GROWTH OF *ACACIA MANGIUM* DURING THREE YEARS FOLLOWING THINNING: PRELIMINARY RESULTS

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AHMAD Z. YAHYA. 1993. Growth of *Acacia mangium* during three years following thinning: preliminary results. The growth response of *Acacia mangium* stands under two thinning intensities is discussed. A mean annual diameter increment of 3.0 *cm* for the whole period could not be achieved even for the 300 biggest crop trees in the heavily thinned stands. The periodic annual increment was 2.0 *cm*. Similar was the periodic annual increment for the 300 selected crop trees (PCT) in the heavily thinned plots (1.9 *cm*). The total volume increment (volume over bark up to 10 *cm* top diameter limit) of three years was highest in the unthinned control (130.51 m^3) and lowest in the heavily thinned plots (110.56 m^3). Live crown ratio gained distinctly from the thinning interventions. At the beginning of the thinning trial live crown ratio ranged from 27.3 % (control plots) to 33.1 % (heavily thinned plots). After three years, live crown ratio ranged from 22.9 % (control plots) to 38.3 % (heavily thinned plots). Highest live crown ratios were found in the heavily thinned plots and lowest in the unthinned control plots. Overall, the thinning trial gave pronouncedly stratified results. *Acacia mangium* reacts favourably to thinning interventions with improvement of the growth rates and crown size. However, it will be impossible to achieve an average diameter increment of 3 $cm\ y^{-1}$ over the rotation time of 15 *y*. As a result, a reduction in the number of final crop trees and raising of the rotation age is advisable.

Keywords: Crown thinning - increment - *Acacia mangium*

AHMAD Z. YAHYA. 1993. Kadar pertumbuhan *Acacia mangium* selepas tiga tahun penjarangan : keputusan awal. Kesan pertumbuhan dirian *Acacia mangium* diselidiki setelah menjalani dua tahap penjarangan. Purata pertambahan perepang tahunan untuk 300 pokok yang terbesar di dalam dirian penjarangan yang tertinggi adalah di bawah paras 3.0 *cm*. Manakala pertambahan perepang seketika "periodic" tahunan pula hanya mencapai 2.0 *cm*. Begitu juga 300 pokok pilihan (PCT), purata pertambahan perepang seketika "periodic" tahunan di dalam dirian penjarangan tahap tertinggi adalah 1.9 *cm*. Jumlah isipadu yang tertinggi (isipadu luar kulit ke paras 10 *cm* perepang) setelah 3 tahun penjarangan adalah di dalam dirian petak kawalan (130.51 m^3) dan terendah di dalam dirian petak penjarangan tahap tertinggi (110.56 m^3). Penjarangan ini juga telah memberikan kesan yang ketara kepada nisbah silara dirian - *Acacia mangium*. Pada peringkat permulaan penjarangan, nisbah silara adalah di antara 27.3 % (petak kawalan) hingga 33.1 % (petak penjarang tahap tertinggi). Selepas 3 tahun nisbah silara dirian adalah dari renj 22.9% (petak kawalan) hingga 38.3% (petak penjarang tahap tertinggi). Nisbah silara yang terbaik adalah dari petak penjarangan tahap yang tertinggi dan peratus yang terendah dari dirian petak kawalan. Secara keseluruhan kajian penjarangan ini telah menstrata keputusan. *Acacia mangium* memberikan gerakbalas yang baik terhadap kesan penjarangan dengan pembaikkan kadar pertumbuhan dan saiz silara. Akan tetapi tujuan untuk mendapatkan purata pertambahan perepang tahunan sebanyak 3.0 *cm* dalam pusingan hidup 15 tahun mungkin tidak akan tercapai. Dengan itu, dicadangkan supaya bilangan pokok tebangan akhir dikurangkan dan pusingan hidup ditingkatkan.

