0.10
F- value	9.62^{**}	9.82^{**}	2.36^{ns}	3.64^{ns}

Notes: * = significantly different at $p < 0.05$; ** = significantly different at $p < 0.01$; ns = not significant at $p > 0.05$ and letters a, b and c in the same column indicate significant differences at $p < 0.05$ and $p < 0.01$, as determined by Tukey HSD.

Aboveground biomass

The aboveground biomass among treatments was significantly different after thinning for years 1-3 (Table 3). In the thinned plots, the aboveground biomass from all parts of a tree was the highest for T_3 plot, while that for T_1 plot was the lowest. However, the aboveground biomass of the T_3 and control plots was similar. Differences in density can significantly affect the production of plantation. This is evident from our observation that the aboveground biomass estimated for the T_3 (169.89 t/ha) and control (185.74 t/ha) plots was relatively high, but was lower than that of a 10-year-old *A. mangium* plantation (1,050 stem/ha) planted on degraded lands in Indonesia, with value of 241.10 t/ha (Hardiyanto *et al.* 2004).

Stem biomass contributed the most to the main productivity, accounting for approximately 81-84% of the total aboveground biomass. On the other hand, the contribution of leaf component to the biomass pool was the lowest (4%). Leaf production of *A. mangium* is not the main objective of a commercial plantation. However, the contributions of leaf biomass and leaf litter were reported to be the most significant in terms of nutrient return to the forest floor (Nambiar & Hardwood 2014; Wongprom *et al.* 2022), as *A. mangium* leaf is rich in nutrient concentration, especially nitrogen. It therefore plays an important role in increasing the soil nutrients, improving the soil properties (Wongprom *et al.* 2020), and promoting nutrient supply for stand growth (Hardiyanto & Nambiar 2014). Previously, it has been reported that the wood production in an *Acacia* plantation is strongly correlated with the soil nutrients (Harwood *et al.* 2017). This observation was similar to Huong *et al.* (2020b), who found that four rotations in *A. auriculiformis* plantation resulted in high growth and production compared to the first rotation.

Table 3 Aboveground biomass of the 8-year-old *A. mangium* under various thinning durations and intensities

Treatment	Aboveground biomass (ton/ha)			
	W_S	W_B	W_L	W_T
After thinning for one year				
T_1	52.02 ± 8.53^{a}	8.16 ± 1.94^{a}	2.65 ± 0.47^{a}	62.83 ± 10.94^{a}
T_2	69.03 ± 6.17^{a}	10.34 ± 1.79^{ab}	3.49 ± 0.35^{a}	82.86 ± 8.33^{a}
T_3	119.95 ± 21.04^{c}	16.34 ± 4.33^{ab}	5.99 ± 1.13^{b}	142.28 ± 24.84^{b}
control	140.77 ± 10.70^{c}	17.22 ± 0.11^{ab}	5.03 ± 0.43^{b}	163.02 ± 11.05^{b}
F- value	33.68**	8.49*	28.03**	30.62**
After thinning for two years				
T_1	61.99 ± 12.05^{a}	10.60 ± 2.99^{a}	3.21 ± 0.67^{a}	75.80 ± 15.71^{a}
T_2	83.16 ± 7.08^{a}	13.67 ± 2.40^{ab}	4.27 ± 0.41^{a}	101.10 ± 9.77^{a}
T_3	141.67 ± 22.63^{b}	21.05 ± 5.16^{b}	7.17 ± 1.24^{b}	169.89 ± 27.01^{b}
control	156.38 ± 7.16^{b}	20.61 ± 0.91^{b}	7.75 ± 0.25^{b}	185.74 ± 6.54^{b}
F- value	33.38**	7.05*	26.51**	30.78**
After thinning for three years				
T_1	66.65 ± 13.09^{a}	11.77 ± 3.41^{a}	3.47 ± 0.73^{a}	81.89 ± 17.24^{a}
T_2	90.42 ± 5.14^{a}	15.05 ± 2.57^{ab}	4.64 ± 0.34^{a}	110.11 ± 7.91^{a}
T_3	152.53 ± 19.82^{b}	23.27 ± 4.66^{b}	7.75 ± 1.09^{b}	183.55 ± 25.54^{b}
control	161.46 ± 6.61^{b}	21.79 ± 1.00^{b}	7.92 ± 0.28^{b}	191.17 ± 6.15^{b}
F- value	42.41**	8.01*	30.89**	37.63**

