GROWTH CHARACTERISTICS AND BIOMASS ACCUMULATIONS OF *ACACIA MANGIUM* UNDER DIFFERENT MANAGEMENT PRACTICES IN INDONESIA

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HERIANSYAH, I., MIYAKUNI, K., KATO, T., KIYONO, Y. & KANAZAWA, Y. 2007. Growth characteristics and biomass accumulations of *Acacia mangium* under different management practices in Indonesia. Tree biomass accumulations and age-related changes of *Acacia mangium* plantations were determined using a destructive sampling technique. These data were used to estimate optimum harvesting time. Tree biomass samples were collected in 3-, 5-, 8- and 10-year-old plantations in West Java, and in 2.5-, 5.5-, 8.5- and 10.5-year-old plantations in South Sumatra. About 15 trees were sampled from each stand. Tree growth characteristics were evaluated for both sites. Specific wood density in unthinned plantation was higher than in thinned plantation. Proportion of stem biomass in thinned plantation was constant during thinning period and thereafter slightly increased with age, whereas leaf biomass decreased. In unthinned plantation, proportion of stem biomass increased with age, while leaf biomass drastically decreased when competition occurred in the young stage but became relatively constant thereafter. Allometric equations were developed for each site to estimate root, stem, branch, leaf, aboveground and total biomass and stem volume. Using these equations, the stem volume and biomass of each component for each stand age were estimated. A single allometric relationship for all sites was found just for estimation of root biomass and stem volume. Therefore, the use of site-specific equation is recommended. According to the optimum productivity values, longer rotation is available to enhance wood quality and wood utilization for thinned plantation in West Java. A rotation of six and eight years is recommended to maximize biomass accumulation and benefits respectively for unthinned plantation in South Sumatra.

Keywords: Management practice, allometric equation, rotation length

HERIANSYAH, I.,MIYAKUNI, K., KATO, T., KIYONO, Y. & KANAZAWA, Y. 2007. Ciri-ciri pertumbuhan *Acacia mangium* dan pengumpulan biojisimnya di bawah amalan pengurusan berlainan di Indonesia. Pengumpulan biojisim pokok di ladang *Acacia mangium* dan perubahan yang berkait rapat dengan umurnya ditentukan menggunakan teknik penyampelan memusnah. Data ini digunakan untuk menganggar masa penebangan yang optimum. Sampel biojisim pokok diambil daripada ladang berumur 3 tahun, 5 tahun, 8 tahun dan 10 tahun di Jawa Barat dan daripada ladang berumur 2.5 tahun, 5.5 tahun, 8.5 tahun dan 10.5 tahun di Sumatra Selatan. Kira-kira 15 pokok disampel daripada setiap dirian. Ciri-ciri pertumbuhan pokok dinilai di kedua-dua tapak. Ketumpatan kayu tentu bagi ladang yang tidak mengamalkan penjarangan lebih tinggi daripada ladang yang mengamalkannya. Peratusan biojisim batang bagi ladang yang mengamalkan penjarangan adalah tetap semasa tempoh penjarangan tetapi bertambah sedikit dengan masa selepas tempoh ini manakala biojisim daunnya menurun. Di ladang yang tidak mengamalkan penjarangan, peratusan biojisim batang bertambah dengan masa manakala biojisim daun menurun dengan mendadak apabila persaingan berlaku pada peringkat muda. Namun biojisim daun menjadi agak tetap selepas peringkat ini. Persamaan alometri dibangunkan untuk setiap tapak bagi menganggar biojisim akar, biojisim batang, biojisim dahan, biojisim daun, biojisim atas tanah, jumlah biojisim dan isi padu batang. Isi padu batang dan biojisim setiap komponen bagi setiap umur dirian dianggar menggunakan persamaan-persamaan ini. Hubungan alometri tunggal untuk semua tapak didapati hanya untuk anggaran biojisim akar dan isi padu batang. Justeru, penggunaan persamaan spesifik tapak disyorkan. Berdasarkan nilai pengeluaran optimum, ladang yang mengamalkan penjarangan di Jawa Barat mempunyai giliran yang lebih panjang. Ini dapat meningkatkan kualiti kayu dan penggunaan kayu. Giliran sebanyak enam tahun dan lapan tahun disyorkan masing-masing untuk memaksimumkan pengumpulan biojisim dan manfaat bagi ladang yang tidak mengamalkan penjarangan di Sumatra Selatan.

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INTRODUCTION

The Kyoto Protocol recognized that afforestation and reforestation could be counted as potential carbon sinks and are therefore useful practices for achieving pledged greenhouse gas emission reductions. The Marrakesh Accords ratified these forestry activities within the Clean Development Mechanism project (AR-CDM). Therefore, AR-CDM could act as a stimulus to enhance sustainable forestry development and contribute to the recovery of forests that have been disturbed and destroyed.

Measurement of planted forests is necessary to understand growth characteristics and to estimate the quantity of carbon sequestered by a forest. Allometry is an effective method for accurately estimating the biomass of trees, tree components and stands (MacDicken 1997).

