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Effect of Fertilization on the Growth and Biomass of *Acacia mangium* and *Eucalyptus hybrid* (*E. grandis* x *E. pellita*)

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ABSTRACT

Effect of fertilization on the growth and biomass of *Acacia mangium* and *Eucalyptus hybrid* (*E. grandis* x *E. pellita*) on third rotation is still not well understood to support judicious application in large scale forest plantations. A field experiment aimed at understanding these questions was conducted in PT. Riau Andalan Pulp and Paper forest concession in Riau during 2011 to 2013. The experiment consisted of 2 trials based on species, each was arranged in a Randomized Completely Block Design with 5 replicates. Treatments for *A. mangium* were zero fertilizer, 23 and 70 kg P ha^{-1} and for *E. hybrid* zero fertilizer, 70 and 210 kg N ha^{-1}. Biomass at 24 months was estimated using allometric equations with diameter at breast height (DBH) as predictor. Significant effects are: increased DBH and stand volume of both species and height of *E. hybrid*. Increased aboveground and root biomass, but decreased root:shoot ratio (R:S) of both species. There was no significant effect of luxury rates of P or N on all parameters in each species. Stem was the biomass component most increased by fertilization resulting in proportional changes in other components except bark. Fertilization increased total leaf area, leaf specific area and stem growth efficiency of both species. Luxury fertilizer rates reduced fertilizer efficiency in both species.

Keywords: *Acacia mangium, Eucalyptus*, fertilization, growth, biomass

INTRODUCTION

Forest plantation establishment outside island of Java Indonesia has started since early 1980s most of which were established for short rotation pulpwood and MDF (medium fiber board). Major species planted are *A. mangium* (860,000 ha), *A. crassicarpa* (245,000 ha), *Eucalyptus pellita* and *E. hybrid* (83,000 ha) as well as *Gmelina arborea* (15.000 ha) and the area keeps on increasing. Increased productivity from these established plantations is very important to meet demand for an increased wood and fiber supply, so strategy to achieve that is through combination of tree improvement, intensive silviculture and improved harvesting techniques (Hardiyanto 2010).

Factors affecting sustained production are genetics of planting stock, long term changes in climatic factors such as rainfall, soil compaction through mechanized operations, weeds and competition for site resources, harvesting and inter-rotational site preparation techniques (O'Hehir and Nambiar 2010). Evans (2000) deeply reviewed sustainable productivity of forest plantations in successive rotations and questionable factors to sustainability are, among others, site quality change caused by forest plantations, organic matter dynamics, risk of pests and diseases due to monoculture and lack of data supporting long range productivity. Concerns about biological sustainability, impact of forest conversion on biodiversity and on local society have also been highlighted by Nambiar and Kallio (2008) as factors that may affect productivity. Without proper management, forest plantation productivity in Indonesia will decrease in long term. Lost nutrients through harvest will be accompanied by soil compaction, erosion and nutrient leaching. The nutrient losses will be greater than nutrient supply through mineral weathering or rainfall inputs (Golani 2006). Across the South East region, *A.mangium* productivity in Sumatra plantations ranged from 22-35 m^3 ha^{-1} yr^{-1} before impacted by fungal diseases. *E. pellita* which started to replace *A. mangium* in Sumatra produced 16-18 m^3 ha^{-1} yr^{-1}. Growth rates were highly variable spatially within estates managed by individual companies for both acacia and eucalypts (Harwood and Nambiar 2014)

Fertilization is one of important factors to increase or maintain plantation productivity in Australia, South Africa, Brazil and Indonesia (Mendham *et al*. 2008; du Toit *et al*. 2010; Stape *et al*. 2010; Hardiyanto and Nambiar 2014). On the other hand, it is not practical to add high rates of fertilizers within a short rotation period without risking off-site impacts, nor is it likely to be feasible or economically sensible under the prevailing conditions. Judicious use of fertilizers has a role in sustainable wood production (Nambiar and Harwood 2014).