Introduction

Acacia mangium is the major species that is planted in the Compensatory Forest Plantation Programme, Peninsular Malaysia. It is supposed to produce general utility timber (Johari Baharuddin 1987, Anonymous 1989). The main target is the production of 300 clean sawlogs per *ha* of 6 *m* length in a rotation of 15 years. By then the trees shall have reached an average size of 40 - 45 *cm* over bark at breast height (Johari Baharuddin 1987). If at all during a rotation time of 15 years, this size can only be achieved by reduction of the number of final crop trees and very early heavy thinning interventions. To obtain clean boles, either a pruning regime must be developed or the branch shedding capacity must be improved, that is through higher initial stand densities. In this trial, only the growth response and the response of the crown to two thinning intensities were considered.

Materials and methods

Site

The trial was established in the Compensatory Forest Plantation in Pahang, Peninsular Malaysia. The area is located in the centre of the Peninsular at 102° 14' East and 3° 25' North. Mean daily temperatures range from 27 to 32° *C*. The annual rainfall is between 1800 to 2030 *mm* indicating that the area receives precipitation at the lower range of rainfall in the humid tropics.

The research area is located at about 80 *m* above sea level. The terrain is level to slightly undulating. The soil parent material is sedimentary and metamorphic rocks formed during the Jurassic and Triassic period. The texture is sandy clay loam. Soil nutrient status is poor with a low cation exchange capacity and deficiency particularly in phosphorus. The soil pH is low. Prior to planting the logged natural forests were clearfelled and sites semi-mechanically prepared. Burning was light and chiefly confined to the stacked debris.

The stands were planted at an initial spacing of 3 × 3 *m*. Upon commencement of the trial, trees had reached small pole size (about 14 *cm* diameter) . The stands were distinctly mono-layered with the canopy closed. Generally, foliage was dense. The stands contained a high proportion of forked trees particularly in the higher diameter classes. On the average, trees had coarse branches and self-pruning was poor. The majority of the trees had multiple leaders when young. Excess leaders had been removed at stand age of one year.

Methods and measurements

The trial consisted of nine 0.49 *ha* plots with three treatments and three replications in a randomised complete block design . The total trial area was 4.41 *ha*. Each of the 0.49 *ha* plots (70 × 70 *m*) contained an assessment plot of 50 × 50 *m*. Each plot had a 10 *m* wide buffer zone.

The treatments were :

(i) unthinned control; mortality was recorded for the purposes of stand increment calculation;
(ii) moderate thinning; 25% basal area was removed at stand age of 4 *y* and 1 *mth* and 60% at stand age of 6 *y* and and 1 *mth;*
(iii) heavy thinning; removal of 50% of the basal area at stand age of 4 *y* and 1 *mth* .

The following tree parameters were measured: diameter at breast height (d in *cm*), total tree height (h in *m*), crown height (h_c in *m*). Total tree height and crown point were measured on a sample of 40 trees in each plot, and trees were sampled over the whole range of height-diameter values. From these measurement data individual height curves were determined for each plot using the method of least squares. The model used is

$$h = a + b^{*}\log d \quad \text{(Curtis 1967)}$$

The coefficients of determination were generally high (between 73 to 91%).

From the height curves the following mean heights were calculated: dominant stand height (h_{dom}), mean stand height (h_g), mean height of 300 largest trees *ha*$^{-1}$ (h_o) and mean height of 300 selected final crop trees (h_s).

The basal area was calculated for each tree (g_i); the basal area *ha*$^{-1}$ (G) was obtained by totalling the individual values and converting the result into a *ha*$^{-1}$ value using the area factor (1:0.25), *i.e.*

$$G = \sum g_i * 1/0.25$$

So far, the volume has been measured on 99 samples trees from the thinning material using the Hohenadl method (see Prodan 1965), and no specific final volume table has been developed for these stands. Instead, a volume function by Watts (1989) for *Acacia mangium* stands in Sabah was used. This table is based on stem measurements up to a minimum top diameter limit of 10 *cm* over bark. The function is

$$\ln (V_{ob}) = -9.35 + 1.81^{*}\ln (D_{ob}) + 0.57^{*}H^{0.5}$$

The average volume per tree (v) was calculated using diameter and height of the stem and the volume per *ha* (V) by multiplying the average volume per tree with the stem number *ha*$^{-1}$ (N).