Several studies have been conducted to evaluate the accuracy of allometric equations. A study by Komiyama *et al.* (2002) in Gifu Prefecture, Japan, suggested that equations using not only tree diameter at breast height but also tree height could reduce relative error from 12.0 to 3.8%. These studies also succeeded in overlapping allometric equations derived from different sites. The data collected to date, however, are limited and more information must be collected to evaluate the validity of the equations. In addition, root biomass data are also very scarce and necessary for a complete estimation of the total carbon sequestered by forests.

The objectives of this study were to compare growth characteristics and biomass accumulations of *Acacia mangium* obtained from two different treatments and to evaluate the possibility of formulating a single allometric equation, and to estimate optimum rotation of *A. mangium* plantations in West Java and South Sumatra, Indonesia.

Acacia mangium is a tropical species that is capable of colonizing infertile sites. It grows well not only in cleared forest sites but also in degraded sites, such as weedy *Imperata* grasslands and mining sites (Awang & Taylor 1993). Important attributes of *A. mangium* include rapid early growth, good wood quality (for pulp, timber and fuel), and tolerance of a range of soil types and pH (National Research Council 1983). Since its introduction to Sabah, Malaysia, as an exotic in 1966, *A. mangium* has become one of the three or four most common plantation tree species in Asia. Its coverage area is rapidly expanding, with the largest plantations in Indonesia and Malaysia (Raymond Tan 1992, Setyarso 1992).

MATERIALS AND METHODS

Study sites

The study was conducted in *A. mangium* plantations in (1) a state-owned enterprise of Java (Perum Perhutani) Unit III, West Java and (2) PT Musi Hutan Persada, South Sumatra, Indonesia (Figure 1). In West Java, plantation thinning is performed at 2, 4 and 6 years of age, and wood products are mainly used for general construction and furniture. In contrast, South Sumatra follows no thinning schedule and all wood products are used for pulp and paper.

Field surveys in West Java were conducted in four *A. mangium* plantation sites with stand ages of 3, 5, 8 and 10 years. The study area was situated on a hillside approximately 60–100 m above sea level (asl), where the annual rainfall is 3000 mm. Soils are classified as Orthic Acrisol and the terrain is flat or gently undulating (Miyakuni *et al.* 2004).

Field surveys in South Sumatra were also conducted in four sites with stand ages of 2.5, 5.5, 8.5 and 10.5 years. The study area was situated at altitudes 100–150 m asl, where the annual rainfall is 2700 mm. The soil is a red-yellow Podsol and the terrain is flat to undulating (Anonymous 1992).

Plot setting

Four 0.06 ha plots (20 × 30 m) for each stand age were established to evaluate tree growth characteristics and to estimate forest biomass. Stem diameter at breast height (D; 1.3 m above ground) and tree height (H) were measured for all *A. mangium* trees in the plot. D was measured using callipers for trees with small D or a diameter tape for trees with large D. H was measured using an ultrasonic hypsometer for heights > 12 m and a measuring rod for heights < 12 m.

Estimation of tree biomass

To formulate allometric equations for trees, about 15 different D-sized (trees > 2 cm in diameter) trees were cut down around the plots.