So far, response of fast growing forest plantation species such as *A. mangium* and *E. hybrid* to fertilizer application on third rotation mineral soil sites in Riau is not well understood and published data is very little to support judicious fertilization program. Much earlier, Turvey (1995) reported that P application (up to 78 kg P ha^{-1}) increased the growth of *A. mangium* on first rotation ex grassland (Ultisols) site compared to control in South Kalimantan at age 30 months. This result was different from what was reported by both Siregar *et al*. (2008) in Riau and by Hardiyanto and Wicaksono (2008) in South Sumatra where P application (up to 19 kg P ha^{-1} in Riau and 31 kg P ha^{-1} in South Sumatra) did not give any significant effect on yield of *A. mangium* on second rotation forest plantation sites (both Ultisols) at age 5 years compared to zero fertilizer, however, was only significant at early age. Further research by Wicaksono *et al*. (2010) using best genetic material of *A. mangium* showed no response to added P more than 40 kg ha^{-1} in term of volume on second rotation site in South Sumatra. In both Riau and South Sumatra of Indonesia, N and K fertilizers did not significantly affect growth and yield of *A. mangium* leading to omission of N application from the practices in both sites. In South Sumatra, the lack of sustained response to P application (Ultisols) was unexpected because concentrations of extractable P were low and declined with stand age and the growth rates remained high, 45-47 m^3 ha^{-1} yr^{-1}. However, response may be changing in the third rotation when additional P gave significant response at age 3 years (Hardiyanto and Nambiar 2014). Until now, P rate higher than 20 kg ha^{-1} has never been tested in Riau so response of *A. mangium* on third rotation is still not known.

Published data on response of eucalypts to fertilization and additional N application in Riau is very scanty. Reports have indicated various responses of eucalypts to fertilization in Brazil (Goncalves *et al*. 2004; Goncalves *et al*. 2008; Stape *et al*. 2010), in Australia (Smethurst *et al*. 2004; Mendham *et al*. 2008) and in South Africa (du Toit *et al*. 2010). However, responses were varied depending on species and sites. Eucalypts in Brazil and South Africa responded to fertilization when water is available. Stape *et al*. (2010) highlighted that application of very high rates of fertilizers including N beyond current operational rates in Brazil did not show significant effect on eucalypts productivity. Response when N was applied higher than 50 kg ha^{-1} in Brazil or higher than 200 kg ha^{-1} in Tasmania Australia was not significant. Smethurst *et al*. (2004) suggested that split application of N ensured maximum benefit from N application.

The effect of fertilizer application on biomass production of *A. mangium* and *E. hybrid* in Riau is not well understood either. Biomass is influenced by species, specific silviculture such as irrigation (Toky *et al*. 2011), fertilization and water availability (Ares *et al*. 2009). However, in poplar (*Populus deltoides*), for instance, N application increased biomass compared with non-fertilized trees. Fertilizer rates starting from 50 up to 100 kg N ha^{-1} increased biomass but then biomass tended to decrease at rate of 200 kg N ha^{-1}. However, Graciano *et al*. (2006) reported that P applications affected *E. grandis* biomass more than N applications in Argentina. Coleman *et al*. (2004) reported that root biomass tended to increase as the fertilizer rate increased, however, proportion to root biomass tended to decrease with fertilizer application, similarly, a reduced root:shoot ratio in poplar (*P. nigra*) following fertilization (Glynn *et al*. 2003). Therefore, a more thorough study on the effect of fertilization applied on third rotation site in Riau is very important and needs to be conducted.

MATERIALS AND METHODS

Study Site

This study was conducted in PT. Riau Andalan Pulp and Paper (RAPP) forest concession area about 150 km South West of Pekanbaru (Provincial capital of Riau). The site is 100 m above sea level with annual rainfall of 2,500 mm well distributed throughout the year. However, common higher rainfall is during January-May and October-December and lower during of June-September. The site undulates with 16-30% slope. The soil type is Ultisols with soil family Typic kandiudult, coarse loamy texture (Tattan 2004). The experiment was

