

Yield Prediction for *Acacia mangium* Plantations in Southeast Asia

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Abstract: *Acacia* species have been widely planted in Southeast Asian industrial plantations. Among them, *Acacia mangium*—identified as a promising fast-growing variety—has been planted on a large scale not only for industrial use, but also for forest remediation in the tropics. This paper investigates the growth characteristics of *Acacia mangium* in Peninsular Malaysia to analyze its growth performance and construct a growth model and yield table applicable to Southeast Asia.

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1. Introduction

Since the beginning of the 1970s, forested regions have been heavily impacted by agricultural clearing, shifting cultivation, and excessive harvesting, among many other factors. According to the FAO (2006) world forest statistics, deforestation has become a serious global problem. Degradation of forest resources—the loss of structure, diversity, function, and other qualitative features—is also an increasingly salient issue, especially in tropical regions.

Many efforts have been made to restore and rehabilitate these tropical forests, including artificial afforestation and reforestation. These efforts have been hampered by difficulties related to seed and sapling production, a problem that seems to be prevalent among tropical tree species. A variety of research and local demonstration projects have been completed, but yield prediction and management techniques for tropical forests still have not been established, even in cases where saplings have been successfully produced and survive an initial period of growth.

Acacia mangium is one of several promising fast-growing tree species in plantations on Peninsular Malaysia, Sabah, and Indonesia; it has also shown a high survival rate in poorer soils. Recent experiments have demonstrated basic conditions for the successful introduction of *Acacia mangium* in tropical regions, as well as the application of appropriate silvicultural treatments.

As a Clean Development Mechanism (CDM) for climate change mitigation, *Acacia mangium* plantations are expected to provide efficient and profitable contributions to the sawlog and pulp markets. Participants in CDM projects are asked to provide key project parameters in a project design document (PDD), which contains information about the project activity, approved baseline methodology, etc. In this context, the construction of a suitable yield table is quite important for

estimating potential sawlog and pulp yields, as well as verifying that proposed projects meet CDM guidelines (Matsumura *et al.*, 2008)

In this paper, we first construct a yield table for *Acacia mangium* based on our study plots, followed by development of a growth model and yield prediction. Using an analysis developed by Matsumura (2004), we validate the proposed yield table's diameter prediction.

2. Materials and methods

The sample plots used in our study are located on Peninsular Malaysia (Fig.1). These plantation forests were allocated to the compensatory forest plantation project (CFPP) with the goal of converting degraded forestland into a plantation of fast-growing exotic *Acacia mangium* for timber production. Stand-level data was obtained from our field inventory; most stands were between 11 and 12 years old, with the exception of a lowland plantation in Chikus where stand age was between three and five years.



Figure 1. Data used for growth modeling

To compare and validate our growth model, we used yield tables established in Sabah, East Malaysia and Sumatra, Indonesia. Growth curves were taken from forest stand data collected in 1995 and 2006

from a lowland *Acacia mangium* plantation growing in an area formerly mined in Chikus, Perak (Inose, 1991, JICA, 1995, Fig.2).



Figure 2. Data used for regional comparison

Each site index is calculated on the basis of average height growth. We estimated mean diameter growth, diameter variance, merchantable volume, and other parameters needed for forest stand growth modeling. Figure 3 and Table 1 show the conceptual flowchart used for the analysis and the list of data used in our study.

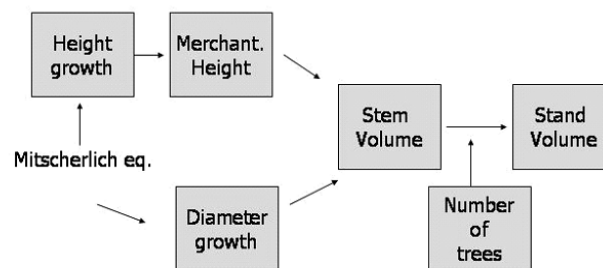


Figure 3. Conceptual flowchart for volume estimation

Our yield table is derived from basic stand level growth parameters, such as mean diameter at breast height (D), mean height (H), merchantable height (HB), the number of trees (N), total basal area