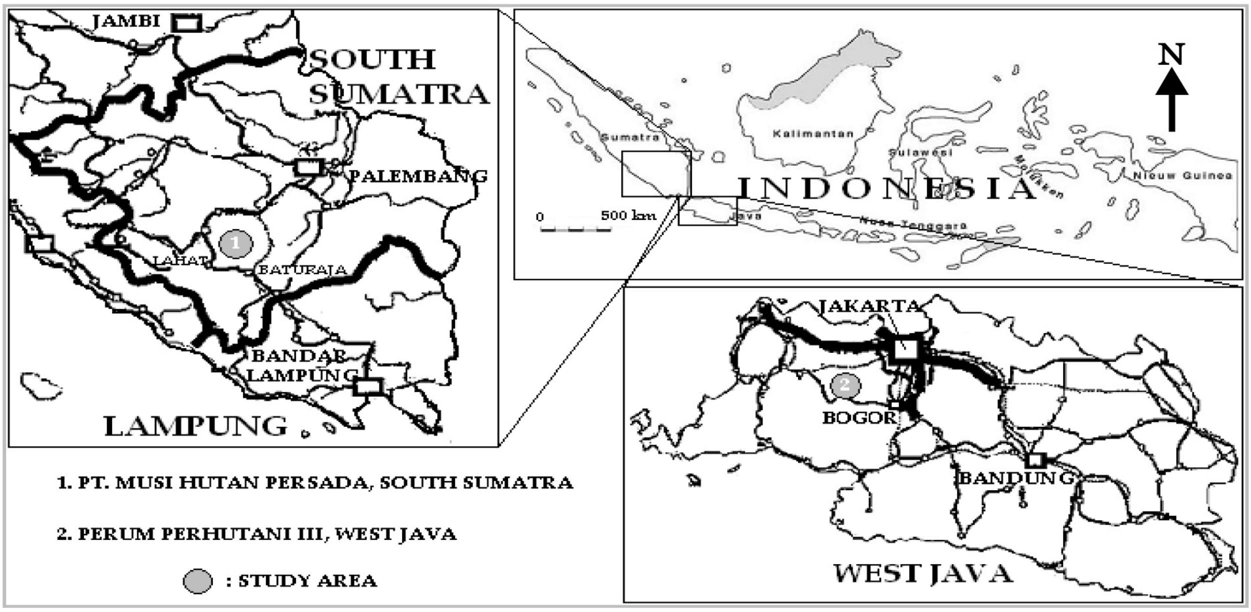


Figure 1 Location of survey sites in Indonesia. Areas surrounded by thin lines indicate the study area.

In total, 115 trees were sampled. After felling and completely unearthing the root system, a sample tree was separated into each component as logs: 0–0.3 m, 0.3–1.3 m, 1.3–3.3 m, etc. every 2 m to the top, and was divided into living branches and twigs, dead branches and twigs, leaves and roots. Tree height, diameter of the logs and weight of tree components of the sample trees were measured in the field. Sub-samples were brought to the laboratory to record the oven-dry weight. Fresh samples were dried at 85 °C in a constant-temperature oven. Drying of leaves and wood biomass < 10 cm in diameter required two days, whereas wood biomass > 10 cm diameter required four days. Ratios of dry/fresh mass were calculated and used to convert fresh mass into dry mass.

In this study, allometric equations to estimate tree component biomass and stem volume of *A. mangium* plantations at each site were established using D and H. We devised equations applicable to each individual stand (model A), as well as a single allometric equation for all stands (model B) using the following allometric relationship:

$$Wi = a\ (D^2H)^b$$

where a and b are constants, D is tree diameter at breast height (cm), H is tree height (m), and Wi is the amount of biomass of component i (kg) or stem volume (m^3).

The aboveground biomass was determined by calculating the sum of the biomass of the stem, branch and leaf. Total biomass was calculated as the sum of aboveground biomass and root biomass (Kira & Shidei 1967, Ogawa & Kira 1977). The total biomass in each plot was calculated from the summed biomass of all trees in the plots. These data were converted into hectares.

Rotation length determination

Rotation length was determined according to management purpose, such as for wood production or for biomass accumulation. The data collected in this study were not yearly and the CAI could not be analysed. Increment was expressed as a mean over a period of years, termed the periodic mean annual increment (PAI). Determining the rotation is defined by the culmination of mean annual increment (MAI), i.e. where the PAI curve crosses the curve for MAI for both biomass and stem volume.

RESULTS AND DISCUSSION

Tree growth characteristics

Table 1 shows stand characteristics of the survey sites. In West Java, initial spacing for all stand ages was 2 × 3 m. The decrease in stand density with age

Table 1 Stand characteristics in survey sites of *Acacia mangium* plantations

Location	Stand age (year)	Stand density (trees ha^{-1})[a]	D (SD) (cm)[a]	H (SD) (m)[a]	Basal area (m^2 ha^{-1})[a]
West Java					
B 23A Maribaya	3	1,838*	7.25 (2.87)*	7.33 (2.02)*	8.78
B 4D Tenjo	5	475*	16.03 (3.17)*	15.06 (1.43)*	9.96
B 13A Tenjo	8	283*	21.14 (3.46)*	18.47 (1.89)*	10.21
B 30C Maribaya	10	225*	27.81 (4.37)*	25.12 (2.12)*	14
South Sumatra					
B6 Subanjeriji	2.5	1,263	10.86 (2.75)	7.66 (1.41)	12.43
B6 Sodong	5.5	758	17.89 (4.24)	17.41 (2.13)	20.12
B18 Toman	8.5	861	17.40 (5.29)	15.92 (5.08)	22.29
B80 Bd. Anyar	10.5	996	15.05 (4.96)	19.19 (3.26)	19.62

[a] Mean and standard deviation of data from four 20 × 30 m rectangular plots
B followed by a number indicates the compartment codes of different sites.
* Source: Miyakuni *et al.* (2004)

was influenced by regular thinning treatments. Thinning treatment was not practised for the plot of 3 years old due to regulation of the local government which prohibits harvest activities in West Java. Two times thinning occurred for the 5-years-old plot and three times treatment for the 8 and 10-years-old plots respectively. In South Sumatra, initial spacing differed between the two youngest and the two oldest stands, i.e. 3 × 3 and 2 × 4 m respectively. Stand density was high in the 10.5-year-old stand, where thinning had never been practised. In this stand, 42.7% of trees had only a single stem, whereas 57.3% of trees had two or three stems.