Table1. Detailed fertilization treatment for *A. mangium* and *E. hybrid.*

Species	Treatments	Element (kg ha^{-1})	Applied Fertilizer (g $plant^{-1}$)	Application Time
A. mangium	0	0	0	
	23	23 P	70 TSP	at planting
		33 K	40 KCl	at planting
	70	70 P	210 TSP	at planting
		33 K	40 KCl	at planting
E. hybrid	0	0	0	
	70	28 N	80 ZA	at planting
		23 P	70 TSP	at planting
		33 K	40 KCl	at planting
		42 N	120 ZA	at 4 months
		33K	40 KCl	at 4 months
	210	28 N	80 ZA	at planting
		23 P	70 TSP	at planting
		33 K	40 KCl	at planting
		42 N	120 ZA	at 4 months
		33 K	40 KCl	at 4 months
		70 N	200 ZA	at 8 months
		70 N	200 ZA	at 12 months

initiated in June 2011 after felling the second rotation plantation with establishment of the experimental stand as third rotation.

Experimental Set Up

This study were comprised of 2 experiments, one each for *A. mangium* and *E. hybrid*. The experimental plants were planted manually and fertilized according to the treatment arrangement. Spacing was 3 m × 2 m (1;667 trees ha^{-1}) with treatment plot size 12 × 13 trees and 72 inner trees were assessed. The *A. mangium* plants were selected family and *E. hybrid* plants were clonal material both propagated as rooted cuttings. Treatments of each experiment were arranged as Randomized Complete Block with 5 replicates. Treatments tested are described in Table 1.

Fertilizers used were (1) Triple Super Phosphate (TSP; 46% P_2O_5, 20% P), (2) Ammonium Sulfate (ZA; 21% N), and (3) Potassium Chloride (KCl; 60% K_2O, 50% K). Soil in each planting point, 20 × 20 × 20 cm, was manually cultivated using planting spade. Planting and treatment application were completed in June 2011.

Measurement and Data Calculation

Stem height (to the crown tip) and diameter at breast height (DBH) were measured every 6 months to 24 months. Individual tree stem volume was calculated using formula:

For *A. mangium* (Lim 1993):

$$V= 0.0396*D^{1.6536} *H^{1.2432}$$

For *Eucalyptus* (Pillsbury *et al*. 1989):

$$V= 0.0000181*D^{1.93943}*H^{1.12009}$$

where V= tree stem volume (in m^3); D = diameter at 130 cm from the ground, and H = height to the crown tip. Stand volume is the sum of individual tree volume per plot converted to hectare basis.

Individual tree aboveground live biomass (kg $tree^{-1}$) was estimated at 24 months using local allometric equations using DBH as predictor for *A. mangium* (Siregar 2012) and *Eucalyptus* (Siregar and Sunarto 2012), are as follow:

***A.mangium*:**

Stem = $0.008(DBH)^{3.278}$ (R^2= 0.94)
Bark = $0.002 (DBH)^{2.830}$ (R^2= 0.92)
Branches = $0.026(DBH)^{2.109}$ (R^2= 0.79)
Leaf = $0.342 (DBH)^{1.518}$ (R^2= 0.71)

***Eucalyptus*:**

Stem = $0.075(DBH)^{2.534}$ (R^2 = 0.93)
Bark = $0.014(DBH)^{2.396}$ (R^2 = 0.98)
Branches = $0.052 (DBH)^{1.964}$ (R^2 = 0.73)
Leaf = $0.024(DBH)^{1.944}$ (R^2 = 0.75)

where DBH is diameter at 130 cm from the ground. For root biomass estimation, the allometric equation used for both *A. magium* and *E. hybrid* was (Cairns *et al*. 1997):

$$\text{Root Biomass} = \mathbf{e}^{\{-1.0850 + 0.9256 * \text{Ln (aboveground biomass)}\}}$$

Where **e** is natural number of 2.718.

