Australian Government
Australian Centre for
International Agricultural Research

Final report

project	**Increasing productivity and profitability of Indonesian smallholder plantations**
project number	FST/2009/051
date published	9/12/2015
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approved by	Tony Bartlett, Forestry Research Program Manager
final report number	FR2015-17
ISBN	978-1-925436-14-3
published by	ACIAR GPO Box 1571 Canberra ACT 2601 Australia

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1 Acknowledgments

We wish to thank all of the people and organizations who have contributed to this project. People include Tony Bartlett (ACIAR), Sadanandan Nambiar (CSIRO), Gary Ogden (CSIRO), Prof. Dr. M Naiem (Dean of the Faculty of Forestry, Gadjah Mada University), Prof. Dr. Imron Zahri (Dean of the Faculty of Agriculture at Sriwijaya University), A/Professor Barbara Ozarska (Melbourne University) and Dr Russell Washusen (Melbourne University). Organizations include CSIRO, Forest Research and Development Agency (FORDA), Gadjah Mada University, Sriwijaya University, PT Musi Hutan Persada, April Asia and Sinarmas Forestry. Dr Chris Harwood made a substantial contribution to the editing of the report.

2 Executive summary

By world standards, Indonesia has a very large installed pulp and paper processing capacity, and further plans for expansion. The value to Indonesia is more than US$4.2B per year. There is a rapid transition in the industry away from natural forest as the main feedstock to sustainably grown plantations. Large areas of plantations have been established, and there is a need to ensure that they remain productive and sustainable in the short and long term, both to protect the remaining natural forest, and to keep generating wealth for Indonesia. Key risks to productivity and sustainability include the fact that the principal species planted by growers, *Acacia mangium*, is substantially threatened by fungal diseases, including *Ganoderma* and *Ceratocystis*.

The aim of this project was to develop new knowledge around best management options for growers to profitably manage plantations in successive rotations, with an emphasis on ensuring that the knowledge can be transferred to smallholder farmers in Indonesia. The biophysical, pathological and social science research was organised under six objectives with activities designed to improve Indonesian hardwood plantation productivity and profitability by targeted species choice and product mix, nutrient management, and root-rot control, to facilitate greater smallholder participation and profitability.

The project demonstrated that eucalypts (*E. pellita* and hybrids) have potential to be a good replacement for *A. mangium*, with volume productivity similar to *A. mangium*, and potential for higher pulp productivity because of greater pulp yields. *Eucalyptus pellita* can be as productive as *A. mangium*, on a volume per hectare basis, which is at the top end of productivity that can be achieved in plantations anywhere in the world. However, eucalypts are not as tolerant to site variation and there is greater variability between sites and clones than with acacias, so it is important to ensure appropriate matching of clones by site. We identified optimal nutrient management strategies, as *Eucalyptus* grown after *Acacia*, and with appropriate site management, does not appear to need further N supplementation for at least 2 rotations. Phosphorus is a critical nutrient that must be applied, even if only at a low level. We also demonstrated that there is significant potential for growing *E. pellita* for sawlogs, as it has good sawing potential, and responds to thinning early in the rotation.

The project found that tree survival, wood production, and cause of mortality were not able to be reliably or consistently related to any one, or combination of, soil and topographic variables using archived pre-harvest inventory, 1:10000 soil mapping and 5 metre digital elevation models. The ability to determine the influence of topography and soil attributes on wood production and cause of mortality was greatly compromised by; lack of site specific soil data, collinear variables, and potential misclassification of the cause of mortality. Future studies should focus on exploring higher resolution spatial approaches such as LIDAR or hyper spectral sensors based on unmanned aerial vehicles, combined with site specific soil sampling and analysis.

Management options for disease management investigated within the project are to change to a less susceptible species or, in the case of Ganoderma root-rot disease, develop a biocontrol system. Even change of species to *E. pellita* still carries some risk of exposure to disease, as *E. pellita* has its own disease spectrum. So far, however, there has been little evidence of catastrophic disease issues in eucalypts such as *Ganoderma* and *Ceratocystis* in *A. mangium*. It is however likely that root-rot incidence (caused by *Ganoderma* or *Phellinus*) will increase in eucalypts with subsequent rotations and this has already been observed by an Indonesian project researcher.

