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ARTICLE

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Nutrient management of contrasting *Acacia mangium* genotypes and weed management strategies in South Sumatra, Indonesia

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ABSTRACT

Tropical plantations are an important source of forest products both to meet the growing demand for wood, and to facilitate the transition from native forests to more sustainably produced forest resources. Management of these plantations for optimal productivity and resource-use efficiency is vitally important, and nutrient management is a critical component of sustainable plantation production. In this study, we explored the response of *Acacia mangium* plantations in South Sumatra, Indonesia, to fertiliser and their requirement for fertiliser, focusing on phosphorus (P) at establishment. Almost all plantations across a series of 11 sites were highly responsive to P fertiliser, with nine of the 11 sites having more than double the productivity in P-fertilised treatments at age 1 year compared with control treatments. However, the quantity of P required for 90% of maximum growth was generally low by age 2 or 3 years, and 10 kg P ha^{-1} at establishment was sufficient to ensure that at least 90% of maximum growth was captured across all the experimental sites. At a 12th site, we explored the interactions between genotype and weed control, and found that both effects were additive in the response of the plantations to P, and thus there was no substitutability between management types: weed control, genotype and P needed to be managed in combination to achieve maximum productivity.

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Tropical plantations; phosphorus management; productivity

Introduction

Nutrients are often a significant limiting resource for plantation growth, and nutrient deficiency is most likely to manifest early in the rotation when the trees are building canopy (Miller 1995). The macronutrients nitrogen (N), phosphorus (P) and potassium (K) are the key limiting nutrients in many environments because, relative to available soil pools, they are often taken up in large quantities in biomass (Sankaran et al. 2005). Acacias, in partnership with *Bradyrhizobium* species, fix atmospheric nitrogen (Wibisono et al. 2015), and so do not generally respond to applied N fertiliser (Hardiyanto & Wicaksono 2008). However, P is a key nutrient for acacias, and studies have found significant responses to P fertiliser. For example, Scowcroft and Silva (2005) found increasing responses of *Acacia koa* up to an application of 1400 kg P ha^{-1} in Hawaii, but responses varied across sites. In Indonesia, Turvey (1996) found significant responses of *A. mangium* to 26–78 kg P ha^{-1} up to 30 months of age in South Kalimantan, while at age 4 years in South Sumatra the response to P fertiliser was small and non-significant (Hardiyanto & Wicaksono 2008).

Extractable soil P can decline over the course of an *Acacia* rotation. For example, in South Vietnam under an *A. auriculiformis* plantation, extractable P declined from around 12 kg ha^{-1} at planting to around 7 kg ha^{-1} from about age 3 years (Huong et al. 2015), and in South Sumatra under second-rotation *A. mangium*, extractable P declined from around 3.2 mg kg^{-1} soil to 1.7 mg kg^{-1} soil between planting and age 7 years (Hardiyanto & Nambiar 2014), suggesting that P management may become more important over multiple rotations of acacias.

The range of reported responses to P, the apparent decline in P availability over time, and the limited number of studies on P fertiliser responses in *A. mangium* reported to date, suggested that there was opportunity to improve the P fertiliser management and productivity of acacia plantations. The aim would be to ensure that plantations would not be limited by P, and conversely that P was not being applied in excess. This latter point is especially important for smallholder farmers, given the rising cost of inputs and their minimal capacity to pay for inputs that have a long payback time.

Tree improvement programs lead to variation in the productivity potential of the genetic material deployed (Harwood et al. 2015). For example, Wibisono et al. (2015) showed that slower field-grown *A. mangium* provenances tended to rely more on P fertiliser inputs for stimulating fixation of atmospheric N compared with better performing provenances. Vadez and Drevon (2001) found similar results in a controlled glasshouse environment for four different *A. mangium* provenances from Papua New Guinea. Thus, it appears that nutrient management strategies might benefit from such knowledge, and from understanding how productivity potential interacts with the capacity of the plant material to fix atmospheric N.