The stand increments calculated were: (i) annual increment, (ii) periodic annual increment, and (iii) mean annual increment. The annual increment is the difference between the growth value at the end of the one-year increment period and the growth value at the beginning, *i.e.*

$$i_G = G_{t+1} - G_t$$

$$i_V = V_{t+1} - V_t$$

These formulae will yield correct results only if the values from the thinnings and/or mortality during the increment period are deducted from the value at the beginning of the period.

The periodic increment was calculated accordingly. The increment value only refers to a period longer or shorter than one year. The periodic annual increment (PAI) is obtained by dividing the periodic increment by the number of years or the fraction of a year, *e.g.* for the stand volume:

$$PAI_V = (V_{t+k} - V_t)/k,$$

where PAI_V = periodic volume increment
V_{t+k} = standing volume at the end of the observation period of length k
V_t = standing volume at the beginning of the observation period
k = length of period

The mean annual increment (MAI) refers to the total production of the stand up to the stand age concerned. This total production is composed of the standing stock and all the removals (thinning and mortality) of the past. The result is divided by the stand age to attain the mean annual increment, *e.g.* for the stand volume:

$$MAI_V = (V_t + \Sigma R)/t,$$

where MAI_V = mean annual increment at stand age t
V_t = standing volume at stand age t
ΣR = total of removals up to stand age t
t = stand age

Results and discussion

Stand development in total

Table 1 shows the stand and stock tables for the average of the three treatments. For each treatment, the stand parameters and the mean annual increment for the stand volume (MAI_V) are presented.

At 4*y* and 1 *mth* (4/1), differences in the dominant height (h_{dom}) (17.10 - 17.80*m*) and in the diameter of the dominant trees (d_{dom}) (17.4 - 17.6 *cm*) between the three treatments were insignificant.. That means that the plots were comparable. This was not so for the mean height, mean diameter, basal area and volume at the beginning of the period. Plots differed distinctly. These differences were used for the allocation of plots to treatments. The unthinned control was allocated to the plots with the highest basal area, moderate treatment to the plots with the next lower basal area and the heavy treatment to the plots with the lowest basal area. It was assumed that in the plots with the lowest basal area some self-thinning and some reactions to it had taken place. On the other hand, plots with the highest basal area were assumed to represent the maximum basal area development for the initial stand density given. It was assumed that no self-thinning had occurred. These plots were taken as control plots. In all cases, where the increment of the thinning plots exceeded that of the control plots, it was safe to assume that there was a thinning effect.

Table 1. Stand and stock tables (stand in total)