Leaf weight and leaf specific area of young fully developed leaves were estimated by collecting 2 young fully developed leaves at mid crown from 5 assigned trees from each plot (10 leaves plot^{-1}) based on DBH distribution within plots. Leaf weight was determined based on oven dry weight (70 ^{o}C for 24 hours) and weighed to the nearest three decimals using a digital balance. Individual leaf area was measured by projecting fresh leaf boundary of each sampled leaf onto a millimeter block paper. Individual leaf specific area was calculated as leaf area divided by leaf weight (cm^{2} g^{-1}). Total tree leaf area is estimated by multiplying the total tree leaf biomass with leaf specific area.

Data Analysis

Effects of treatments on parameters were analysed in Analysis of Variance at 95% confidence level. Further mean comparisons were carried out using Least Significance Difference test at 95% confidence level to see difference between treatments.

RESULTS AND DISCUSSION

Effect of P Fertilizer on *A. mangium*

Fertilization did not affect survival of *A. mangium* until 24 months. Survival of *A. mangium* was 79.2%, 75.0%, and 82.5% respectively for zero fertilizer, 23 and 70 kg P ha^{-1}. There was no

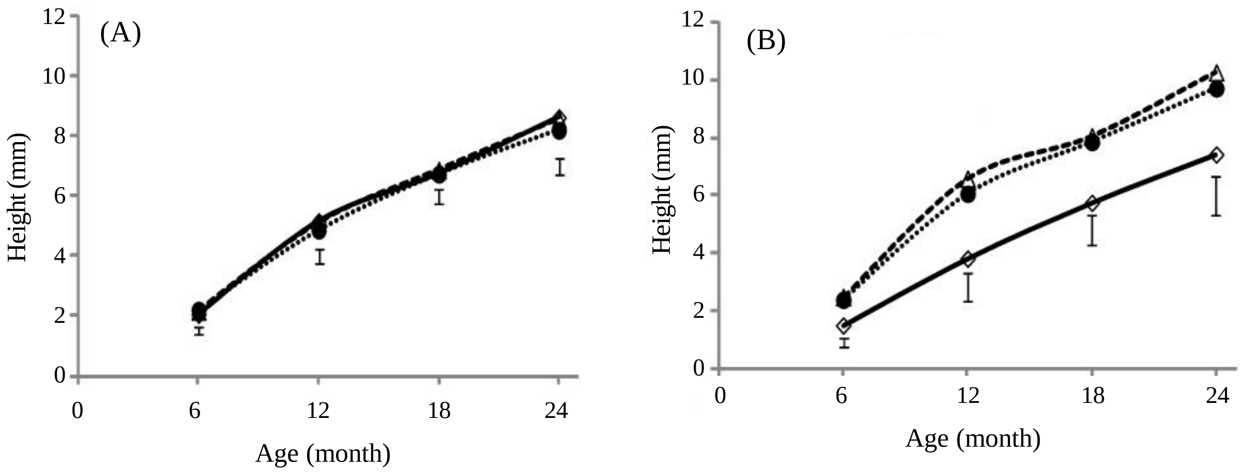

Figure 1. Height of *A. mangium* (A) and *E. hybrid* (B) affected by fertilization. Vertical bars in the graphs are LSD$_{(0.05)}$. (A) —: zero fertilizer, ···: 23 kg P ha^{-1}, - - -: 70 kg P ha^{-1}. (B) —: zero fertilizer, ···: 70 kg N ha^{-1}, - - -: 210 kg N ha^{-1}.