A second potentially interacting factor in the response of acacias to P fertiliser is weed control (e.g. Woods et al. 1992). Experiments are normally conducted under conditions of complete weed control. However, one of the indirect benefits of P fertiliser may be early occupation of the site, so that the trees suppress weeds. Equally, for smallholder-farmers, it is conceivable that the cost of weed control may be lower

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than that of fertiliser, so it may be possible to reduce P fertiliser application but maintain productivity through rigorous weed control in some circumstances.

Indonesia has established substantial areas of short-rotation plantations, typically producing timber on 4–6 year rotations. These plantations are necessary to provide a sustainable supply of timber to several large industrial pulp-mills that have been constructed in recent decades, mainly in Sumatra. Harwood and Nambiar (2014) reported that there were around 1.2 M ha of *Acacia* plantations in Indonesia, mainly *A. mangium* on mineral soils and *A. crassicarpa* on peat. Plantation forestry has been recognised as an important contributor to regional development in Indonesia, which has resulted in a plan by the Government of Indonesia to increase the plantation area managed by communities to 5.5 M ha by 2019 (Jong 2015). It is recognised that there are both benefits and drawbacks to expanding the areas of short-rotation plantations (Cossalter & Pye-Smith 2003), but it is also clear that the benefits are increased through ensuring that plantations established on any given area of land are as productive and sustainable as possible (Nambiar 1999).

To explore the response to P fertiliser and be able to make recommendations to growers, it is necessary to establish a number of sites with a range of potential responses to P. For example, Mendham et al. (2002) derived a diagnostic of P availability for *Eucalyptus nitens* and *E. globulus* plantations in southern Australia by utilising 24 different experimental sites with a range of soil characteristics. This study therefore tested whether: (1) P is the main nutrient that needs to be managed in an *A. mangium* plantation system; (2) response to P varies across different provenances of *A. mangium*; (3) response to P can be predicted, and thus managed, across different site types; and (4) there is an interaction between P fertiliser and weed control in *A. mangium* plantations. We tested these hypotheses at a range of sites in South Sumatra, Indonesia.

Materials and methods

Study sites

We established a total of 12 experimental sites to examine (1) interactions between genotype and response to P fertiliser (the G × P series); (2) responses to P fertiliser across a broader range of sites (the P response series); and (3) interactions between P fertiliser and weed control (the P × weed control response experiment) (Table 1). The sites were all within an area of approximately 35 × 35 km in the PT Musi Hutan Persada concession in South Sumatra, and were serviced from the Subanjeriji field headquarters located at approximately 3.8°S, 104.0°E. They were all at a similar elevation, around 100 m asl, exposed to similar climatic conditions, received around 3000 mm annual rainfall, and experienced a dry season from about June to September. The sites were chosen to represent a range of productive potential, based on the measured productivity of the previous first or second rotations of *A. mangium*. The previous vegetation at all the sites was grassland dominated by *Imperata cylindrica*.

Experimental design

All experiments were established in a randomised block design, with either four (G × P series), or three (P response series) replicates. The G × P series had a factorial combination of genotype by P application rate treatments (Table 2), the P response series had a range of P application rate treatments, and the P × weed control experiment had a factorial combination of P application rate and weed control treatments. The experiments were kept weed-free by regular glyphosate application in all experiments, except for the 'manual' weed control treatment of the P × weed control experiment in which weeds were controlled by manual cutting. Basal fertiliser—with rates per ha of 46 kg N, 42 kg K, 28 kg Ca, 2.4 kg Mg, 0.8 kg Zn, 1.5 kg S, 0.04 kg Mo, 1.9 kg Mn, 13 kg Fe, 0.8 kg Cu and 0.08 kg B—was applied to all treatments except for the X100 treatment (Table 2). Response to nutrients other than P was tested using the basal complete fertiliser at the P100 rate at the three sites in the G × P experimental series. P was applied as triple superphosphate fertiliser in all cases.

Treated plots were square, consisting of 6 rows × 6 trees at 3 × 3 m spacing. The outer trees in each plot were used as a buffer; growth was assessed on the inner 16 trees of each plot.