Age	N	h_{dom}	d_{dom}	h_g	d_g	G	V	MAI
		m	*cm*	*m*	*cm*	m^2	m^3	$m^3\ ha^{-1}$
Unthinned control								
4/1(1988)	1137	17.10	17.6	15.90	14.3	18.20	118.40	30.00
Removal	24			13.60	11.7	0.26	1.46	
Remaining	1113			15.90	14.3	17.94	116.94	
5/1(1989)	1113	19.50	19.4	18.10	15.6	21.27	157.96	31.36
Removal	17			17.19	13.7	0.25	1.79	
Remaining	1096			18.06	15.6	21.02	156.17	
6/1(1990)	1096	21.92	21.4	19.83	16.4	23.24	190.71	31.88
Removal	44			19.17	15.1	0.79	6.32	
Remaining	1052			19.87	16.5	22.45	184.39	
7/1(1991)	1052	25.47	22.6	22.78	17.2	24.43	239.42	35.15
Periodic increment		(1988-1991)			2.8*	7.53	130.59	
Moderate thinning								
4/1(1988)	1127	17.80	17.5	15.30	14.0	17.49	108.15	26.48
Removal	245			15.50	14.5	4.04	25.42	
Remaining	882			15.30	13.9	13.45	82.73	
5/1(1989)	882	18.90	19.2	17.80	16.0	17.68	128.43	30.26
Removal	28			12.40	9.0	0.18	0.97	
Remaining	854			17.80	16.2	17.50	127.46	
6/1(1990)	854	22.24	21.8	20.09	16.9	19.14	159.52	30.40
Removal	272			20.19	17.1	6.28	52.23	
Remaining	582			20.04	16.8	12.86	107.29	
7/1(1991)	582	25.62	22.6	23.00	18.3	15.29	150.14	32.15
Periodic increment		(1988 -1991)			4.3*	8.30	120.61	
Heavy thinning								
4/1(1988)	1087	17.80	17.4	14.60	14.0	16.65	99.07	24.26
Removal	515			14.00	13.6	7.54	42.57	
Remaining	572			14.60	14.2	9.11	56.50	
5/1(1989)	572	19.10	19.4	18.48	17.1	13.16	98.32	27.72
Removal	4			17.12	14.9	0.07	0.49	
Remaining	568			18.48	17.1	13.09	97.83	
6/1(1990)	568	21.81	22.1	20.26	18.6	15.52	127.57	28.05
Removal	12			19.71	17.5	0.29	2.33	
Remaining	556			20.31	18.7	15.23	125.24	
7/1(1991)	556	24.52	23.5	22.88	19.8	17.07	164.24	29.59
Periodic increment		(1988 -1991)			5.5*	8.32	110.56	

Note: * significant at 1% level; (see Appendix 1); N = number of stems ha^{-1};
h_{dom} = dominant stand height; d_{dom} = diameter of dominant trees;
h_g = mean stand height; d_g = mean stand diameter; G = basal area ha^{-1};
V = volume over bark up to 10 *cm* top diameter limit ha^{-1}; MAI = mean annual increment.

In the 3 y period the mean diameter increased by 2.8 *cm* for the control plots, by 4.3 *cm* for the moderate treatment plots and by 5.5 *cm* for the heavy treatment plots.The differences were significant at p = 0.001 for any comparison of diameter increments (Appendix 1). The thinning intervention caused distinct and significant differences in diameter increment.

The periodic increment of basal area and volume depends as with other increments on the stem number per *ha* (N). Therefore, it was to be expected that the annual increment declined with increasing thinning intensity. The periodic volume increment is highest for the control (130.59 m^3) and lowest for the heavy treatment (110.56 m^3).

The mean annual volume increment (MAI_V) increased over the three years in all three treatments. Since the current annual volume increment is still larger than the mean annual increment, the mean annual increment has not yet reached its peak. Based on the standing stock retained, the highest mean annual increment was observed in the control plots and the lowest in the heavy treatments plots.

For the control the MAI_V increased from 30.00 to 35.15 m^3, for moderate treatment from 26.48 to 32.15 m^3, and for the heavy treatment from 24.26 m^3 to 29.59 m^3. It can be expected that the mean annual increment over the whole rotation period will be above 25 m^3 in all three treatments. As a result, a total minimal production of 375 m^3 of overbark volume (up to 10 *cm* top diameter) can be expected.

Development of subpopulations

More important than the growth and yield of the total stand is the growth and yield of the potential final crop trees. Table 2 presents a comparison between yield and increment of the subpopulation of the 300 largest trees ha^{-1} and of the 300 potential final crop trees ha^{-1}(PCT).

Prior to thinning in each plot, an equivalent number of 300 potential crop trees ha^{-1} were selected. The selection criteria were: (i) straight trunk, (ii) no fork, (iii)no visible defects, damages and diseases, (iv) diameter average and above. A subpopulation of 300 largest trees ha^{-1} was selected to obtain an indication of the extent of the loss, in case the largest trees are not simultaneously the potential crop trees. Since large trees are often of relatively bad quality, they will not be included in the potential crop trees. That means that the potential crop trees in the average are smaller in size and have lower increment. Codominants are most likely to be selected. This is what Table 2 shows. Average diameters of the PCT are smaller than the average diameters of the biggest trees. The PCT start smaller in size. Even if the average diameter increments of both subpopulations are about equal, as is the case for the moderate and heavy thinning treatment, the population of the biggest trees will still have a higher average basal area and volume increment. This means that the absolute difference between the average size of the biggest trees and the size of the PCT becomes increasingly larger. This is pronounced in the case of the control plots and less pronounced for the treatment plots.