The project has conducted fundamental scientific research that will underpin the development of potential biocontrol agents for *Ganoderma phillipi*, including understanding the risks and potential impacts. Progress in the project towards a biological control agent for *Ganoderma* has been promising, with propagation mechanisms tested for several candidate biocontrol agents, which were subsequently screened for

pathogenicity and have recently been tested in the field. However, it needs to be recognised that biological control agents are notoriously difficult to deploy commercially, and the progress made in this project is still some way from deployment of a commercial biocontrol agent. It also needs to be recognised that *Ganoderma* is being considered as a lesser disease issue since the project inception, as *Ceratocystis* is now causing much greater mortality levels in acacias than *Ganoderma*, although mortalities due to root-rot can be significant. However, further development of biological control strategies for root-rot is still worthwhile as planting of *A. mangium* will continue if germplasm resistant to *Ceratocystis* can be developed.

The social studies that were conducted as part of this project identified several issues with equity and transparency in current partnership (outgrower) arrangements, suggesting that greater community acceptance of partnerships would require increased income share to the communities/farmers, shorter contract lengths, provision of insurance, and inclusion of community development programs that allow greater access to infrastructure such as roads. Independent farmers, such as those in Java, tend to be more active in tree growing and marketing for higher value products, and trees are a much more important part of their livelihood strategy than for farmers from Sumatra and Kalimantan. For farmers in Gunung Kidul, Java, trees were found to be an important component of their livelihood strategy, helping them to deal with large, unexpected expenses such as medical bills. However, access of these farmers to information was best done through local extension officers, who are apparently not being actively replaced, and their numbers are dwindling.

The main impacts of the project will be in helping to ensure that the plantation resource can be sustainably managed for high productivity into the future, with optimal levels of inputs and options for value-added processing in the future. This impact will be for the companies, smallholder farmers, and communities, and should lead to greater community wealth, employment, the stimulation of local sawn timber industries and reduced land conflicts with local villagers, even if only partially implemented. We have also worked directly with a wide range of researchers in industry, government and universities, and have made a strong impact on the capacity of those staff to conduct well planned, well designed, and well implemented projects.

Sustained production from plantation forestry will need continued attention to research and management to ensure that growers are able to adapt to new risks and threats, and that farmers and communities continue to share in the benefits that this industry can provide. A number of recommendations in this regard are made at the end of this report.

The project has undertaken a range of formal and informal capacity building activities and made a substantial contribution to the scientific knowledge about aspects of the project's research through the development of 22 publications, including journal articles, conference papers and project reports.

3 Background

The pulp and paper industries form a significant part of Indonesia’s economy with US$4.2B in export sales in 2008. Indonesia's forest industries are dominated by the pulp and paper sectors, although there is significant smallholder interest in higher value species and products, especially in Java. As part of the need to place these industries onto a more sustainable footing and become less reliant on their pulpwood from native forest, Indonesia's Ministry of Forestry has promoted policies that encourage the development of a plantation-based wood supply. Two species, *Acacia mangium* and *Eucalyptus pellita* and hybrids account for the majority of the plantings on mineral soils because of their rapid growth; *A. mangium* has been preferred because of its fast growth and low management requirements, though the area of *Eucalyptus* plantations has been growing rapidly, due to pest and disease problems that are making acacias non-viable in some areas of Sumatra (Nambiar and Harwood, 2014).

The supply of sawn timber has been dominated by logs harvested from native forest. However the security of this supply is threatened because of community and market concerns about widespread deforestation. Increased productivity and development of a plantation-based sawn-timber industry will benefit Indonesia, as well as its smallholders, sawmill operators and potential value-adding industries like furniture manufacturers. It was recognised that establishment and maintenance of large areas of sustainably productive plantations was the only way to minimise clearing of the remaining natural forest, as the huge pulp capacity and planned expansion will need to draw its feedstock either from plantations or from the natural forest.