Productivity assessment

Height and diameter of each tree in the 16-tree plots were measured at intervals between 6 months and 3 years after

Table 1. Experimental sites used in this study. Sites are grouped into three series: genotype by phosphorus response (G x P), phosphorus response (P response), and phosphorus by weed response (P x weed response)

Site	Rotation	Surface soil texture	Soil C (%, 0–10 cm)	Bray P (mg kg^{-1}, 0–10 cm)	Establishment date	Standing volume measured at age (year)
G x P experiments						
Sodong	3rd	Clay	2.89	3.84	Apr 07	0.5, 1
Lematang	2nd	Silty clay loam	1.87	4.09	Feb 08	0.5, 1, 2, 3, 4
Gemawang	3rd	Silty clay loam	1.82	5.41	Feb 08	0.5, 1, 2, 3, 4
P response experiments						
Keruh 57	3rd	Sandy clay loam	2.17	7.91	Jan 08	0.5, 1, 2
Lagan 115	2nd	Silty clay loam	1.47	4.77	Feb 08	0.5, 1, 2
Lagan 113	2nd	Sandy clay loam	2.34	4.35	Feb 08	0.5, 1, 2
Niru 75	3rd	Silty clay loam	4.64	10.52	Feb 07	0.5, 1, 2, 3
Niru 79	3rd	Silty clay loam	1.08	12.86	Feb 07	0.5, 1, 2, 3
Niru 232	3rd	Silt loam	4.21	11.01	Feb 07	0.5, 1, 2, 3
Subanjeriji 119	3rd	Silty clay loam	2.7	8.00	Feb 07	0.5, 1, 2, 3
Banding Anyar 2	3rd	Silty clay	3.36	9.25	Feb 07	0.5, 1, 2, 3
P x weed control response experiment						
Niru 249	3rd	n/a	n/a	n/a	Apr 09	1

n/a – not applicable

Table 2. Treatments used in this study

Factor/treatment	Experimental series	Description
Genotype		
Subanjeriji landrace	G × P	Unimproved seed from Subanjeriji landrace
Subanjeriji improved	G × P	Selected seed from Subanjeriji landrace
Wipim Oriomo (PNG)	G × P	Seed from superior natural provenance
Selected seed orchard	G × P	Seed from first generation seedling seed orchard
P application rate		
P0	G × P, P response	No P applied, with basal fertilizer
P10	G × P, P response	10 kg ha^{-1} P applied at planting, with basal fertilizer
P20	P response	20 kg ha^{-1} P applied at planting, with basal fertilizer
P100	G × P, P response	100 kg ha^{-1} P applied at planting, with basal fertilizer
X100	G × P (2 sites)	100 kg ha^{-1} P applied at planting
Weed control		
Good	P × weed	Control with glyphosate 3 times/year
Poor	P × weed	Manual weed control through slashing

establishment (Table 1). The Sodong site was compromised by root rot after age 1 year, and so was not measured beyond age 1 year. Tree volume was calculated using the conical volume method (Rance et al. 2012), which was validated for *A. mangium* using a subset of felled trees (Hardiyanto and Nambiar 2014). Standing volume was calculated on an area basis (m^3 ha^{-1}) using the aggregate volume of the trees in each plot.

P response assessment

To assess the response to P fertiliser, an exponential model of the form shown in Equation (1) was fitted to the data for each site at each measurement time, where *y* was the standing volume (m^3 ha^{-1}), *x* was the rate of P fertiliser applied (kg ha^{-1}), and *a, b* and *c* were fitted parameters; *a* was the asymptote (i.e. the non-P-limited standing volume in m^3 ha^{-1}).

$$y = a + bc^x \quad (1)$$

Volume response to P fertiliser (m^3 ha^{-1}) was assessed as the difference between the non-P-limited standing volume, *a*, and the productivity of the non-P-fertilised treatments assessed from Equation (1) as the value of *y* at *x* = 0 (equivalent to *a* + *b*); which simplifies to − *b*. A proportional response was also calculated as the fertilised standing volume relative to the non-P-fertilised standing volume (calculated as above), using Equation (2).

$$\text{Proportional response to P fertiliser} = -b/(a+b) \quad (2)$$

The P fertiliser requirement (kg P ha^{-1}) was calculated as the value of *x* where *y* was equal to 90% of *a* (i.e. 90% of maximum yield).