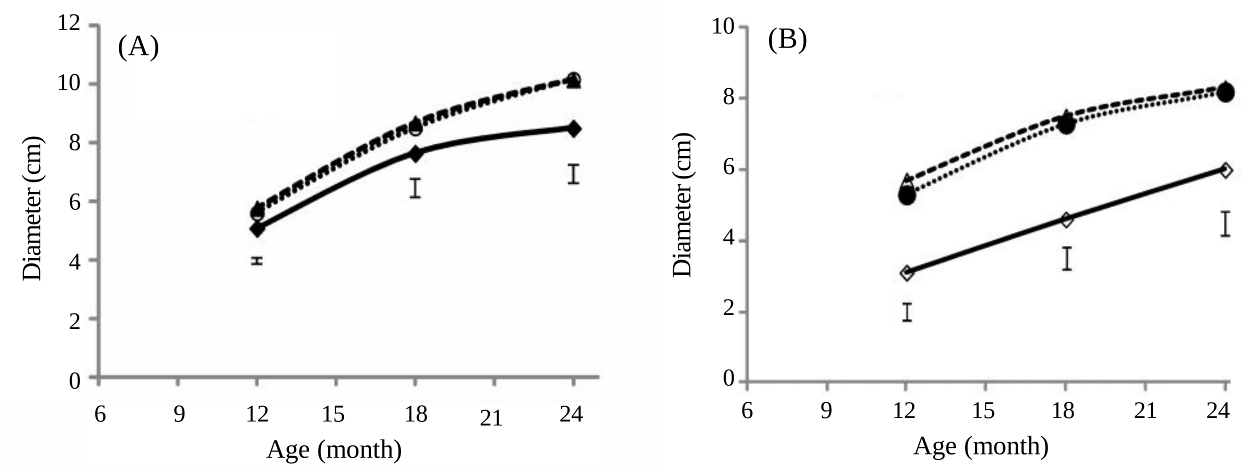

Figure 2. Effect of fertilization on diameter of *A. mangium* (A) and *E. hybrid* (B). Vertical bars in the graphs are LSD$_{(0.05)}$. (A) —: zero fertilizer, ···: 23 kg P ha^{-1}, - - -: 70 kg P ha^{-1}. (B) —: zero fertilizer, ···: 70 kg N ha^{-1}, - - -: 210 kg N ha^{-1}.

significant effect of treatments on height of *A. mangium* at 24 months (Figure 1A).

DBH of *A. mangium* was significantly increased by fertilization but there is no significant difference between 23 and 70 kg P ha^{-1}. *A. mangium* DBH was increased by 20% following fertilization (Figure 2A).

Fertilizer application significantly increased stand volume of *A. mangium* but no effect of luxury P rate on volume (Figure 3A). Fertilizer application increased volume of *A. mangium* by 37- 47% at 24 months. Increased rate of P fertilizers reduced P agronomic efficiency (ratio between additional volume gain to kg of fertilizer applied) in both species (Table2).

Fertilizer application significantly increased total aboveground and root biomass of *A. mangium* at 24 months (Table 3). All aboveground biomass components were significantly increased by fertilization, however, increased rates of P had no significant effect on biomass.

Root biomass of *A. mangium* was significantly increased by fertilizer application but no significant effect of higher P rate. Increased aboveground biomass following fertilization resulted in a significant reduction of root:shoot ratio (R:S) (Table 4). Effect of fertilizer application on leaf characteristics of *A. mangium* is shown in Table 5. Based on these results, it is estimated that *A. mangium* had a total leaf area of 22,000 - 32,000 m^2 ha^{-1} equivalent to estimated leaf area index of 2.2 to 3.2 at 24 months.

Effect of N Fertilizer on *E. hybrid*

Fertilization did not affect *E. hybrid* survival significantly until 24 months. Survival of *E. hybrid* was 96.4%, 92.5%, and 91.1% respectively for zero fertilizer, 70, and 210 kg N ha^{-1}.

Fertilization increased height of *E. hybrid* significantly compared to zero fertilizer (Figure 1B), however, there is no significant difference between treatments 70 and 210 kg N ha^{-1}. Fertilizer application increased *E. hybrid* height by 31-39% compared to zero fertilizer at 24 months. DBH of *E. hybrid* was significantly increased by fertilization but there is no significant difference between 70 and 210 kg N ha^{-1} (Figure 2B). *E. hybrid* DBH was increased by 36-38% compared to zero fertilizer respectively at 24 months after planting.

Fertilizer application significantly increased stand volume of *E. hybrid* but no significant effect of luxury N rate on volume at 24 months (Figure 3B). Fertilizer application increased volume of *E. hybrid* by 150-160% compared to zero fertilizer. Increased rate of N fertilizers reduced N agronomic efficiency (ratio between additional volume gain to kg of fertilizer applied) in both species (Table2).