The Government of Indonesia's Ministry of Forestry (MoF) planned to double the production of pulp to 16 Mt per year by 2020, requiring an additional 9 M ha of plantations, of which ~60% (~5.4 M ha) was to be grown in smallholder lots of around 15 ha each, all located in Sumatra and Kalimantan (MoF, 2007). However smallholders studied to date have achieved yields of only 50% of potential from their first-rotation plantations primarily due to lack of application of appropriate management.

Furthermore, the sustained productivity of *A. mangium*, the principal species planted by smallholders, was threatened by the build-up of root-rot disease which can result in more than 50% mortality in severely affected areas. One of the key management options for some root-rot affected areas was likely to be a complete change of species, with *Eucalyptus pellita* (and its hybrids) showing the most promise. *Eucalyptus pellita* grows well in other tropical areas, and is used as a pulp and solid-wood species, but it is known to have higher input and maintenance costs, partly because it has a higher nitrogen requirement. The use of *E. pellita* planted after 1 or 2 rotations of *A. mangium* may require lower intensity of management due to the accumulation of soil N under an *A. mangium* plantation. Some of the industrial partners in this project are planting *E. pellita* routinely on root-rot affected areas, but the management requirements of *E. pellita* in smallholder rotations have not yet been explored.

Although *A. mangium* and *E. pellita* are both exotics in Sumatra and Kalimantan, they are recognised as well-suited to these environments and for plantation forestry, although *E. pellita* is more site specific and not always a suitable alternative to *A. mangium*. This issue has parallels that are found elsewhere; how can plantation monocultures be made sustainable from one rotation to the next? This project asked this question in the context of nutrient, water and disease management, which are challenges often associated with intensively managed monocultures and sustainability.

A significant issue was to ensure that technology such as developed during this project could be adopted and have an impact on smallholder farmers. It is important to note that research in an earlier project (FST2004/058) found that productivity of smallholder-owned short-rotation plantations was around half of those managed by the industry. This difference in productivity can be attributed to several factors, including, but not restricted to farmer’s lack of knowledge. Past community forestry research projects in Indonesia have also found lower productivity in outgrower plantations, relative to company-managed plantations (Nawir et al., 2003). They were generally caused by farmers having limited time to work on the land and a lack of interest in managing the trees themselves. It is important to recognise that these farmers’ behaviours may have been the result of inequitable benefit sharing arrangements with the timber company. Farmers were often reliant on other income sources to maintain their livelihood and therefore were limited in their capacity to manage their own plantations. Our research suggests that such inequitable partnerships are common in Indonesia and do not serve the original intention to assist poverty stricken farmers.

Project participants have a long history of involvement in research into sustainable management of temperate and tropical eucalypts and acacia for solid wood products. FST/2000/123 focused on the silviculture and disease management required to produce sawlogs from *A. mangium*. Synergies between two active projects, FST2003/048 and FST2004/058 were discussed at a joint meeting in 2008. The outcome was that site management and crop protection were identified as two essential and related components of plantation wood production system in Indonesia.

The project aimed to address priorities within Subprograms 4 and 5 of ACIAR's Indonesian priorities. Subprogram 4.2: Profitable smallholder agroforestry systems. Understanding incentives for community plantings, analysis of outgrower schemes and markets, matching community forestry sites to species, site classification (including root-rot risk), selection of species, taking markets into account (including that for sawn timber). Selection of silvicultural systems and development of extension models adapted for small-scale plantings. Subprogram 5.2: Profitable utilisation of forestry resources. Application of improved silvicultural strategies to appropriately sited plantation species, capturing more value from forestry plantation species through development of new products (solid wood from *A. mangium* & *E. pellita*) matched to appropriate markets, and root-disease management for plantation forests.