Table 2. Standing stock for the 300 biggest trees ha^{-1} and 300 potential crop trees ha^{-1} at the beginning and at the end of the observation period

	300 biggest trees ha^{-1}					300 potential crop trees (PCT)				
Age y/m	h_o m	d_o cm	G_o m^2	V_o m^3	% of control	h_s m	d_s cm	G_s m^2	V_s m^3	% of control
Control										
4/1	16.9	17.1	6.92	46.23		16.2	15.6	5.70	37.36	
7/1	24.8	21.0	10.38	110.27		23.5	18.5	8.04	81.30	
p.i	7.9	3.9	3.46	64.04	100	6.7	2.9**	2.34	46.94	100
% of 300 biggest trees ha^{-1}						85	74	68	64	
Moderate										
4/1	16.3	16.3	6.26	40.73		15.6	14.8	5.19	32.54	
7/1	24.8	21.1	10.50	111.22		23.8	19.5	8.97	91.01	
p.i	8.5	4.8	4.24	70.49	110	8.2	4.7**	3.78	58.47	124
% of 300 biggest trees ha^{-1}						96	98	89	83	
Heavy										
4/1	16.0	15.7	5.79	37.26		15.7	15.0	5.28	33.58	
7/1	24.1	21.6	10.98	111.26		23.5	20.6	9.99	99.34	
p.i	8.1	5.9	5.19	74.00	116	7.9	5.6**	4.71	65.76	140
% of 300 biggest trees ha^{-1}						98	95	91	89	

Note: ** = significant at 1% level (see Appendix 2);
h_o, h_s = mean stand height of 300 largest trees and 300 selected trees, respectively ;
d_o, d_s = mean stand diameter of 300 largest trees and 300 selected trees, respectively ;
G_o, G_s = mean basal area of 300 largest trees and 300 selected trees, respectively ;
V_o, V_s = mean overbark volume of 300 largest trees and 300 selected trees, respectively;
p.i = periodic increment.

The periodic volume increment both for the 300 biggest trees ha^{-1} and the 300 PCT ha^{-1} increases with thinning intensity. However, the increase for the PCT is more distinct. The biggest trees occupy the most favourable positions in crown space with relatively little competition from neighbouring trees. Therefore, the removal of competing neighbour trees did not cause such a distinct increment reaction in the 300 largest trees as it caused in the PCT, which is mainly in codominant position as competitors. As a result, the PCT reacted much stronger than the subpopulation of largest trees.

The production goals of the *Acacia mangium* plantations state that the final crop trees shall have achieved an average diameter of 40 - 45 *cm* in 15 years. It is quite clear that even under another thinning regime and with heavy early interventions this aim can never be attained. Raising the rotation age seems to be the only alternative left.

Live crown ratio

Table 3 gives the average crown parameters for the nine plots. The average live crown ratio of the control plots decreased during the observation period from 30.5 to 21.9 %, whereas the live crown ratio of the moderate treatment increased from 27.3 to

31.4% and the heavy treatment from 31.1 to 38.3%. Reduction in crown size in the unthinned control is the result of unrestricted between-tree competition with little growing space left for the crowns. The preferable proportion of crown to be retained is within 30 - 40% (Evans 1982). Reduction in crown size, whether naturally by raising of the green crown level in dense stands or artificially by pruning , causes growth depresssion. Lessening of competition between trees has two main effects on the crown, *i.e.* deeper crowns on remaining trees and lateral expansion of the crown. Only the heavy thinning treatment could provide enough growing space to obtain the desirable live crown ratio. However, ocular assessment of canopy closure during field work in December 1991 indicated that 300 PCT could not probably be retained until the rotation age without sacrificing crown size and with it increment.