Fertilizer application significantly increased total aboveground and root biomass of *E. hybrid* at 24 months (Table 3). All aboveground biomass components were significantly increased by fertilization, however, increased rates of N had no significant effect on biomass. Root biomass was significantly increased by fertilizer application but no significant effect of luxury N rate. Despite increased biomass, root:shoot ratio (R:S) was significantly reduced by fertilizer application (Table 4).

Fertilization only increased leaf area of *E. hybrid* significantly. There was no significant effect of fertilizer on individual leaf weight, however, fertilizer application increased leaf specific area

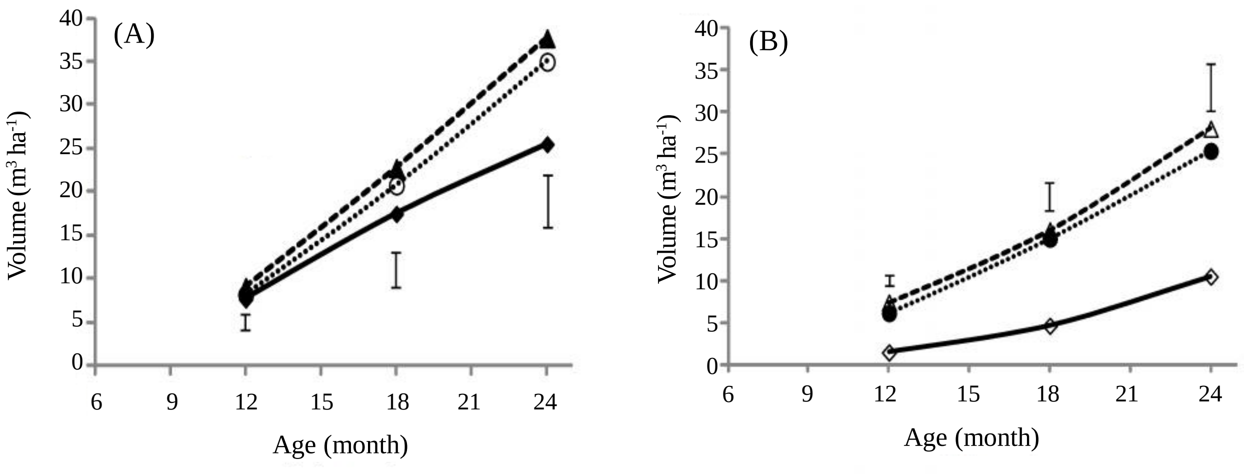

Figure 3. Effect of fertilization on stand volume of *A. mangium* (A) and *E. hybrid* (B). Vertical bars in the graphs are LSD$_{(0.05)}$. (A) —♦—: zero fertilizer, ···○···: 23 kg P ha^{-1}, - -▲- -: 70 kg P ha^{-1}. (B) —♦—: zero fertilizer, ···○···: 70 kg N ha^{-1}, - -▲- -: 210 kg N ha^{-1}.

Table 2. Fertilizer efficiency in *A. mangium* and *E. hybrid.*

Species	Treatments (kg ha^{-1})	Volume (m^3 ha^{-1})	Volume increase (m^3 ha^{-1})	Fertilizer Agronomic Efficiency (m^3 kg^{-1} fertilizer)
A. mangium	0	25.5	0	0
	23 P	35.0	9.5	0.41
	70 P	37.7	12.7	0.18
E. hybrid	0	10.5	0	0
	70 N	25.4	14.9	0.21
	210 N	28.1	17.6	0.08

Table 3. Effect of fertilization on biomass of *A. mangium* and *E. hybrid* at 24 months.