At the time of project inception, first rotation *Eucalyptus pellita* plantations were being established in sub-tropical Australia for pulp and solid wood products. There was little guarantee that the silvicultural systems currently in place would sustain productivity at the time that the project was initiated, but these plantations were largely destroyed by cyclone Yasi in 2011, such that they were disinvested in by Australian industry, and there are currently no known plans to re-invest in an *E. pellita* industry in Australia. These plantations were used to obtain information on log processing and wood properties of plantation-grown *E. pellita* (Bailleres, 2008).

4 Objectives

The aim of this project was to develop new knowledge around best management options for growers to profitably manage plantations in successive rotations, with an emphasis on ensuring that the knowledge can be transferred to smallholder farmers in Indonesia.

Key objectives and activities of the project were:

- **Objective 1:** To assess the potential for *E. pellita* (and *E. pellita* x *grandis* hybrid) as a second/third-rotation crop to benefit from the higher soil N derived from *A. mangium* grown in previous rotations and to manage the risk and consequence of pathogen build-up.

  The activities required to support this objective included establishment of core sites on company land to explore a factorial combination of the 2 species with fertilizer (N and P) and different intensities of weeding. Empirical information from these experiments was used to inform our understanding of the processes occurring in the system by validating and/or modifying our process-based model, CABALA, to ensure that it is adequately predicting productivity. CABALA was used to generate the project outputs which explore productivity and profitability of the different management options.

- **Objective 2:** To explore the interactions between site edaphic properties, soil fertility, slope, water availability and effects of management on productivity, and test if the relationships derived in South Sumatra are more generally applicable to other plantation regions within Sumatra.

  A key part of Objective 2 was to characterise a wide range of existing plantations (up to 30 across the partners, representing a wide range in productivity), including a description of the soil profile, land form, land-use history, and management. This information could be used to extend/validate the outcomes from FST2004/058 about relationships between soil characteristics and plantation productivity beyond South Sumatra. We tested the hypothesis that soil depth (depth to plinthite) influences plantation productivity through inducing differential tree water stress. This was done retrospectively on experiments already established where the trees had a known history and were growing at different rates.

  A second part of Objective 2 was to understand if there were any impact of treatments and site in existing experiments on selected wood quality attributes.

- **Objective 3:** To provide management options for enhancing profitability through smallholder plantation systems producing wood for both pulp and sawn timber

  The key task was to explore and demonstrate best-bet management options to maximise the value of the standing crop. Acacia and eucalypt plantations are currently managed for pulpwood only. Strategically placed demonstration plantations were established to compare the requirements for pulpwood silviculture with those needed for solid-wood production.

- **Objective 4:** To investigate the site factors and/or host properties which reduce the risk of root-rot incidence and/or severity.

  Five activities were planned to support this objective, including: 1. Root-rot surveys at the sites characterised under objective 2 to link the soil profile, land form, land-use history, and management information to the incidence of root rot on these areas, 2. testing of slash removal effects on root rot incidence, 3. Pot-trials to examine in a controlled experiment the interaction of host-species with factors identified under (1) as being associated with higher incidence of root rot, 4. Exploration of the differences in root histology associated with differences in susceptibility to root rot observed in activity 4.3, and 5. Exploring the root structure of naturally regenerated *A. mangium* wildlings in comparison to planted acacia cuttings and seedlings. Activities 1 and 2 were changed following the inception meeting to increase the likelihood of more robust outcomes, with a greater focus on spatial analysis and less on plot-scale assessment.

- **Objective 5:** To test the effectiveness of potential biological control agents discovered by project FST2003/048.

  This objective aimed to take possible biocontrol agent fungi (BCAs) identified in FST2003/048 and test these through: 1. *In vitro* testing of antagonism against known pathogens both on agar and on wood, 2. factorial pot-trials designed to demonstrate the absence of any pathogenicity of the potential BCA, its effectiveness in reducing mortality due to root rot and any differences in effectiveness between the potential BCAs developed, and 3. Contingent upon the results of (2) a field test of the successful BCAs will be undertaken. This would be a plot-based replicated factorial experiment of host species by BCA agent.

