Water Status and Radiation Environment in Rubber (*Hevea brasiliensis*) Systems: A comparison between monoculture and mixed rubber-*Acacia mangium* plots

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ABSTRACT

Interplanting of *Acacia mangium* within *Hevea brasiliensis* plot may be an attractive option for smallholder rubber farmers in the tropics to increase their land productivity. Indeed, economic prospect for timber is good as timber resource in natural forest has become severely depleted and particularly so in Sumatra where this study is conducted.

A. mangium being a very fast growing tree species, careful timing and management of *A. mangium* is probably required to reduce light competition with rubber trees. Furthermore a large portion of rubber planted area in Indonesia is subject to two or more dry months during which rubber may shed its leaves and stops its growth. Competition for water use between trees species in periods of low rainfall may be another constraint to growth of the rubber tree. When soil water is gradually depleted trees can maintain their transpiration rates if they can continue to function at more negative plant water potential. At equal rooting patterns, the trees with the almost negative plant water potential will win the contest for remaining soil water.

This study compares a series of growth and physiological parameters measured on rubber trees grown either in monoculture (6 x 3.3 m and 6 x 2 x 14 m) or associated with *A. mangium* (3 x 3 x 17 m). In the fifth year after plot establishment, variation in the growth of rubber was analyzed in relation to leaf water potential and light interception by canopy. Leaf water potential was used as an indicator of plant water status, but also as indicator of competitive strength. Predawn leaf water potential of rubber trees grown in mixed systems or in monoculture plantation did not significantly different in the beginning of dry season. However, the girth and canopy size of rubber trees grown in mixed systems with *A. mangium* was significantly smaller. Leaf water potential of *A. mangium* was more negative than that of rubber in the mixed system, but not as negative as that in a monoculture of *A. mangium* (where *A. mangium* trees were competing conspecifically rather than with rubber). Better growth of *A. mangium* in the mixture than in monoculture can thus have above as well as belowground explanations. The net effect *of A. mangium* on depressing rubber growth, however, is likely to be primarily caused by shading.

Keywords: intercrop systems, leaf water potential, light intercepted by canopy, tree growth

INTRODUCTION

Currently Indonesia is the second biggest natural rubber producer in the world with 84% of the total production area constituted by smallholder rubber. However, rubber smallholdings tend to have lower productivity and quality than estate plantations. Joshi *et al*. (2002) reported that the productivity of jungle rubber in Jambi was approximately 58% lower than clonal plantation.

Interplanting of *Acacia mangium* within rubber plot may be an attractive option for smallholder rubber farmers in the tropics to increase their land productivity. Indeed, economic prospect for timber is good as timber resource coming from natural forest has become severely depleted and particularly so in Sumatra where this study is conducted.

A. Mangium being a very fast growing tree species, careful timing of planting and spacing arrangement of *A. mangium* is probably required to reduce light and water competition with rubber trees. Furthermore a large portion of rubber planted area in Indonesia is subject to two or more dry months during which rubber may shed its leaves and stop its growth. Competition for water use between trees species in periods of low rainfall may be another constraint to growth of the rubber tree.

When soil water is gradually depleted and light availability is low, trees can maintain their transpiration rates if they can continue to function at more negative plant water potential. Given a certain identical rooting pattern, the trees with the most negative plant water potential will compete more efficiently for the remaining soil water. Martini, 2001 reported that the growth parameters of rubber seedling in pot experiment such as tree diameter, leaf area, tree height indicate significantly smaller subject to soil water deficit. Fewer and smaller stomata were also shown by rubber seedling grown under low water availability. Soil water deficit had significant effects on the leaf water potential and net photosynthesis rate of *Fagus sylvatica* (Leuschner *et al*., 2001). Water deficit at the leaf level can influence carbon gain and growth of trees through reducing of the leaf area of tree because cell extension is highly sensitive to water deficit (Hsiao *et al*., 1976; Boyer, 1988; Winkel T., *et al*., 1993).