Species	Treatments (kg ha^{-1})	Stand Biomass (Mg ha^{-1})				
		Stem	Bark	Branch	Leaf	Total Above ground
A. mangium	0	13.7 (68) a	1.3 (6) a	3.2 (16) a	2.1 (10) a	20.3 a
	23 P	22.9 (72) b	1.9 (6) b	4. 5 (14) b	2.5 (8) ab	31.8 b
	70 P	26.6 (72) b	2.2 (6) b	5.1 (14) b	2.8 (8) b	36.8 b
E. hybrid	0	13.6 (67) a	1.9 (9) a	3.2 (16) a	1.4 (9) a	20.2 a
	70 N	28.0 (70) b	3.8 (10) b	5.4 (14) b	2.4 (6) b	39.7 b
	210 N	29.3 (71) b	4.0 (10) b	5.6 (13) b	2.5 (6) b	41.5 b

Value in brackets are percentage to the total aboveground. Value in the same column within species followed by the same letters are not significantly different at LSD(0.05).

Table 4. Biomass and R:S of *A. mangium* and *E. hybrid* at 24 months.

Species	Treatments (kg ha^{-1})	Biomass (Mg ha^{-1})		R:S
		Above ground	Roots	
A. mangium	0	20.3 a	5.5 a	0.27 a
	23 P	31.8 b	8.3 b	0.26 b
	70 P	36.8 b	9.6 b	0.26 b
E. hybrid	0	20.2 a	5.6 a	0.28 a
	70 N	39.7 b	10.4 b	0.26 b
	210 N	41.5 b	10.9 b	0.26 b

Value in the same column within species followed by the same letters are not significantly different at LSD(0.05).

significantly in both species (Table 5). At 24 months, *E. hybrid* had a total leaf area of 16,000 – 39,000 m^2 ha^{-1} which is equivalent to estimated leaf area index of 1.6 to 3.9.

DISCUSSION

Growth

Lack of response to higher P application may be due to less P availability in the soil. In Loblolly pines, for example, lack of response was because P was not absorbed by trees and remained in the soil in labile form or leached in lateral flow in the soil making it unavailable to trees (Scott and Bliss 2012) or caused by P fixation by clay mineral and Al/Fe oxide complexes in the soil (Shen *et al*. 2011) or both. Oxisols soil with kaolinitic mineral in Jambi Sumatra, for example, potentially can fix as much as 2,200 mg P kg^{-1} soil within 0-5 cm layer and 1,900 mg P kg^{-1} soil in 5-15 cm layer (Ketterings *et*

Table 5. Leaf characteristics of *A. mangium* and *E. hybrid* in relation to fertilization

Species	Treatments (kg ha^{-1})	Individual Leaf Weight (g)	Individual Leaf Area (cm^2)	Specific Leaf Area (cm^2 g^{-1})
A. mangium	0	0.872 a	92.3 a	107.3 a
	23 P	0.856 a	94.2 a	113.3 b
	70 P	0.811 a	90.6 a	114.8 b
E. hybrid	0	0.41 a	42.6 a	117.3 a
	70 N	0.36 a	48.8 b	162.2 b
	210 N	0.40 a	53.0 b	156.3 b

Value in the same column within species followed by the same letters are not significantly different at LSD(0.05).

al. 2002). So, even applying 210 g of TSP mixed with soil at planting point of *A. mangium* may still have low P availability due to fixation although the amount fixed in Ultisols may be different. On the other hand, eucalypts lack of response to N fertilization because natural sources of N, mainly mineralization of organic matter, were enough to meet plant demand (Goncalves *et al*. 2004).

In this study, P fertilizer application in planting hole of *A. mangium* or applying N in slits near the *E. hybrid* did not affect the soil extractable P or total N concentration significantly at plot level (0-10 cm layer) despite changes in all treatments with time when subsequently sampled until 24 months after planting (data not presented). This condition was different from what was reported by Nurjaya and Nursyamsi (2013) where incorporation of rock phosphate into the soil (Inceptisols) in Lampung increased soil P status after maize harvesting based on a much smaller plot size. Localized P fertilizer application ensures P is available near the roots to be easily taken up when plants start to grow actively. After plant establishment, not all plant nutrient requirements are met by the applied fertilizer but rather from other parts of the soil much beyond the planting holes and partly from the nutrient re-translocation within plant itself. Lack of response to luxury N application in *E. hybrid* may be attributed to high soil N content on site (on average 2,200 – 2,500 kg N ha^{-1} within 0-10 cm soil layer). At average, retained harvest slash on this study site was 54 Mg ha^{-1} (including bark, wood, branches and litter) which contained around 255 kg N ha^{-1}. Siregar *et al*. (2008) reported that N influx through litter fall in *A. mangium* stand in Riau was 72 kg N ha^{-1} yr^{-1}. This organic N will be slowly available to plants through decomposition process. And yet, important questions remain: Can liming help reduce P requirement in *A. mangium* in more advanced rotation? If not responding to N application, what is the role of P and K in *E. hybrid*? Do these nutrients need to be much increased in application rate before *E. hybrid* start to give significant response?