In West Java, the MAI for D ranged from 2.4 to 3.2 cm year^{-1}, and a high MAI value was recorded for trees 5 years old, after which MAI values generally declined to 2.6–2.8 cm year^{-1}. The MAI for H ranged from about 2.3 to 3.0 m year^{-1}, and a high value was recorded for trees 5 years old, although H decreased to 2.3–2.5 m year^{-1} in older trees. Unthinned plantations in South Sumatra indicated different growth patterns from those in West Java. The MAI for D ranged from about 1.4 to 4.3 cm year^{-1}, and a high value was recorded for young trees, which were 2.5 years old. The MAI for H ranged from 1.8 to 3.2 m year^{-1}, and a high MAI value was recorded for trees 5.5 years old. In the South Sumatra site, age effects on MAI could not be directly compared because the initial spacing differed.

A considerable number of published reports on the growth of *A. mangium* confirm that this species can achieve MAI in D up to 5 cm and MAI in H up to 5 m in the first four or five years, and growth declines rapidly after seven or eight years (Lim 1992). Therefore, the MAI recorded in this study confirms the general patterns found for stand age obtained thus far. Compared with the growth rates of planted *A. mangium* forest in Sabah State, Malaysia (Inose 1991), the growth rates in our study fell between the rates for Sites III and II of the Sabah forests for 3- to 8-year-old stands in West Java and for all stands in South Sumatra, and between rates for Sites II and I for 10-year-old stands. Thus, we consider the growth rates in our study to be typical of the region.

Figure 2 shows specific wood density (ratio of stem dry weight [kg]/fresh volume [m^3]) of sample trees with different stand ages. Analysis of variance showed that the mean specific wood density tended to be higher in South Sumatra than in West Java ($F = 9.54$; $p < 0.037$), and mean specific wood density increased on power function with age in West Java ($r^2 = 0.9035$; $p < 0.049$) and in South Sumatra ($r^2 = 0.9892$; $p < 0.005$).

Low thinning (thinning from below) treatments performed in the West Java site provided more growing space for remaining trees, thereby encouraging diameter and height increments as well as improving stand hygiene. In addition, they removed suppressed, intermediate and some co-dominant trees, and future increments are concentrated on the healthiest remaining trees. On the other hand, in unthinned plantations, as in the South Sumatra site, crown lift and mature wood production, i.e. specific wood density (Evans 1992), are accelerated. Genetics, location, soil and age affect growth response and wood density, and silvicultural practices influence these factors (Goudie 1999).

Tree biomass

The biomass storage in different components and stand ages of *A. mangium* trees is shown in Figure 3. In West Java, the proportion of stem biomass up to 8 years old was constant and after that slightly increased, but the proportion of leaf biomass decreased. The contribution of different components to total biomass was in the order of stems > branches ≥ roots > leaves. The contributions of stem, branches, root and leaf biomass at the plantation level were 63–71, 11–17, 14–16, and 2–10% respectively. A different pattern of biomass proportion was observed in unthinned plantation in South Sumatra. The proportion of stem biomass increased with age, while proportion of leaf biomass decreased drastically from 2.5 to 5.5 years old and relatively constant thereafter. The contributions of stem, branch, leaf and root biomass were 58–77, 10–18, 2–13 and 11–13% respectively.

Allometric equations were established from an analysis of the relationship between tree growth parameters and tree component biomass and stem volume data. These equations are shown in Figures 4 and 5, and summarized in Table 2. Each formulation was well fitted, and the biomass of different tree components and stem volume were calculated on this basis.

A single allometric equation to estimate the amount of biomass (Table 3 and Figure 4) and stem volume (Table 3 and Figure 5) of *A. mangium* was formulated to apply to all plantations in different managements practised.