Notes: * = indicates a significant difference at $p < 0.05$; ** = significantly different at $p < 0.01$; letters a, b, and c in the same column indicate significant difference at $p < 0.05$, as determined by Tukey HSD. W_S, W_B, W_L, and W_T are the stem, branches, leaf biomass, and total aboveground biomass, respectively.

Stem volume, merchantable volume, and sawlogs

After thinning for three years, the stem and merchantable volumes of the thinned and control *A. mangium* plots were significantly different ($p<0.01$) (Table 4). In addition, the production of small, medium, and large saw logs was also significantly different among the treatments. However, stem and merchantable volumes of the T_3 and control plots were similar. Thinning intervention positively affected the diameter of logs. Heavy thinning in the T_1 plot resulted in a high proportion of large saw logs (67% of merchantable volume). The proportion of large saw logs in the thinned plots was higher than both the medium and small sized saw logs. In contrast, the proportion of small saw logs was high in the unthinned plot (25%), while those in the T_1, T_2, and T_3 was 9, 14 and 16%, respectively. This indicates that thinning increased the merchantable volume and the number of large saw logs. For 9-year-old *A. auriculiformis* plantation (1,333 stem/ha), the medium sized saw logs formed the major proportion of saw logs obtained from the unthinned plot (Huong *et al.* 2020a). Thinning is important for improving the DBH class of a stand as well as the merchantable volume and is usually used as a plantation management strategy to increase growth and utilization.

For 9 and 10 year plantations, the current annual increment of volume (CAI_V) was found to be significantly different ($p<0.01$), with the T_3 plot having the highest CAI_V. However, CAI_V of the T_3 and unthinned plots was similar for the 11-year-old plantation. Low thinning resulted in a significant increase of stand stem volume (Fig. 3). After thinning for one and two years, CAI_V of the T_1 and T_2 plots increased, while the values were not different for the unthinned plot. Heavy and moderate thinning intensity had a significant influence on the increment in stem volume of the *A. mangium* plot, given that the trees had a positive response to thinning.

Table 4 Stem volume, merchantable volume, and saw logs of the thinned 11-year-old *Acacia mangium* stand under various thinning intensities

Treatment	Stem volume (m^3/ha)	Merchantable volume (m^3/ha)	Sawlogs (m^3/ha)		
			Small	Medium	Large
T_1	135.83 ± 16.79^a	127.92 ± 17.37^a	11.25 ± 1.75^a (9%)	31.25 ± 6.75^a (24%)	85.42 ± 21.11^a (67%)
T_2	187.92 ± 6.71^b	180.99 ± 13.65^b	25.75 ± 5.88^b (14%)	47.83 ± 10.07^a (27%)	107.41 ± 23.46^a (59%)
T_3	353.83 ± 23.76^c	326.19 ± 23.73^c	51.00 ± 3.54^c (16%)	101.08 ± 7.44^b (31%)	174.16 ± 24.56^b (53%)
control	351.10 ± 22.33^c	298.44 ± 15.27^c	74.60 ± 10.69^d (25%)	95.49 ± 7.07^b (32%)	128.33 ± 12.57^a (43%)
F-value	145.57^{**}	92.44^{**}	165.70^{**}	51.05^{**}	7.54^{*}

Notes: * = indicates a significant difference at $p < 0.05$; ** = significantly different at $p < 0.01$; letters a and b in the same column indicate significant difference at $p < 0.05$, as determined by Tukey HSD. The numbers in brackets are percentage of saw log types estimated for each treatment.