  Objective 6: To better understand the knowledge, social experiences and conditions of the small landholders in order to enhance their capacity to manage their short-rotation plantations. This included understanding of effective knowledge transfer systems to ensure all knowledge acquired in the research can be fed back to the smallholder growers.

  The activities supporting this objective included an assessment of the capacity of smallholder farmers to adopt new or improved acacia farming practices, development of an understanding of the current social forestry partnership arrangements, and an evaluation of the viability of demonstration sites as a means of communicating with smallholder farmers in Sumatra.

5 Methodology

5.1 Methodology

Experiments were conducted predominantly in Sumatra, with some additional experimentation established in Kalimantan and Gunung Kidul (Java). We partnered with 3 industrial companies to assist in the installation, maintenance and monitoring of experiments. The CFBTI/FORDA mycology laboratory in Yogyakarta, Java, was used as a base for the mycological experiments.

The general approach was to conduct experiments to address current gaps in knowledge, and to understand how to extend this knowledge in a form that is useful to growers. Key taxa that were examined were *A. mangium* and *E. pellita*. The methodology employed in each of the objectives was as follows:

5.1.1 Objective 1

A range of core and satellite experiments were established to service both of Objectives 1 and 2. Three core experiments were established in Sumatra to try to better understand the dynamics of nutrients and water in plantation systems with differing rotational strategies for acacias and eucalypts. The 3 sites were at Subanjeriji, Lipat Kain, and Teso East, which were respectively established and managed by PT MHP, Sinarmas and RAPP. The location of the core experiments is shown in Fig. 1.

Fig. 1 – Locations of the 3 core experiments in Sumatra. The provinces of Riau and South Sumatra are highlighted.

The 3 core experiments were established in mid 2011 (Teso East), or early 2012 (Subanjeriji, Lipat Kain), and were monitored for soil moisture and tree growth. Tree growth in response to treatments was assessed for the remainder of the project. Key treatments and characteristics of the core sites are shown in Table 1.

Table 1 : Field site locations, soil moisture monitoring period and rainfall.

Field site	Province	Trial planted	Soil moisture monitoring period	Annual rainfall (mm)
Teso East	Riau	June 2011	March 2010 - December 2014	2981
Lipat Kain	Riau	June 2012	January 2013 – April 2015	2428
Subanjeriji core	South Sumatra	February 2012	December 2012 – March 2015	2605

Teso East (RAPP)

The trial consisted of a split block replicated plot design in which *E. pellita* and *A. mangium* were planted in adjacent blocks on opposing sides of a small valley. Soil moisture access tubes were installed in March 2012. Six soil moisture tubes were installed (Fig. 2) in each block, three in plots with no fertilizer and where slash had been removed, and three in plots where slash and understory litter had been retained and fertilized with three times the standard operating application of fertilizer (for treatment details, see Table 2). Treatments that were monitored for soil moisture were *E. pellita* with no fertilizer and slash removed (E0S-), *E. pellita* with 210 kg N /ha and slash and understory litter retained (EN210S+), *A. mangium* with no fertilizer and slash removed (A0S-), and *A. mangium* with 70 kg P /ha and slash and understory litter retained (AP70S+). It is important to recognise that the slash retention and nutrient application treatments were combined, so any responses could not be attributed solely to either factor.

Tree heights and diameters were measured regularly, and tree volumes were calculated using company-specific volume equations.

Table 2 – Treatments applied at Teso East

Species	Treatment	Slash	Element (kg ha^{-1})	Time of application
A. mangium	A0S-	Removed	0	n/a
	AP23S+	Retained	23 P	at planting
	AP70S+	Retained	70 P	at planting
EH	E0S-	Removed	0	n/a
	EN70S+	Retained	28 N	at planting
			42 N	at 4 months
	EN210S+	Retained	28 N	at planting
			42 N	at 4 months
			70 N	at 8 months
			70 N	at 12 months

[1]TSP: Triple super phosphate (20% P), ZA: Ammonium sulfate (21% N)

Figure 2 – Installation of soil moisture probes at Teso East, March 2012 (a) *Eucalypt*, (b) *A. mangium*.