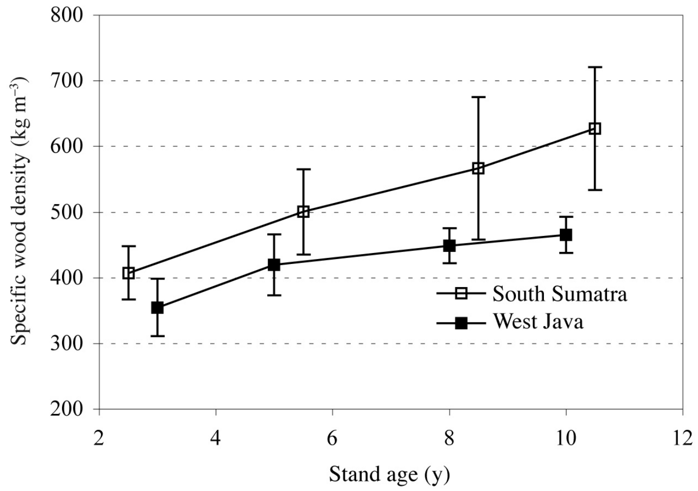


Figure 2 Specific wood density of *A. mangium* in two regions

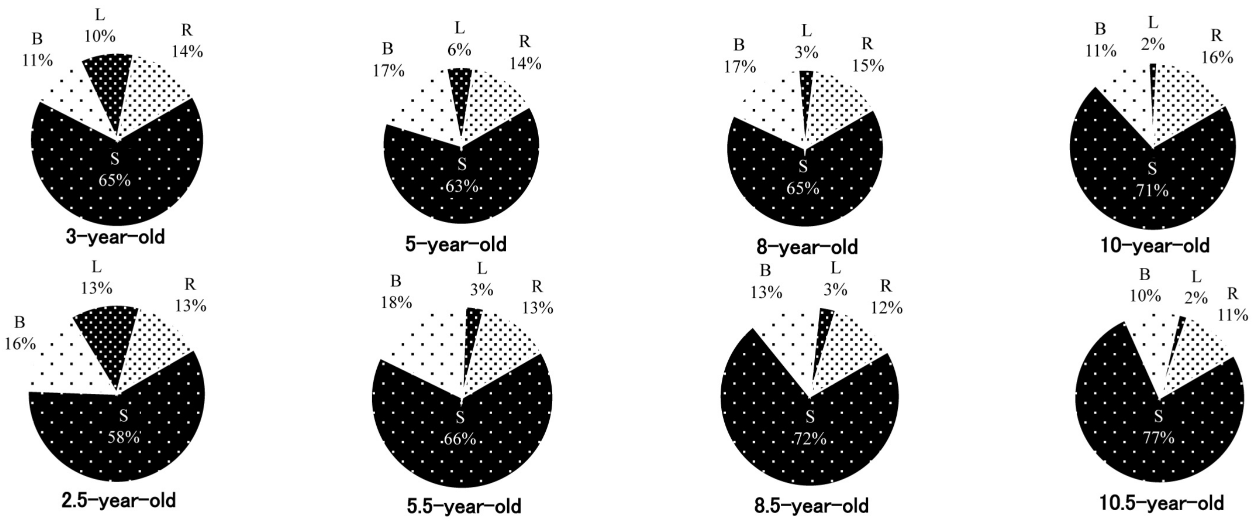


Figure 3 Biomass storage of different components with age in West Java and South Sumatra. S: stems, B: branches, L: leaves, R: roots

Stand-level values for all tree component biomass and stem volumes were estimated from the D and H of all trees in the plots (Table 3). Estimated stem, branch and leaf biomass using models A and B differed, with the exception of trees aged 3, 5.5 and 8.5 years respectively. Estimated root biomass using models A and B did not differ significantly ($p = 0.329–0.935$), except for 2.5 years ($p = 0.002$). Estimated aboveground and total biomass differed significantly between models A and B at 3, 10, 2.5, 8.5 and 10.5 years old, whereas the relative error between models was less than 9.31 and 8.61% for aboveground and total biomass respectively at 5, 8 and 5.5 years old. Stand-level stem volume estimated using models A and B did not differ significantly ($p = 0.054–0.965$). Based on this analysis, a single allometric equation was thought to be moderately applicable just for root biomass and stem volume estimations. Because specific wood density of stems was known, it may be possible to estimate stem biomass in a stand without destructive sampling using the single regression line of stem volume to D^2H.