Whether an individual tree will be successful in tolerating water stress will depend on a number of adaptation processes. Thus, this study compares a series of growth and physiological parameters measured on rubber trees grown either in monoculture (6 x 3.3 m and 6 x 2 x 14 m) or associated with *A. mangium* (3 x 3 x 17 m) in the fifth year after plot establishment.

MATERIALS AND METHODS

Site characteristics

The study area is in the tropics with mean annual rainfall approximately 2200 mm. Rainfall is distributed with a peak in January - March and a dry season in July – September. The soil fertility status and bulk density after five years of plot establishment did not show any significant difference between the four systems studied. The data presented in Table 1 are average values over the four systems studied. According to Marx, *et al*., 1996 the soil may be characterized as strongly acid soil with low fertility.

The soil texture of the *H. brasiliensis* 6 x 3.3 m treatment (Table 2) shows slightly - albeit significantly - higher sand and lower silt content than other three treatments. However these differences do not affect significantly the bulk density.

Table 1. Soil fertility status and bulk density of the site experiment from depth 0 – 5 cm to 60 – 100 cm.

Soil Depth, cm	pH	C	N	P_{Bray2}	K	Ca	Mg	CEC	Bulk Density[1)]
		%		mg kg^{-1}	me/100 g				g cm^{-3}
0 - 5	4.3	1.48	0.15	7.38	0.13	0.49	0.39	9.22	1.34
5 – 20	4.4	1.11	0.13	5.88	0.12	0.54	0.44	8.43	1.35
20 – 40	4.5	0.69	0.09	5.56	0.07	0.59	0.37	8.98	1.36
40 – 60	4.5	0.52	0.07	5.62	0.11	0.58	0.47	9.29	1.32
60 - 100	4.6	0.39	0.10	6.32	0.08	0.58	0.40	10.46	1.33

1) bulk density estimated using pedotransfer, Woesten, *et al.*, 1998.

Table 2. Soil texture of the site experiment from depth 0 – 5 cm to 60 – 100 cm.

Systems	**Soil Depth, cm**	**Sand**		**Silt**		**Clay**		**Class texture**
		%						
A. mangium 3 x 3 m	0 - 5	46.67		26.67		26.67		Sandy clay loam
	5 – 20	46.00		27.33		26.67		Sandy clay loam
	20 – 40	41.67	**b**	26.67	**b**	31.67	**a**	Clay loam
	40 – 60	39.33		25.33		35.33		Clay loam
	60 - 100	36.67		24.67		38.67		Clay loam
H. brasiliensis monoculture 6 x 3.3 m	0 - 5	54.00		19.67		26.33		Sandy clay loam
	5 – 20	51.00		20.00		29.00		Sandy clay loam
	20 – 40	47.67	**a**	17.00	**a**	35.33	**a**	Sandy clay
	40 – 60	47.67		15.00		38.67		Sandy clay
	60 - 100	40.67		19.33		40.00		Clay
H. brasiliensis monoculture 6 x 2 x 14 m	0 - 5	46.67		26.67		26.67		Sandy clay loam
	5 – 20	43.67		24.00		32.33		Clay loam
	20 – 40	41.67	**b**	26.67	**b**	31.67	**a**	Clay loam
	40 – 60	41.67		21.00		37.33		Clay loam
	60 - 100	38.67		27.67		37.00		Clay loam
H. brasiliensis 6 x 2 x 14 m + *A. mangium* 3 x 3 x 17 m	0 - 5	48.00		29.00		24.00		Loam
	5 – 20	44.67		29.00		26.33		Loam
	20 – 40	44.00	**b**	27.00	**b**	29.00	**a**	Clay loam
	40 – 60	39.00		27.67		33.33		Clay loam
	60 - 100	37.33		25.00		37.67		Clay loam

Value followed by the same letters are not significantly different (P = 0.05).

Experimental plot

The measurement conducted in existing experimental plot. Treatments were spacing and interplanted trees. The treatment combinations were *H. brasiliensis* monoculture 6 x 2 x 14 m, *H. brasiliensis* monoculture 6 x 3.3 m, *H. brasiliensis* 6 x 2 x 14 m + *A. mangium* 3 x 3 x 17 m and *A. mangium* monoculture 3 x 3 m. The experiment was using recommended production clone which is RRIC 100.