Table 3. Crown development of the potential crop trees during the observation period

Plots	Height	Crown length	Crown ratio	Height	Crown length	Crown ratio
	November 1988			November 1991		
	(*m*)	(*m*)	(%)	(*m*)	(*m*)	(%)
Unthinned control						
4	16.5	4.9	29.7	23.38	5.5	23.1
5	16.2	5.5	34.0	23.66	5.3	22.4
6	16.5	4.6	27.9	24.01	4.9	20.2
Mean	16.4	5.0	30.5	23.68	5.2	21.9
Moderate thinning						
1	16.1	4.5	28.1	23.34	6.9	29.6
2	15.5	4.5	29.1	23.18	7.0	30.0
9	15.8	3.9	24.8	24.04	8.3	34.5
Mean	15.8	4.3	27.3	23.52	7.4	31.4
Heavy thinning						
3	16.3	5.5	33.7	23.00	8.5	37.0
7	15.9	4.5	28.3	23.61	9.2	39.0
8	15.7	4.8	31.2	24.04	9.4	39.0
Mean	16.0	4.9	31.1	23.55	9.0	38.3

Conclusions

The first and still preliminary results from this thinning trial show that *Acacia mangium* stands do react to reduction in stand density with distinct increase in diameter increment for the total stand, 300 selected potential crop trees and the 300 largest trees. After thinning trees react with crown expansion. Both increment and crown expansion are distinctly larger for the heavy treatment than for the control and the moderate treatment. It is most unlikely that a diameter increment of 3 *cm* annually can be achieved over the whole rotation age. It is also unlikely that a live crown ratio of about 40% can be retained until rotation age while retaining 300 final crop trees.

The obvious consequences for the *Acacia mangium* tending regimes for sawlog production are : (i) reduction of the number of final crop trees, and (ii) raising of the rotation age.

The tending regimes proposed (Anonymous 1989, Weinland & Ahmad Z. Yahya 1991) have to be revised at this point. A final tending regime can be set up only after the problems of branch formation and pruning (self-pruning or artificial) and of heart-rot have been solved to such an extent that allows for continuation of sawlog production from *Acacia mangium.* Both problem areas are closely linked to the initial stand density and the early growth of *Acacia mangium* stands. In the future, important alterations to the tending regime for *Acacia mangium* have to be made for the initial stand density.

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Appendix 1

Analysis of variance

Diameter increment for stand population with 3 thinning intensities from a complete block experiment with 3 replications

Analysis of variance of diameter increment stand population

Source of variation	Degrees of freedom	Sum of squares	Mean square	Computed F	Tabular F 5%	Tabular F 1%
Replication	2	0.1200	0.0600			
Treatment	2	10. 9666	5.4833	143.918**	6.94	18.0
Error	4	0.1534	0.0381			
Total	8	11.2400				

Coefficient of variation: 4.6%
** - significant at 1% level.

Since the computed F - value of 143. 918 is greater than the tabular F at 1 % level of significance, the difference among the three treatments is highly significant. Hence, the chances are less than 1 in 100 that all observed differences among the three treatment means are due to chance.

Appendix 2

Analysis of variance

Diameter increment for the PCT subpopulation for 3 thinning intensities from a complete block experiment with 3 replications

Analysis of variance of diameter increment of PCT

Source of variation	Degrees of freedom	Sum of squares	Mean square	computed F	Tabular F 5%	Tabular F 1%
Replication	2	0.0213	0.0106			
Treatment	2	0.9258	0.4629	69.089**	6.94	18.0
Error	4	0.0268	0.0067			
Total	8	0.9739				

coefficient of variation : 5.4%
** - significant at 1 % level.

Since the computed F-value of 69.089 is greater than the tabular F at 1 % level of significance, the difference among the three treatments is highly significant. Hence, the chances are less than 1 in 100 that all observed differences among the treatment means are due to chance.