Forest productivity and optimum rotation age

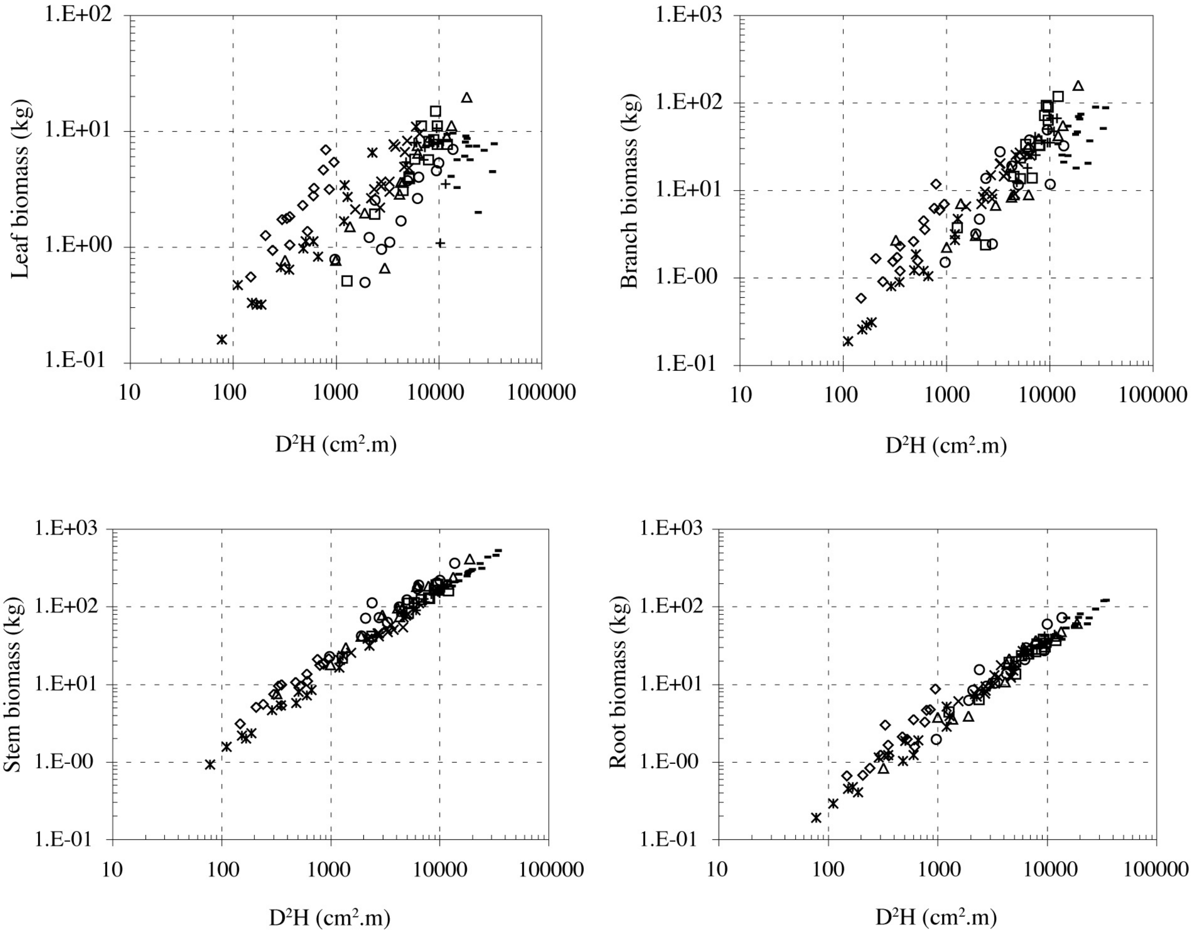
Depending on allometric equations in each stand (model A), stem volume, stem and total biomass of every stand age could be calculated (Figure 6). These data could be used to calculate MAI and PAI in order to estimate the optimum rotation age of thinned and unthinned plantations of *A. mangium*. The optimum rotation age was determined when the MAI and PAI curves crossed and their analyses were separated depending on management purposes, i.e. for AR-CDM project or for wood production.

As indicated in Figure 6, the 10-year-old *A. mangium* stand in West Java accumulated stem volume, stem biomass and total biomass of 155.6 m^3 ha^{-1}, 71.9 and 99.8 Mg ha^{-1} respectively. The stand of 10.5-year-old *A. mangium* in South

Table 2 Allometric equations used to estimate biomass of *A. mangium* in West Java and South Sumatra, using a combination of D and H

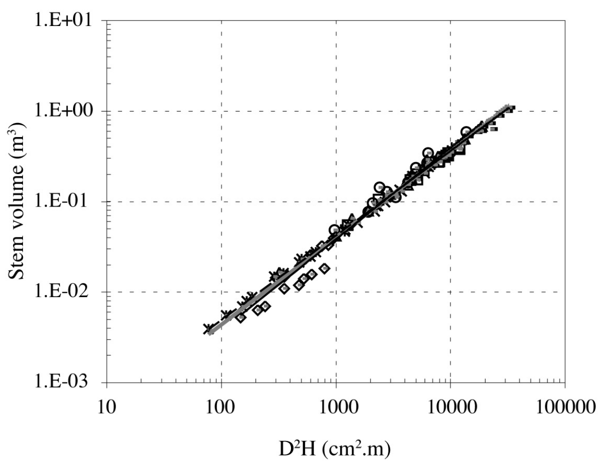
Tree biomass	Model	West Java				South Sumatra			
		Age (y)	-log a	b	r^2	Age (y)	-log a	b	r^2
Stem	A	3	2.0051	1.0581	0.9857	2.5	1.5879	0.9765	0.9049
		5	1.4827	0.9089	0.9316	5.5	1.6665	0.9787	0.9580
		8	1.6283	0.9612	0.9399	8.5	1.6112	0.9876	0.9720
		10	1.4112	0.9104	0.9355	10.5	1.4146	0.9512	0.9090
	B	*All sites*	*1.7143*	*0.9934*	*0.9721*				
Branch	A	3	3.3715	1.2733	0.9629	2.5	3.2095	1.3699	0.8205
		5	2.4864	1.0297	0.6494	5.5	5.2572	1.7689	0.8375
		8	4.8637	1.6361	0.8179	8.5	2.5044	1.0108	0.7829
		10	2.1082	0.8760	0.2631	10.5	3.2245	1.1887	0.6311
	B	*All sites*	*2.4877*	*1.0087*	*0.8641*				
Leaf	A	3	2.5808	0.9626	0.9148	2.5	2.6584	1.1275	0.8106
		5	3.4770	1.1685	0.7462	5.5	4.3242	1.3348	0.8791
		8	-2.7749	-0.5096	0.0562 ns	8.5	2.6130	0.8788	0.8017
		10	-1.5793	-0.1857	0.0182 ns	10.5	3.1325	0.9542	0.7742
	B	*All sites*	*1.6106*	*0.6173*	*0.6463*				
Root	A	3	2.6779	1.0515	0.9583	2.5	2.9417	1.2301	0.8105
		5	2.6517	1.0548	0.8384	5.5	2.5822	1.0326	0.9450
		8	2.2752	0.9626	0.8486	8.5	2.8491	1.1087	0.9655
		10	2.3636	0.9805	0.8103	10.5	3.1632	1.2020	0.9122
	B	*All sites*	*2.5121*	*1.0193*	*0.9700*				
Stem volume	A	3	4.1548	0.9244	0.9977	2.5	4.4332	0.9881	0.8327
		5	4.3649	0.9829	0.9765	5.5	3.9076	0.8599	0.9892
		8	4.2206	0.9462	0.9810	8.5	4.1020	0.9198	0.9947
		10	3.7000	0.8217	0.9372	10.5	4.0678	0.9171	0.9513
	B	*All sites*	*4.2966*	*0.9655*	*0.9891*				