Soil sampling and analysis

Soil properties at each site were assessed at the beginning of the study. Samples from the 0–10, and 10–20 cm depth ranges were taken from ten cores per site. The samples from each depth range were bulked together from the ten cores to make one representative sample per site for each depth range. Soil samples were analysed for Total P, N and C, Bray P, pH, conductivity, exchangeable cations, DTPA-extractable trace elements, particle size and soil colour, all via standard methods based on Rayment and Higginson (1992), at the CSBP analytical laboratories, Perth, Western Australia.

Statistical analysis

Treatment effects were assessed using double and single factor analysis of variance, as appropriate. Regression analysis was used for analysing P responses (see above). All analysis was conducted using the Genstat statistical package (VSN International 2011).

Results

Response to nutrients other than P

There was no effect of the basal fertiliser on standing volume, either at age 1 year for all three G x P sites, or at age 2 years for the two G x P sites that were not compromised by root rot (Table 3). The basal fertiliser also did not significantly influence height or diameter individually (data not shown).

G × P series of experiments

There were significant and substantial responses to both genotype and P fertiliser in all three G x P experiments (Fig. 1). The response to P fertiliser was highly significant ($P < 0.001$) at all sites, and the response to genotype was also highly significant ($P < 0.001$) at the Sodong site, and significant ($P < 0.05$) at both the Lematang and Gemawang sites. At age 1 year, the proportional response to P fertiliser (Equation (2), above) ranged between 80 and 110% across the three sites. The genotype effect was also consistent across sites. Subanjeriji landrace and Subanjeriji improved had the lowest productivity, Wipim-Oriomo was intermediate, and the selected seedling seed orchard material had the best productivity.

The biggest absolute gains from both the P fertiliser and genotype treatments were at the higher productivity Sodong site. The proportional effect of the treatments across the sites was similar and between 80 and 110% for the P fertiliser treatments, but the effect of genotype was greatest

Table 3. Standing volume (m^3 ha^{-1}) in response to basal fertiliser treatment at three sites. P values were calculated on a replicate basis (n = 4)

	Age 1 year			Age 2 years		
Site	Without basal fertiliser (X100)	With basal fertiliser (P100)	P value	Without basal fertiliser (X100)	With basal fertiliser (P100)	P value
Sodong	22.9	24.2	0.641	n/a	n/a	n/a
Lematang	15.4	16.9	0.375	60.8	63.7	0.772
Gemawang	7.63	8.88	0.698	40.8	37.3	0.604

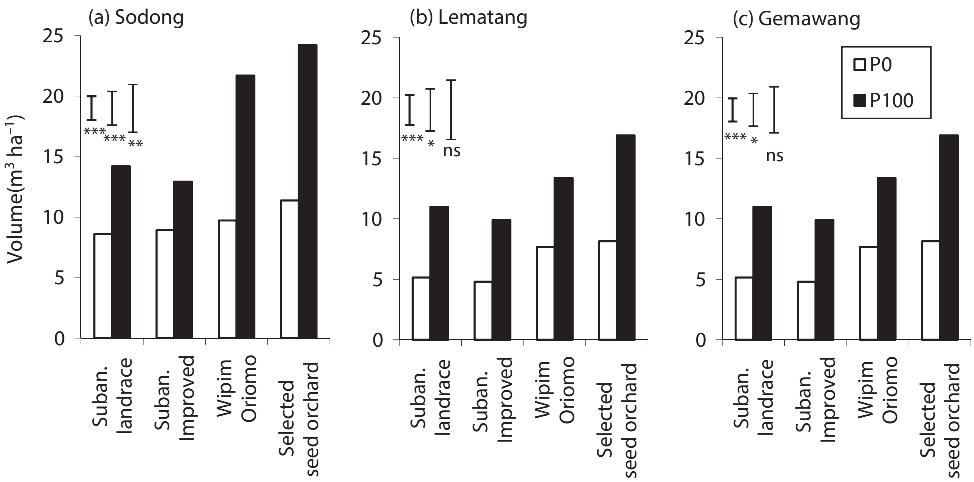

Figure 1. Response to genotype and P fertiliser at age 1 year at the (a) Sodong, (b) Lematang and (c) Gemawang sites. Bars show the least significant differences (LSDs) for (from left to right) the main effect of P, the main effect of genotype, and the interaction between P and genotype at each site. Asterisks show the significance of (from left to right) the main effect of P, the main effect of genotype, and the interaction between P and genotype at each site: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; ns, not significant

at the lower productivity Gemawang site, with a 180% increase in the best material compared to the Subanjeriji landrace, compared with a 55–56% increase for the same comparison at the Sodong and Lematang sites.