Measurement

Tree growth was recorded since 26 month after planting trees every four to six month. In the fifth year after plot establishment, variation on the growth of rubber was analyzed in relation to light intercepted by canopy and leaf water potential.

Starting in the fifth year girth measurement was recorded at 130 cm height bi-monthly using meter tape. An independent series of leaf water potential of tree in each treatment was measured at predawn when leaf and tree water potential are balanced and leaf water potential is at its maximum (Clearly *et al.*, 1998). The leaf water potential was measured every week during the dry season.

The light intercepted by the canopy was calculated by measuring the ratio of PAR simultaneously in an open area and below the canopy. For mixed plot, PAR was also measured above the canopy of *H. brasiliensis* and below the canopy of *A. mangium* since *H. brasiliensis* growth in mixed plot have smaller and shorter canopy. Light interception by canopy and light use efficiency was estimated using the following equation :

$$LightUseEfficiency(LUE), gMJ^{-1} = \frac{\Delta AGB}{R}$$

where AGB : different above ground biomass of two consecutive sampling dates, kg m^{-2}
R : cumulative amount of intercepted light, MJ m^{-2}

$$R = \sum_{day=1}^{day=n} (R_o x R_p)$$

where R_o = light intensity of open area, µmol/m^2/second
and R_p (ratio light interception) = 1 – L_B/L_A

where L_B : light intensity below the canopy, µmol/m^2/second
L_A : light intensity above the canopy, µmol/m^2/second

Others support data such as rainfall was also recorded.

RESULT and DISCUSSION

Tree Growth

Although the soil nutrient status did not show any significant difference between the systems studied, the growth of *A. mangium* under mixed systems with *H. brasiliensis* was significantly greater to monoculture. The growths of *H. brasiliensis* in mixture with *A. mangium* were significantly smaller than in monoculture, while different spacing in monoculture did not affect the growth of *H. brasiliensis* (Figure 1).

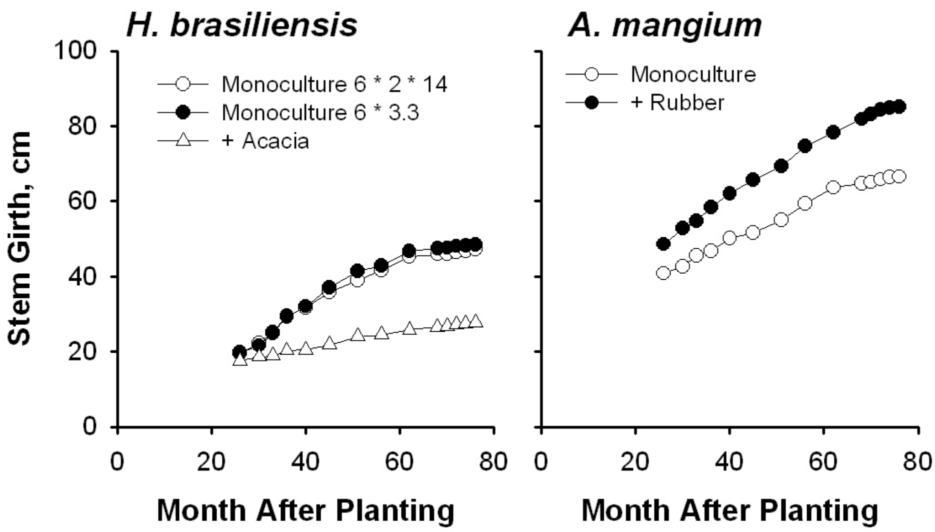

Figure 1. Stem girth, cm of *H. brasiliensis* under monoculture and associated with *A. mangium* since 20 month after planting

Leaf Water Potential

A few rains occurred during the dry season period and leaf water potentials tended to vary accordingly (Figure 2). During wet period the leaf water potential increase and decrease during the dry period. The graph also shows that leaf water potential of *H. brasiliensis* under different systems studied did not show any consistent difference between treatments and remained within the range (- 5.75) – (-1.33) bar. While the leaf water potential of *A. mangium* tended to be more negative in pure plantation within the range (-10.25) – (-5.20) bar than in mixed plantations (-8.17) – (-3.40) bar. This difference is probably related to higher density and correlative higher water demand in *A. mangium* monoculture plot.