Biomass

Although fertilization increased all biomass components, it changed the proportion (allocation) among the aboveground biomass components in each species. Fertilization only increased proportion of stem biomass but reduced proportion of branches and leaf in both species. An increase of 4% stem biomass proportion in *A. mangium* resulted in a reduction of 2% biomass proportion of branches or leaf while proportion of bark did not change regardless treatments. Similarly, an increase of 4% in stem biomass proportion of *E. hybrid* by fertilizer application was followed by a 2-3% reduction in branches or leaf proportion, however, *E. hybrid* bark biomass proportion increased by 1% due to fertilizer application. An increase in 4% stem biomass proportion corresponded with 67-95% and 106-15% increase in stem biomass of *A. mangium* and *E. hybrid* respectively. Results from this study conformed with other studies stating that each biomass component closely correlated with tree size, which in this case was represented by tree diameter (du Toit 2008; Henry *et al*. 2011). However, when aboveground growth especially stem height and diameter and biomass of fertilized trees were significantly increased by fertilizer application, unfertilized trees allocate resource preferentially more towards roots, as well as branches and leaf.

Other trees such as poplar, cottonwood and sycamore had reduced proportion of biomass to roots although root biomass in total increased following fertilization (Coleman *et al*. 2004; Coyle and Coleman 2005). Different results have been reported by Eyles *et al*. (2009), biomass allocation to roots was not affected by fertilization but rather by other biotic factors such as defoliation. Therefore, results in this study conformed with biomass equilibrium principle that plant responded to limited underground resources by allocating biomass to roots and allocating biomass to the aboveground parts when aboveground resources are limited (Poorter and Nagel 2000; Poorter *et al*. 2012).

Increased leaf specific area of both species due to fertilization in this study was similar with of *E. globulus* where leaf specific area increased following N fertilization (up to 250 kg N ha^{-1}) in Western Australia, although significant only in one of four sites tested (White *et al*. 2010). We also estimated the stem growth efficiency of both species by comparing the total stem wood biomass over the total leaf biomass. Stem growth efficiency of *A. mangium* was 6.5, 9.2, and 9.5 Mg wood Mg^{-1} leaf for zero fertilizer, 23 and 70 kg P ha^{-1} at 24 months respectively, while *E. hybrid* had stem growth efficiency of 9.7, 11.6 and 11.7 Mg wood Mg^{-1} leaf respectively for zero fertilizer, 70 and 210 kg N ha^{-1}. Both species showed an increased stem growth efficiency following fertilization, however, *E. hybrid* seemed to be more efficient than *A. mangium* in term of wood production despite having lower stem biomass at the same age. This may be strongly attributed to its higher leaf specific area and leaf area index compared to *A. mangium.*

CONCLUSIONS

Fertilization is still important to sustain forest plantation productivity in third rotation in Riau. Fertilizer rate of 23 kg P ha^{-1} together with basal fertilizer 33 kg K ha^{-1} for *A. mangium* and 70 kg N ha^{-1} along with basal fertilizers 23 kg P ha^{-1} and 66 kg K ha^{-1} for *E. hybrid* are adequate to give sufficient growth and biomass production. Increased fertilizer rates reduced fertilizer efficiency in both species therefore there is no evidence, so far, to justify higher rates of fertilizer application. Fertilization is also important to increase stem biomass as the main forest product since both *A. mangium* and *E. hybrid* stem responded well to fertilization, however, so far *E. hybrid* was more efficient in term of stem growth than *A. mangium*.

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