Equations in West Java were developed from trees aged 3 (n = 15), 5 (n = 16), 8 (n = 12), and 10 (n = 16) years, whereas equations in South Sumatra were developed from trees aged 2.5 (n = 15), 5.5 (n = 14), 8.5 (n = 14), and 10.5 (n = 13) years.
Model A: equations for individual stand ages; model B: equation for all stand ages combined.



◇: 2.5-, □: 5.5-, △: 8.5-, ○:10.5-, ✻: 3-, ×: 5-, +: 8-, -: 10-year-old stands. Solid black and black dotted lines represent log-linear regression lines for each stand in South Sumatra and West Java, respectively (model A), and the thick gray line represents all stands combined (model B).

Figure 4 Leaf, branch, stem, and root biomass of planted *A. mangium* forests in West Java and South Sumatra using a combination of D and H



◇: 2.5-, □: 5.5-, △: 8.5-, ○:10.5-, ✻: 3-, ×: 5-, +: 8-, -: 10-year-old stands. Solid black and black dotted lines represent log-linear regression lines for each stand in South Sumatra and West Java respectively (model A), and the thick gray line represents all stands combined (model B).

Figure 5 Allometric equation of stem volume of planted *A. mangium* forests in West Java and South Sumatra using a combination of D and H

Table 3 Comparison of the biomass of each tree component and stem volume estimation using individual stand allometric (model A) and single allometric equations (model B)

Stand age (years)	Model	Stem biomass Mg ha^{-1}	Branch biomass Mg ha^{-1}	Leaf biomass Mg ha^{-1}	Root biomass Mg ha^{-1}	Stem volume m^3 ha^{-1}
	A	13.88	2.39	1.93	2.82	40.38
3	B	17.58	3.33	2.02	3.35	37.85
	RE (%)	-26.68	-39.05	-4.58	-19.09	6.27
	A	29.79	8.26	2.43	6.81	72.58
5	B	35.59	6.92	1.74	7.11	72.89
	RE (%)	-19.46	16.23	28.21	-4.44	-0.43
	A	40.13	11.66	1.76	9.17	89.35
8	B	44.21	8.69	1.56	9	88.79
	RE (%)	-10.18	25.43	11.17	1.86	0.62
	A	71.88	10.26	1.4	16.25	155.56
10	B	81.77	16.29	2.01	17.25	162.76
	RE (%)	-13.76	-58.76	-43.26	-6.14	-4.63
	A	27.08	10.36	6.72	6.98	42.15
2.5	B	22.82	4.35	2.1	4.4	48.57
	RE (%)	15.73	58.03	68.73	36.91	-15.24
	A	82.11	23.78	4.2	15.91	133.37
5.5	B	83.54	16.35	3.41	16.87	169.16
	RE (%)	-1.74	31.25	18.87	-6.01	-26.83
	A	112	17.47	4.13	19.12	196.37
8.5	B	92.96	18.24	3.64	18.86	187.34
	RE (%)	17	-4.45	11.86	1.36	4.6
	A	129.15	16.44	2.41	21.59	213.81
10.5	B	93.86	18.37	3.96	18.94	190.21
	RE (%)	27.32	-11.71	-64.28	12.25	11.04

A: model for each stand age, B: model for all stand ages, RE: relative error = (A–B)/A 100

Sumatra accumulated 213.8 m^3 ha^{-1}, 129.2 and 169.59 Mg ha^{-1} of stem volume, stem biomass and total biomass respectively.

In this study, stem volume and biomass accumulation of *A. mangium* plantations in South Sumatra were higher than in West Java. This age-related change in density is one of the factors that should be considered when determining harvest age (rotation). In West Java, the highest MAI value was recorded for 10-year-old trees. Thinned plantations nevertheless grew well and the highest productivity was found in the oldest plantation (10 years old).