Table 1. Analysis procedures and data used

Field data		
used data for modelling	JICA project site	Chikus/Perak State
	Peninsular Malaysia	Lowland plantation 3,5 yrs
		BatuArang/Selangor State
		11, 12 yrs
		Kemasul/Pahang State
		Old plantaion 12 yrs
		Setul/Negeri Sembilan State
		12 yrs
		Ulu Sedili/Johor State
		12 yrs
Validation data	East Malaysia	Sabah State
	Sumatra, Indonesia	Benakat
Yield table construction		
Growth model	Height growth, site index	Mitscherlich eq.
	Diameter growth	Mitscherlich eq.
	Diameter variance	Mitscherlich eq.
	Merchantable height	linear function
	number control	Exponential function
	volume growth	Allometric eq.
Validation of yield table		
Growth model	East Malaysia	Sabah State
	Sumatra, Indonesia	Benakat
Field data	Diameter data	Chikus in 17 yrs

(GF), and merchantable volume (V) (Wan Razali *et al.*, 1989). To calculate the growth prediction, we input height and diameter growth data into the Mitscherlich equation. Stand inventory data from the Chikus site was used to estimate the variance of height and diameter growth over time; changes in these parameters can also be predicted by the Mitscherlich equation. Note that the Mitscherlich equation is often used as a monomolecular reaction equation and demonstrates relatively high goodness of fit for tree diameter growth and its variance over time (Suzuki, 1979).

Silvicultural treatments were completed following guidelines from the Forestry Department of Peninsular Malaysia (FDPM), which included an initial planting density of 900 seedlings per hectare and two thinning treatments that each reduced stand density by approximately 30%. We used an exponential function to describe the change in the number

of trees over time. That is, the initial number of trees was set at 900 per ha and then decreased exponentially with each thinning. The yield table derived from this procedure was compared with other tables constructed by Matsumura and Ismail (1996) for stands in Sabah and Sumatra.

3. Results

Basic forest stand growth elements, i.e. mean diameter at breast height (D) and mean height (H), were calculated using least squares estimation via the following Mitscherlich equations:

$$[1] \quad D(t) = 41.10 * (1 - 0.8950 * \exp(-0.0783 * t)) \quad (R^2 = 0.934)$$

$$[2] \quad H(t) = 26.04 * (1 - 1.0747 * \exp(-0.2477 * t)) \quad (R^2 = 0.974)$$

The fitted growth curves are shown in Figures 4 and 5.

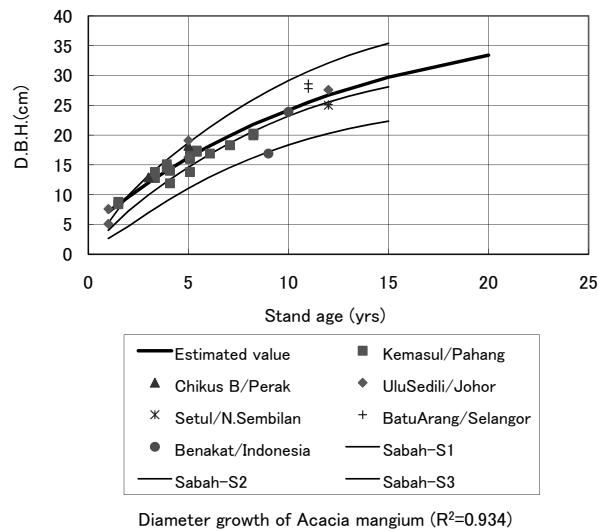
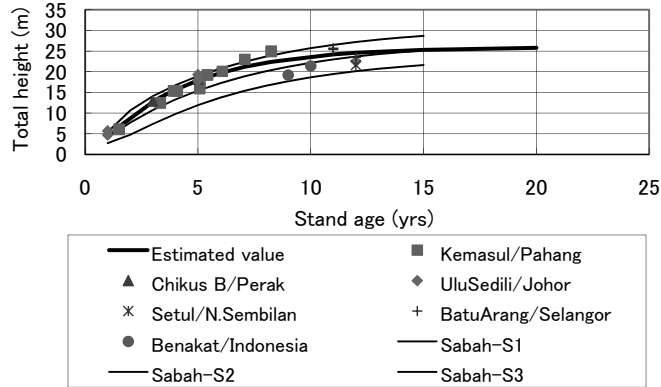


Figure 4. Regional comparison of diameter growth



Height growth of *Acacia mangium* ($R^2=0.949$)

Figure 5. Regional comparison of height growth

Results from the case studies in Indonesia and Sabah are used for comparison purposes. Average tree height at the Chikus site fell between the upper and middle site class in Sabah, and outperformed growth in Indonesia. Compared to other growth data from Peninsular Malaysia, the *Acacia* plantation in Chikus demonstrated better performance (Figs.4 and 5).