There was an interaction between genotype and P fertiliser at the Sodong site, where the higher yielding genotypes had a greater response to P fertiliser, but at the lower productivity Lematang and Gemawang sites the responses to P fertiliser and genotype were additive, with no significant interaction.

P response series of experiments

The 11 experiments in the G x P and P response experiments demonstrated a range of responses to P fertiliser, with only one site, Keruh, not responding to P at age 1 year (Fig. 2). The other sites had marked responses to P fertiliser, with a > 100% proportional response at nine of the remaining ten sites.

The data from these 11 experiments were synthesised across the dataset, as the responses to P and responses over time followed similar trends across the sites. The modelled average non-P-limited standing volume (across genotypes) increased from around 20 m^3 ha^{-1} at age 1 year, to around 137 m^3 ha^{-1} at age 3 years (Fig. 3(a)). The volume response to P was substantial, around 15 m^3 ha^{-1} up to age 2 years increasing to around 30 m^3 ha^{-1} at age 3 years (Fig. 3(b)), but the proportional response declined dramatically, from an average of 120% at age 1 year, down to around 28% at age 2–3 years (Fig. 3(c)).

The P-fertiliser requirement for 90% maximum yield at age 1 year averaged around 23 kg P ha^{-1}, but this had declined to an average of 2.7 kg P ha^{-1} by age 3 years (Fig. 4). All of the P-response sites had a calculated P-fertiliser requirement of <10 kg ha^{-1} at their final measure.

Few soil properties were well related to P-fertiliser response. DTPA-extractable iron was the soil property most closely related to both P response ($P < 0.05$) and P-fertiliser requirement ($P < 0.001$, Fig. 5).

P x weed control experiments

Trees responded significantly both to P fertiliser and weed control, with an average 58% proportional response to weed control ($P < 0.01$), and 91% proportional response to P100 ($P < 0.001$), compared with the poor weed control and P0 treatments respectively (Fig. 6). The effects of weed control and P fertiliser were additive (i.e. there was no significant interaction between these treatments).

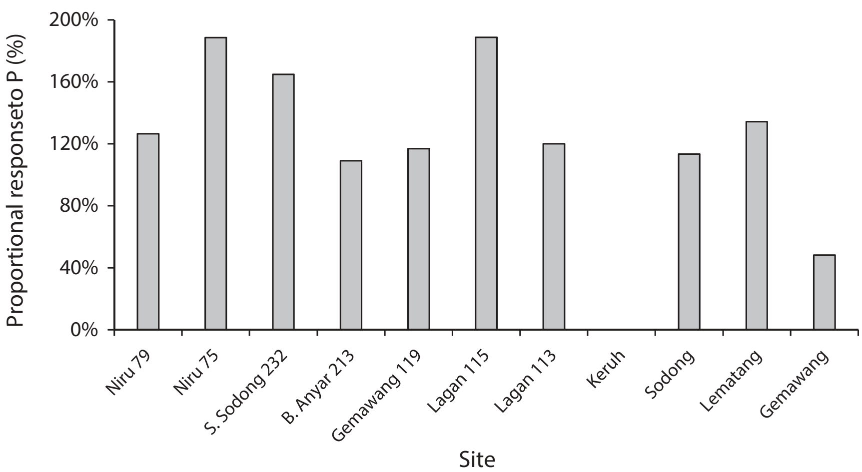

Figure 2. Proportional response to P across the 11 G x P and P-response sites at age 1 year (averaged across genotypes). Note that the proportional response to P at Keruh was 0%