Leaf water potential of *A. mangium* was more negative than that of rubber in the mixed system, but not as negative as that in a monoculture of *A. mangium* (where *A. mangium* trees were competing conspecifically rather than with rubber). Better growth of *A. mangium* in the mixture than in monoculture (Figure 1) can thus have above as well as belowground explanations.

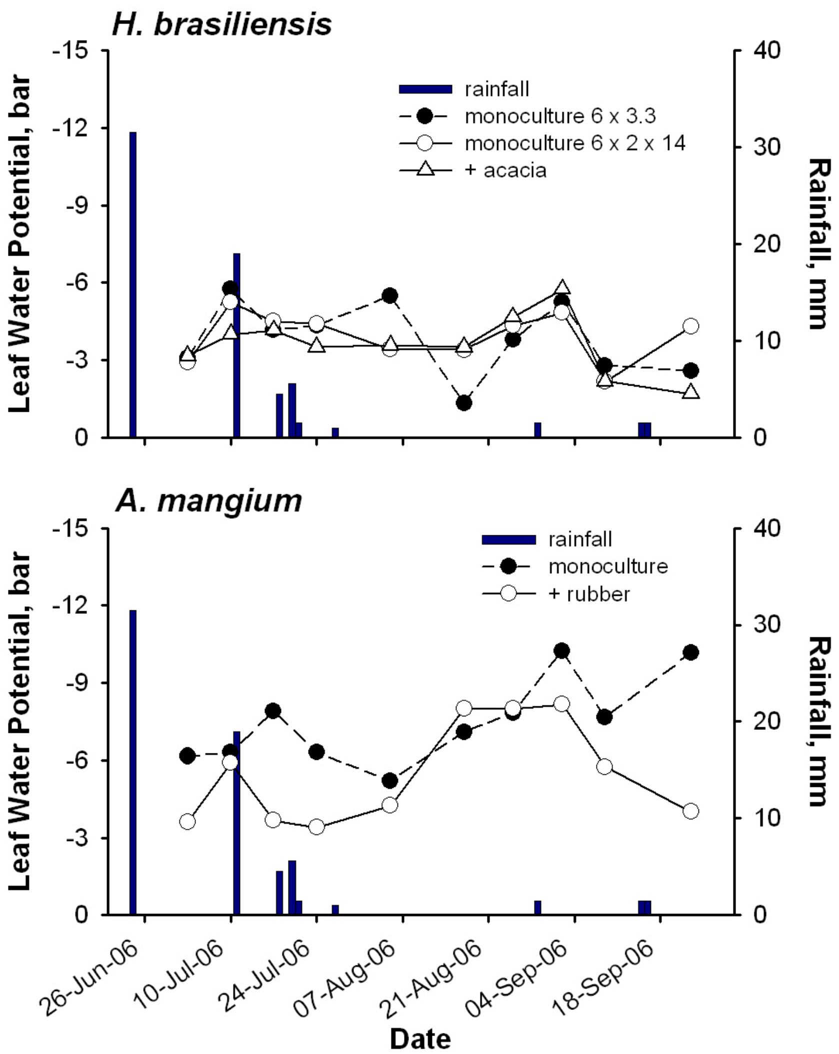

Figure 2. Weekly leaf water potential, bar of H. brasiliensis and A. mangium under monoculture and associated systems.

Light interception and light use efficiency (LUE)

Data used to estimate Light Use Efficiency (LUE) are reported in table 3. It appears that the amount of PAR intercepted by *H. brasiliensis* associated with *A. mangium* is significantly lower than that of *H. brasiliensis* in monoculture. Thus, the net effect of *A. mangium* on depressing rubber growth, however, is likely to be primarily caused by shading.