Site classification was based on the average values and variance of height growth. Upper and lower guide curves were derived by $\pm 1\sigma$ of the average height growth curve in the medium site class. Diameter variance VD was estimated by the following Mitscherlich equation:

$$[3] \quad VD(t) = 24.78 * (1 - \exp(-0.2939 * t))$$

Merchantable height (HB) was derived as a linear function of average height H (Fig.6) via the following equation:

$$[4] \quad HB(H) = 0.3539 * H + 4.9397 \quad (R^2 = 0.075)$$

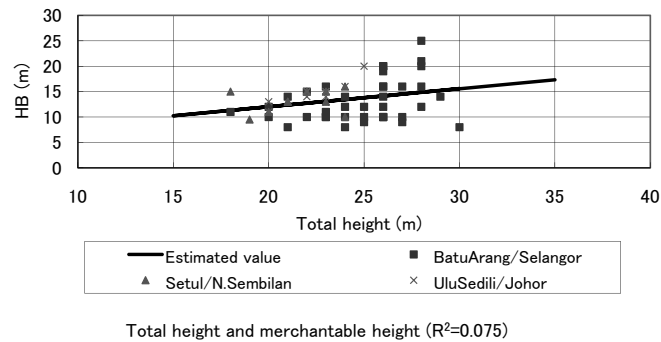


Figure 6. Estimation of merchantable height

Goodness of fit was especially low when $HB(0)$ had a high initial value—an issue that should be addressed in future analyses.

Stand density was assumed to decrease exponentially over time, a result of natural self-thinning and scheduled treatments, described by the following equation:

$$[5] \quad N(t) = 900 * \exp(-b * t)$$

Parameter b is the rate of decrease in stand density, which was estimated at 0.0541. Table 2 shows the derived yield table.

Average tree height at the Chikus site, which was based on average height at age 10, also showed growth performance between the upper and middle site class in Sabah, outperforming growth in Indonesia. Compared to other height growth data from Peninsular Malaysia, the *Acacia* plantation in Chikus demonstrated better performance (Tab.3).

When compared to measurements taken from the Chikus site at ages

Table 2. Derived yield table for *Acacia mangium*

Merchantable volume of *Acacia mangium*

Age (yrs)	H (m)	Range (m)	HB (m)	DBH (cm)	N (/ha)	GF (m ² /ha)	V (m ³ /ha)	Sr (%)	MAI (m ³ /ha/yr)
1	4.2	3.9–4.5	2.3	7.1	853	3	11	81.0	11.0
2	9.0	8.3–9.6	4.9	9.6	808	6	31	38.5	15.5
3	12.7	11.8–13.6	9.4	12.0	765	9	72	27.9	24.0
4	15.6	14.5–16.8	10.5	14.2	725	12	98	23.1	24.5
5	17.9	16.6–19.2	11.3	16.2	687	15	123	20.6	24.6
6	19.7	18.3–21.1	11.9	18.1	651	18	146	19.1	24.3
7	21.1	19.6–22.6	12.4	19.8	616	21	167	18.2	23.9
8	22.2	20.6–23.8	12.8	21.4	584	24	186	17.6	23.3
9	23.0	21.4–24.7	13.1	22.9	553	26	202	17.3	22.4
10	23.7	22.0–25.4	13.3	24.2	524	28	214	17.2	21.4
11	24.2	22.5–25.9	13.5	25.5	496	30	225	17.2	20.5
12	24.6	22.8–26.4	13.6	26.7	470	31	234	17.2	19.5
13	24.9	23.1–26.7	13.8	27.8	445	33	242	17.3	18.6
14	25.2	23.4–27.0	13.9	28.8	422	34	247	17.5	17.6
15	25.3	23.5–27.2	13.9	29.7	400	34	249	17.8	16.6
16	25.5	23.7–27.3	14.0	30.5	379	35	251	18.0	15.7
17	25.6	23.8–27.5	14.0	31.3	359	35	251	18.3	14.8
18	25.7	23.9–27.6	14.0	32.1	340	36	251	18.6	13.9
19	25.8	23.9–27.6	14.1	32.7	322	35	250	18.9	13.2
20	25.8	24.0–27.7	14.1	33.4	305	35	248	19.3	12.4