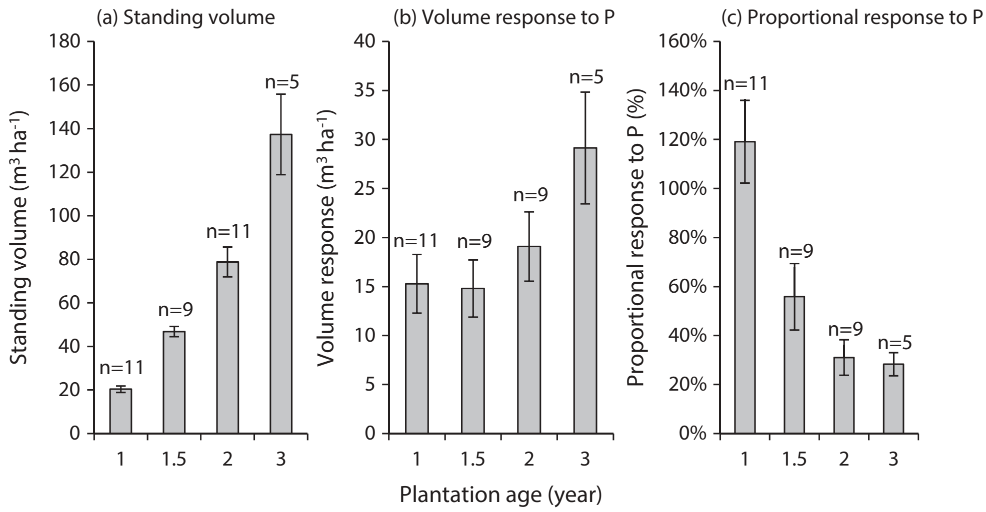

Figure 3. Responses to P across plantation age. (a), standing volume in treatments with sufficient P; (b) volume response to P; (c) proportional response to P. Data are means of the P-response and G x P sites measured at each age. Bars represent ±1 standard error. Not all sites were measured at age 1.5 or 3 years, so different numbers of sites were used in calculating mean values as shown

Figure 4. Fertiliser requirement for 90% of maximum yield across the P-response and G x P sites measured at each age. Bars represent ±1 standard error. Not all sites were measured at age 1.5 or 3 years, so different numbers of sites were used in calculating mean values as shown in Figure 3

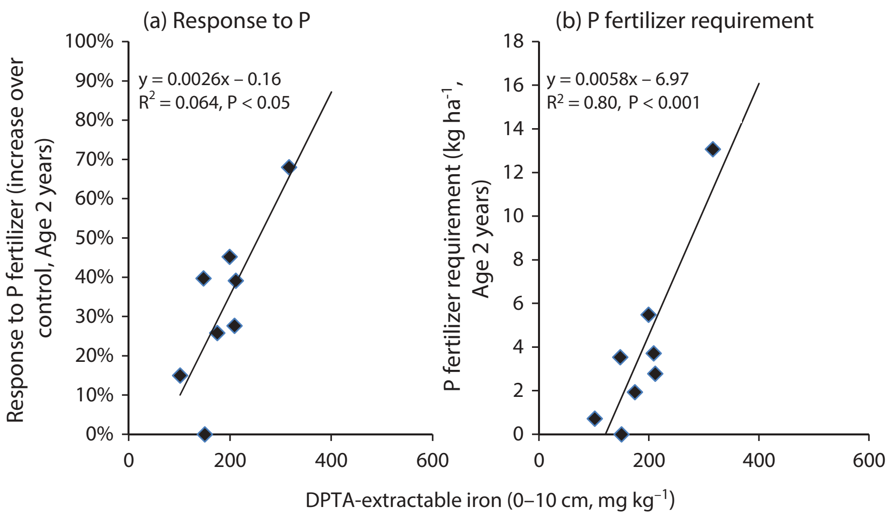

Figure 5. Relationships between soil DTPA-extractable iron and (a) response to P fertiliser, (b) requirement for P fertiliser, for the P-response sites at age 2 years

Discussion

The productivity of *A. mangium* in South Sumatra was found to be high by world standards, with an average mean annual increment of 45 m^3 ha^{-1} y^{-1} at the five sites that were measured to age 3 years. The productivity of these plantations was in the top 16% of plantations in subregions 1–3, and the top 5% of plantations in subregions 4–6, as reported by Harwood and Nambiar (2014) for Sumatra. As the location of the subregions was deliberately obfuscated by these authors to protect the sources of the data, their exact locality is unknown. The productivity reported for