LUE are consistent with values reported in the literature, e.g. (Landsberg and Hingston 1996, Green et al. 2001). Light use efficiency of *H. brasiliensis* during period between 20 February and 5 July 2006 did not vary significantly between the various treatments and remained in the range 0.17 – 0.31 g MJ^{-1}. *A. mangium* had significantly higher LUE than rubber and LUE was higher in mixed plots (2.11 g MJ-1) than in pure plantation 1.25 g MJ^{-1}.

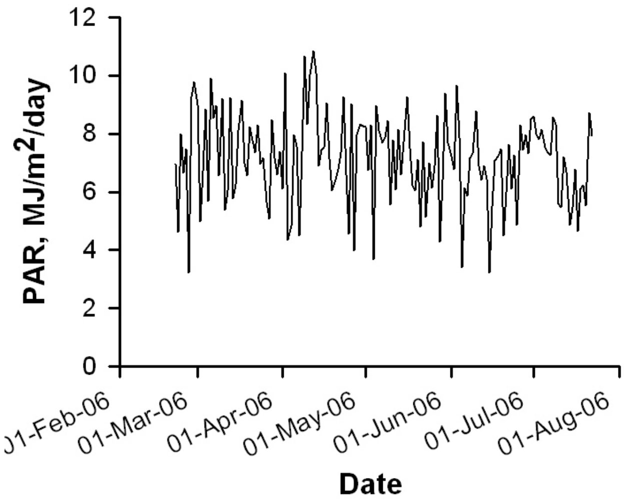

Figure 3. Daily Photosynthetic Active radiation (PAR), MJ/m2/day of open area during period between 20 February and 22 July 2006.

Table 3. Bi-monthly recorded of stem girth, cm, above ground biomass (AGB), kg m^{-2} and light use efficiency (LUE), kg MJ^{-1} during period between 20 February and 5 July 2006 of *H. brasiliensis* and *A. mangium* under monoculture and associated systems

Trees	**Systems**	**Month, 2006 (MAP)**	**Stem Girth, cm**		**AGB*), kg m^{-2}**		**Δ AGB, g m^{-2}**	**∑ PAR, MJ m^{-2}**	**LUE, g MJ^{-1}**
H. brasiliensis	Monoculture 6 x 2x 14	Feb (70)	46.0		5.51				
		Apr (72)	46.5	**a**	5.68	**a**	236.6 **a**	775.6 **a**	0.31 **a**
		July (74)	46.7		5.75				
	Monoculture 6 x 3.3	Feb (70)	47.6		6.12				
		Apr (72)	48.1	**a**	6.30	**a**	217.2 **a**	782.4 **a**	0.26 **a**
		July (74)	48.2		6.34				
	+ *A. mangium*	Feb (70)	26.8		1.23				
		Apr (72)	27.2	**b**	1.28	**b**	91.2 **a**	626.9 **b**	0.17 **a**
		July (74)	27.5		1.32				
A. mangium	Monoculture	Feb (70)	65.0		21.31				
		Apr (72)	65.7	**c**	21.81	**c**	1003.1 **b**	861.2 **c**	1.25 **b**
		July (74)	66.4		22.31				
	+ *H. brasiliensis*	Feb (70)	83.1		36.21				
		Apr (72)	84.2	**d**	37.26	**d**	1714.4 **c**	853.0 **c**	2.11 **c**
		July (74)	84.9		37.93				

*) above ground biomass of *H. brasiliensis* was estimated using $W = 0.002604G^{2.7826}$ (Shorrocks *et al*., 1965) and *A. mangium* using $W = 0.2769D^{2.1585}$ (Hiratsuka *et al*., 2003). G : stem girth, cm and D : stem diameter, cm, W : tree biomass, kg/tree.
Value followed by the same letters are not significantly different (P = 0.05).

CONCLUSION

The monitoring of growth, light interception and leaf water potential during the dry season in various planting systems suggests that that the depressing effect of acacia on rubber in mixed plots is primarily caused by light competition. Careful timing of planting and management such as pruning of acacia is probably required to reduce light competition with rubber trees.

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