Table 3. Height growth in Chikus and other regions

(H10 : Average height at 10, Range : Height range, Ratio : 100 for Chikus site)

	Sabah			P.Malaysia	Sumatra
	I	II	III	Chikus	Benakat
H10	25.71	22.18	18.66	23.7	21.4
Range				22.0–25.4	
Ratio	108	94	79	100	90

7, 13, and 17, the height growth prediction was slightly overestimated, but the diameter growth prediction was well within the expected range (Tab.4).

Additional regional forest stand yield tables and growth data are provided in Table 5. Using the Chikus site with a stand age of 10 as reference, we calculated average height, diameter at breast height, stand density and volume, and merchantable stand volume for comparison with sites in Sabah and Sumatra. For average diameter and

Table 4. Verification of diameter and height growth model

<i>Acacia mangium</i>					
Age (yr)		Height (m)	H-range (m)	DBH (cm)	Stand Volume (m ³ /ha)
7	Data	18.6		19.5	
	Model	21.1	19.6–22.6	19.8	167
13	Data	20.9		26.6	
	Model	24.9	23.1–26.7	27.8	242
17	Data	–	–	37.0	
	Model	–	–	31.3	–

volume, the Chikus site performed equally well when compared to the mid-range site at Sabah. When compared to Sumatra, stand density was 30% higher and total volume 70% higher at Chikus.

Table 5. Regional Comparison at age 10

	Sabah			P.Malaysia	Sumatra
	I	II	III	Chikus	Benakat
H10	25.71	22.18	18.66	23.7	21.4
Ratio	108	94	79	100	90
D10	29.14	23.18	18.34	24.2	23.9
Ratio	120	96	76	100	99
N10	429	530	641	524	673
Ratio	82	101	122	100	128
vol10	0.646	0.372	0.206	0.408	0.542
Ratio	158	91	50	100	133
V10	277	197	132	214	365
Ratio	129	92	62	100	171

4. Conclusion

We used field survey data from Peninsular Malaysia to construct a primary yield table for *Acacia mangium*, a promising fast-growing species planted throughout Southeast Asia. This yield table was compared to tables from Sabah, East Malaysia and Sumatra, Indonesia.

Average height growth in Peninsular Malaysia was comparable to that in the medium site class at Sabah, and outperformed the site in Sumatra. Diameter growth showed a similar tendency, but total stand volume was less than that in Sumatra because of different stand densities. As for the basic stand growth model, its prediction slightly overestimated actual values, and should be re-examined in light of observed forest stand data. Considering the range of thinning treatments applied to these stands, additional thought should be given to how thinning is incorporated into the growth model. The model should also include pulp, pole, and sawlog production as the final forest products produced from these stands (Fig.7).



Figure 7. *Acacia mangium* plantation at Chikus (17 yrs)

Acacia plantations are recognized as valuable assets in climate change mitigation and have been widely introduced throughout tropical regions in conjunction with CDM projects. Despite some of the current model's limitations, the derived stand table can inform CDM project design documents for large- and small-scale plantations (Matsumura, 2004).

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東南アジアにおけるアカシア・マンギウム人工林の成長予測

松村直人

要約: 東南アジアの産業植林において、アカシア類は広範囲に植林されている。特に、アカシア・マンギウムは大面積産業植林だけでなく、熱帯荒廃地の森林再生にも有望な早生樹の一つとして植林された。本論文では、半島マレーシアのアカシア・マンギウムの成長特性について検討した。半島マレーシアにおけるアカシア・マンギウムの植林事例について分析し、成長モデルと収穫表を作成し、東南アジアにおける成長予測の一例として、有益な資料となると思われる。

キーワード: 成長モデル、収穫表、アカシア・マンギウム、早生樹、半島マレーシア