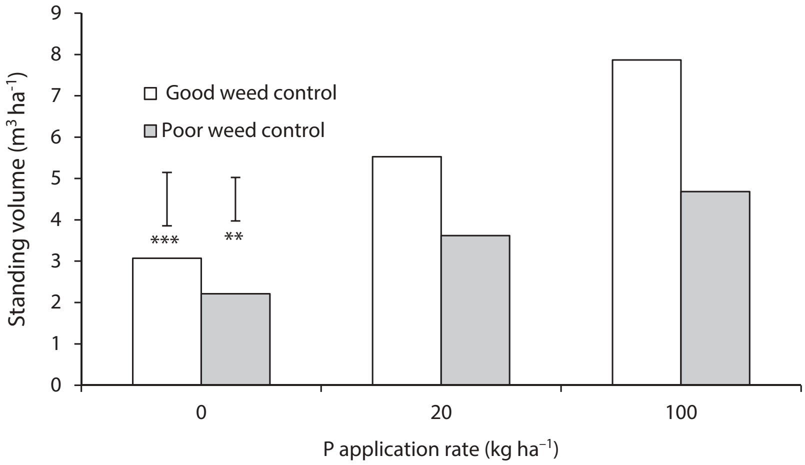

Figure 6. Standing volume at different P application rates and weed control at age 1 year. Data from the Niru P x weed response site. Bars show the least significant differences (LSDs) for (from left to right) the main effect of P, and the main effect of good weed control. There was no interaction between P fertiliser application and good weed control. Asterisks show the significance of (from left to right) the main effect of P, and the main effect of good weed control: ***, $P < 0.001$; **, $P < 0.01$.

Sumatra by Harwood and Nambiar (2014) was 27–80% higher than the levels recorded for the other three countries in southeast Asia that they surveyed (Thailand, Vietnam and China). The productivity in our experiments also compared favourably with *Eucalyptus* productivity in Brazil reported by Stape et al. (2010), who found average MAIs of 46 m^3 ha^{-1} $year^{-1}$ across eight locations with fertiliser applied but no irrigation.

However, it does need to be recognised that acacias are no longer a preferred species in Sumatra because of their susceptibility to *Ganoderma* root rot (Glen et al. 2009) and *Ceratocystis* fungal wilt (Tarigan et al. 2010), and these growth rates are no longer achievable with *A. mangium*.

The soils of the plantation areas in South Sumatra are ultisols, described as highly weathered with many chemical and physical constraints (Nurudin et al. 2013). Despite these constraints, not only was the productivity of the acacia plantations high, there was also no apparent response to any fertiliser except P at the two sites where this was tested. This supported the finding of Turvey (1996) at a single site in South Kalimantan, on similar soils to those in this study, that P was the sole nutrient to which *A. mangium* responded. In other environments, Herbert and Schönau (1989), in synthesising results from a range of nutrient experiments in South Africa, also found that acacias were predominantly responsive to P. These authors also found some evidence of a response to K, but the effect was not consistent, and difficult to elucidate. It is likely that K may become more of a limitation in later rotations as it is removed in harvested crops. Progressively developing K deficiency over multiple rotations has been found in eucalypt plantations in Brazil (Almeida et al. 2010), and responsiveness to K should continue to be monitored in South Sumatra to ensure that K deficiency does not impact on productivity over multiple rotations into the future.