Lipat Kain (Sinarmas)

The experiment at Lipat Kain was established in a randomised complete block design (with 3 replicates) in the Lipat Kain District, Riau. Treatments were designed to explore responses to N, P or K in *E. pellita, A. mangium and A. mangium wildlings* following the previous *A. mangium* rotation (see Table 3 for more detail on treatments). Wildlings in the natural regeneration plot were thinned such that the remaining trees were retained in the same configuration and stocking rate as the planted plots. Each plot had a total of 81 trees (9 x 9 rows), with a spacing of 3 x 2 m. Soil moisture probes were installed (Fig. 3) in November 2012 within an existing complete randomized block trial. Soil moisture access tubes were installed in three plots of *E. pellita* with 126 kg N/ha in the form of urea (EP-P1N2), *E. pellita* with no nitrogen fertilizer (EP-P1N0), and *A. mangium* with no nitrogen fertilizer (AM-P1N0).

Tree heights and diameters were measured regularly, and tree volumes were calculated using company-specific volume equations.

Table 3 – Treatment detail for the Lipat Kain core experiment

Number	Short name	Species	ERP[1] (g/tree)	P elemental (kg/ha)	Urea (g/tree)	N elemental (kg/ha)
T1	AW-P1N0	*A. mangium* *(natural reg.)*	70	14	0	0
T2	AM-P0N0	*A. mangium*	0	0	0	0
T3	AM-P1N0	*A. mangium*	70	14	0	0
T4	AM-P2N0	*A. mangium*	400	82	0	0
T5	EP-P0N0	*E. pellita*	0	0	0	0
T6	EP-P1N0	*E. pellita*	70	14	0	0
T7	EP-P2N0	*E. pellita*	400	82	0	0
T8	EP-P0N1	*E. pellita*	0	0	55	42
T9	EP-P1N1	*E. pellita*	70	14	55	42
T10	EP-P2N1	*E. pellita*	400	82	55	42
T11	EP-P0N2	*E. pellita*	0	0	165	126
T12	EP-P1N2	*E. pellita*	70	14	165	126
T13	EP-P2N2	*E. pellita*	400	82	165	126

Figure 3 (a) Lipat Kain site, November 2012, (b) installation of soil moisture access tube in plot T6R1.

Subanjeriji Core experiment (PT MHP)

A randomised complete block trial with 5 replicates was established in February 2012, at Subanjeriji, Gemawang, South Sumatra to explore the effects of N and P fertilizer on productivity of *E. pellita*, and *A. mangium*, both of which were derived from locally improved seed orchard material. See Table 4 for a description of the treatments applied. Soil moisture access tubes were installed in three replicate plots of *A. mangium* with no nitrogen fertilizer (AM-N0P30), and three replicate plots of *E. pellita* with 120 kg/ha of nitrogen (EP-N120P30K0), and 3 replicate plots of *E. pellita* with no nitrogen fertilizer (EP-N0P30K0). Permanent logging soil moisture probes were also established in one replicate of 2 treatments (AM-N0P30 and EP-N120P30K0). All treatments in which soil moisture access tubes were installed also received 30 kg/ha of P. Annual rainfall for both sites at Subanjeriji averaged 2605 mm with 183 rain days in which minimum monthly rainfall occurred between June and September.

Tree heights and diameters were measured regularly, and volumes were calculated using company-specific volume equations.

Table 4 – Treatments applied at the Subanjeriji core site

Treatment	Species	Nutrients applied (kg/ha, elemental)			
		N	P	K	Ca
AM-N0P0K0-Lime	*A. mangium*	0	0	0	
AM-N0P30K0-Lime	*A. mangium*	0	30	0	
EP-N0P0K0-Lime	*E. pellita*	0	0	0	0
EP-N0P0K0+Lime	*E. pellita*	0	0	0	2500
EP-N0P30K0-Lime	*E. pellita*	0	30	0	
EP-N40P0K0-Lime	*E. pellita*	40	0	0	
EP-N40P30K0-Lime	*E. pellita*	40	30	0	
EP-N40P30K70-Lime	*E. pellita*	40	30	70	
EP-N40P30K0-Lime	*E. pellita*	40	30	0	
EP-N120P0K0-Lime	*E. pellita*	120	0	0	
EP-N120P30K0-Lime	*E. pellita*	120	30	0	

Figure 4 – Presence of shallow groundwater at the Subanjeriji core site, March 2012.