Trees in the suppressed and intermediate crown classes usually die by self-thinning if they are not thinned. Low thinning removed them and some co-dominant trees, and improved the growth of residual trees. Thinning affected the growth of residual trees in terms of MAI and PAI of diameter and height. The study concluded that thinning is recommended for increasing the growth rate and yield of trees, and longer rotation is available to enhance wood quality and wood utilization.

Unthinned *A. mangium* plantations in South Sumatra are capable of accumulating more for the younger age of 5.5 compared with the 10.5 years, i.e. 1.75, 1.21 and 1.42 times for stem volume, stem biomass and total biomass respectively.

Even unthinned plantation had a higher volume and biomass per ha, suggesting that maximum productivity is reached at a younger age despite differences in initial spacing. The study in unthinned plantation in South Sumatra concluded that a rotation of six years may be recommended to maximize total biomass accumulation and a rotation of eight years is recommended to maximize benefits (Figure 6).

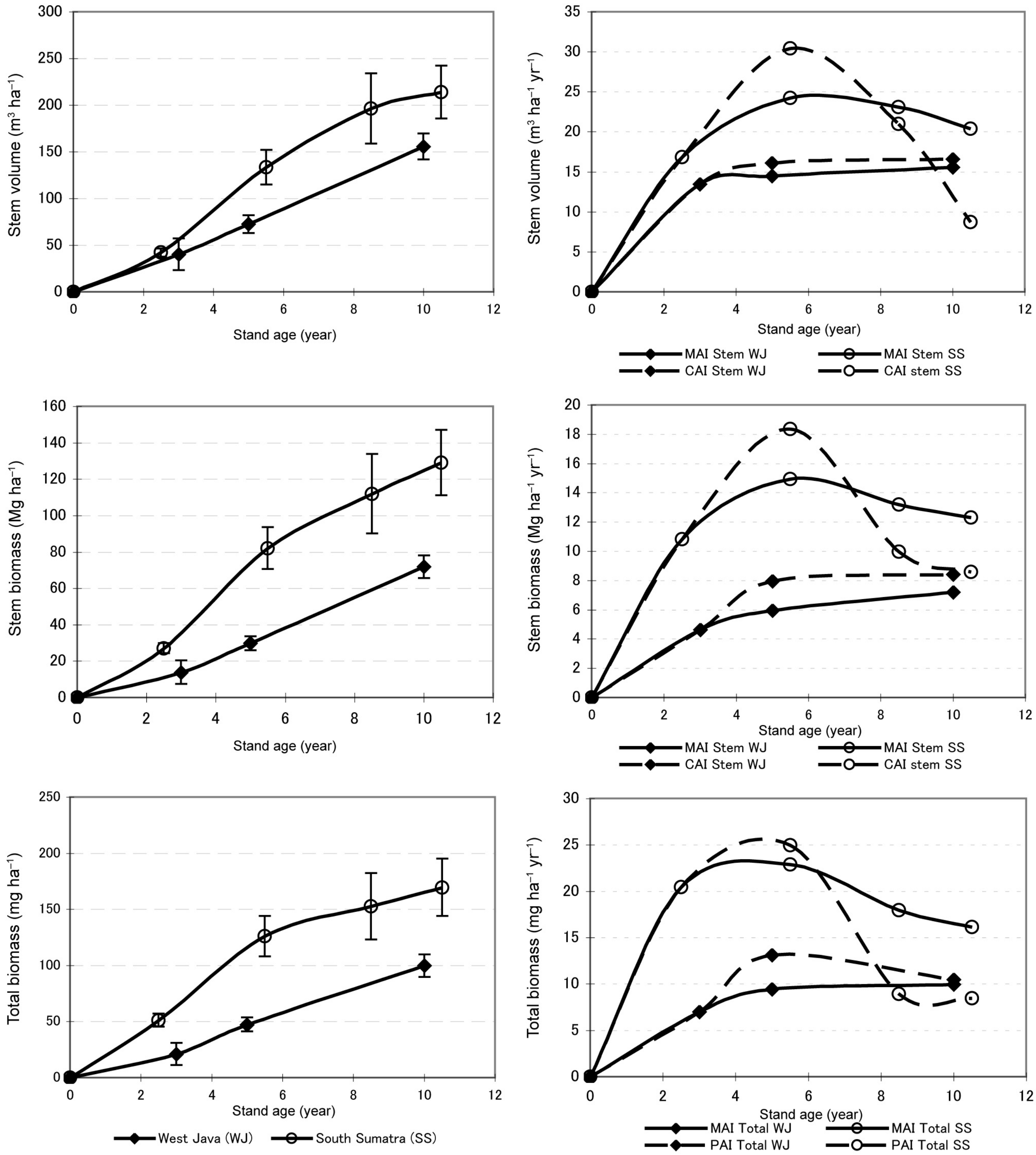


Figure 6 Stem volume, stem biomass, total biomass accumulation (left), mean annual increment and current annual increment (right) of *A. mangium* plantations in West Java and South Sumatra

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