Acacias were responsive to P fertiliser at all sites, irrespective of the genetic make-up of the planting material. While both genotype and P had strong main effects on productivity, the only significant interaction between genotype and P response was at the Sodong site where the response to P was not quite as marked in the 'improved' Subanjeriji landrace material. The benefits of improved genetic material are well known (Midgley 2006), but the management of improved material to obtain maximum gains has not been fully elucidated in tropical acacias. Boreham and Pallett (2009) also found a lack of interaction between plantation management and eucalypt planting material, and concluded that the effects were mainly additive across five sites in South Africa. In contrast, Roth et al. (2007) found a significantly different response between two contrasting *Pinus taeda* provenances in southern USA to nutrient treatment after 13 years of sustained nutrient addition, but the differences were minor compared to the highly significant main effects of nutrition and family. Roth et al. (2007) also suggested that the interaction between genotype and fertiliser application was associated with the faster growing provenance being pushed by the fertiliser treatment into earlier self-thinning because of its higher growth rate. Their suggestion that the fertiliser interaction was purely due to self-thinning was supported by the observation that there were no significant interactive effects between fertiliser and genotype on individual tree height or diameter, only at the stand level.

Ten of the 11 P-response experiments had significant responses to P, and nine had more than double the productivity of the non-P-fertilised control at age 1 year, a result that highlights the importance of P at establishment for achieving high yields. The average absolute volume gain in response to P fertiliser was around 15 m^3 ha^{-1} up to age 2 years, and close to 30 m^3 ha^{-1} at age 3 years, although the proportional response declined. The decline may be due to greater access to soil P by the roots, and/or reduced access to fertiliser P through soil P fixation processes. The fertiliser required to achieve this level of response was high at age 1 year, an average of 23 kg P ha^{-1}, but rapidly declined with age, such that 90% of the yield gain by age 3 years was achieved with only 0.2–4.4 kg P ha^{-1}, and an average of 2.7 kg P ha^{-1}. This suggests that application of only 10 kg P ha^{-1} at establishment is sufficient to achieve maximum productivity at all sites. Even though there was a positive relationship between DTPA-extractable iron and response to added P, from an operational point of view it makes more sense to use a fixed application rate of 10 kg P ha^{-1} than to tailor a rate to each site.

The finding of a requirement for such a low level of P across a wide range of sites contrasts with Turvey (1996), who found that *A. mangium* in South Kalimantan responded to up to 52 kg P ha^{-1}, although there was an absolute volume gain of only 3 m^3 ha^{-1} at age 30 months with increasing P addition from 26 to 52 kg P ha^{-1}, and this difference was likely to decline over time. At another site in South Sumatra, Hardiyanto and Wicaksono (2008) found that there was no response to applications of >19 kg P ha^{-1} by age 5 years. Nevertheless, the requirement for P may need to be monitored in the future, as levels of available P can decline under *Acacia* plantings over the course of the second rotation at sites in both Indonesia (Hardiyanto and Nambiar 2014) and Vietnam (Huong et al. 2015). The impact that such declines in available P may have on the future response to P fertiliser is as yet unknown.

Weed competition for nutrients can have a significant influence on the productivity of the stand. In *Eucalyptus*, weed control can reduce competition for N (Adams et al. 2003; Eyles et al. 2012), but N is not likely to be an issue in *Acacia* plantations because of their high N fixation capacity (Wibisono et al. 2015). The weed × P experiment in this study demonstrated that P addition, even in a spot near the base of the trees, did not reduce the impact of weed competition. Effects were additive in this study, suggesting that the weed competition was for resources other than P. Similarly, with *P. taeda* in the southern USA, Martin and Shiver (2002) found that the effects of genotype and vegetation control were additive, such that improved genotypes could not substitute for weed control. Also, Woods et al. (1992) found that the effects of N fertiliser and weed control were additive in *Pinus radiata* plantations in Australia. Improved nutrient management thus cannot directly substitute for weed control in *A. mangium* plantations.

Conclusions

We found that *A. mangium* plantations in South Sumatra almost universally required P at establishment for maximum productivity, with more than double the productivity under P-fertilised treatments at age 1 year compared to non-P-fertilised treatments at nine of 11 sites. However, the quantities of P required to obtain maximum productivity were relatively low, equivalent to <10 kg P ha^{-1}. The plantation estate in South Sumatra has now been mostly transitioned to *Eucalyptus pellita*, but we anticipate that these findings would be applicable elsewhere where *A. mangium* is planted, and probably also transferrable to the new *E. pellita* plantings in South Sumatra, although this would need some testing before deployment in operational plantings. The lack of interaction between weed control and P fertiliser addition suggests that both of these operations are necessary to attain maximum productivity.

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Disclosure statement

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