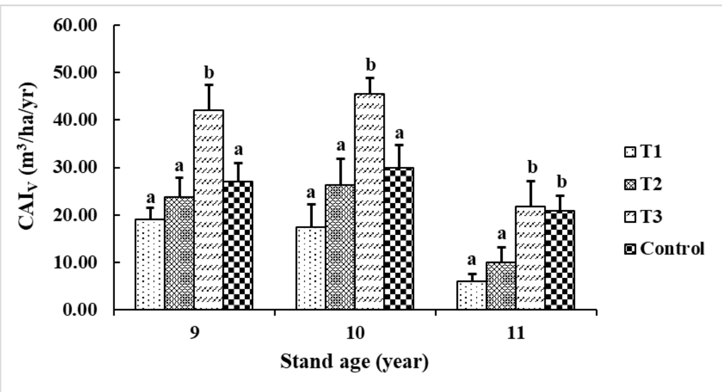

Figure 3 The current annual increment of stem volume (CAI_V) of the thinned 9 to 11-year-old *A. mangium* plots under various thinning durations

In southern Thailand, the local sawmills have a high demand for large saw logs to make wood furniture, as these products fetch a higher value compared to woodchips. In Thailand, during the year 2021, the timber imported was approximately 220,000 m^3 (Royal Forestry Department 2021). As such, fast-growing tree plantations can reduce the import bill related to import of timber wood, while also reducing the illegal cutting of natural forests. Thinning can be a valuable management strategy in plantations to increase the domestic timber production. A short rotation period (4-7 years) is generally used for the production of fuelwood and woodchips from *A. mangium* plantations.

The growth, aboveground biomass, and stem volume estimates reported in this study are based on a plantation established on poor soil conditions in an abandoned mining area where soil nutrients and organic matter were very low (Anunsiriwat 1986; Thaiutsa & Rungruangsilp 1990). However, *A. mangium* was able to grow well in this area as the site receives a high amount of rainfall (more than 3,500 mm/yr), with a rainfall of more than 2,500 mm/yr being suitable for the optimum growth of *A. mangium* (National Research Council 1983). The DBH and H of the T_2 plot (24.30 cm and 25.69 m, respectively) in the 10-year-old *A. mangium* plantation was similar to that of *A. mangium* planted in West Java, Indonesia, with a DBH, H, and density of 27.81 cm, 25.12 m, and 225 stem/ha, respectively (Heriansyah *et al.* 2007). In addition, the estimated total aboveground biomass and stem volume in this study was not different from that of other areas with a similar stand density. For example, the aboveground biomass estimated for the lightly thinned 11-year-old *A. mangium* plantation, with a density of 600 stem/ha was similar to that of an *A. mangium* plantation in southeastern, Vietnam (Cuong *et al.* 2020).

CONCLUSION

In this study, we presented the results of thinning on the growth of *A. mangium* trees in a naturally regenerated 8-year-old plantation in the Phangnga Forestry Research Station, with three different thinning schemes, which were compared with the control (unthinned plot). The growth and production of the remaining trees after thinning were observed to be affected by thinning. After thinning, the DBH and CAI_{DBH} of trees in the thinned plots were found to be significantly higher than those in the control plot. However, tree height was only slightly affected by thinning. A reduction in CAI_{DBH} was observed after thinning for three years, possibly resulting from a stronger competition for resources. The total aboveground biomass and stem volume in the lightly thinned T_3 plot was similar to that of the control plot. The thinning intensity significantly affected the growth and productivity of the *A. mangium* stand. CAI_V of the T_3 plot was relatively higher than that of the T_1 and T_2 plots. However, the large saw logs obtained from the T_3 and unthinned plots was significantly different, suggesting that thinning should be done for promoting stem growth and to obtain large sized timber wood.

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