In addition to the soil moisture monitoring, logging band dendrometers were set up on well-fertilized *A. mangium* and *E. pellita* at the Subanjeriji and Lipat Kain sites (3 replicates each).

Satellite sites

The core experiments were supported by a range of satellite experiments that were established by the industrial partners to better understand the effects of species change on productivity, disease impacts and nutrient cycling. The locations of the satellite experiments are shown in Fig. 5. The site details are shown in Table 5.

Fig. 5 – Locations of the satellite sites

Table 5 – Details of the satellite experiments

Field site	Province	Trial planted	Annual rainfall (mm)
Lipat Kain satellite	Riau	June 2012	2428
Subanjeriji ex-*Acacia*	South Sumatra	February 2012	2605
Subanjeriji ex-*Eucalyptus*	South Sumatra	February 2012	2605
Subanjeriji ex-secondary forest	South Sumatra	November 2014	2605
Teso East and (pot experiment)	Riau	June 2011	n/a

Lipat Kain satellite experiment

The Lipat Kain satellite experiment was set up approximately 500 m from the core experiment, on an ex-*E. pellita* site, designed to contrast with the ex-*Acacia* core site. Only a subset of the core site treatments were established, with AM-P1N0, EP-P1N0, and EP-P1N1 included in the design. Plot sizes and other experimental details were the same as for the core experiment.

Subanjeriji ex-Acacia and ex-Eucalyptus

Two adjacent satellite experiments were established nearby (~500 m) to the core experiment. The experiments were established such that they were on ex-*Acacia* (2-rotations), and ex-*Eucalyptus* (that was 10 years old at harvest, and had previously had 1 rotation of *Acacia*). The satellite experiments had a subset of the core experimental treatments, with AM-N0P30, EP-N0P30, and EP-N120P30 treatments imposed in each of the ex-*Acacia* and ex-*Eucalyptus* sites.

Subanjeriji ex-secondary forest

An ex-secondary forest site was established in late 2014 to better understand the responses to N and P fertilizer in an environment where acacias had not been grown previously. The treatments (all with E. pellita) were P0N0, P0N40, P0N120, P30N0, P30N40 and P30N120.

RAPP pot experiment

A pot experiment was established by RAPP to explore the response of both *Eucalyptus* and *Acacia* to N and P addition in soils from acacia plantation areas, and from adjacent natural forest. Soils were sampled from the 0-20 cm depth range from the Teso East experiment and adjacent natural forest, and from a 3rd rotation plantation at Baserah, and adjacent natural forest. The soils from each of the native forest and the plantation were sieved (<5 mm) and thoroughly mixed. Four fertilizer regimes were applied per pot as follows

- F1 – Zero fertilizer
- F2 – Zero N + 80 g of triple superphosphate (TSP) + 40 g muriate of potash (MOP) at planting
- F3 – 80 g Ammonium sulfate (AS) + 80 g TSP + 40 g MOP at planting, followed by 120 g AS and 40 g MOP at 4 months (this treatment is the standard operating procedure)
- F4 – same as F3, except AS added at 240 g at establishment, and at 350 g at 4 months.

Soil and fertilizers were mixed and put into 20 L plastic pots. One ramet of a hybrid eucalypt clone was planted in each pot, with the pots arranged in a randomised complete block design with 10 replicate pots per treatment and soil combination.

5.1.2 Objective 2

In addition to utilization of the experiments described above for Objective 1, a range of existing plantations were assessed to understand whether the relationships between soil properties and productivity found in South Sumatra could also be applied in Riau. The original intention was to do this for *A. mangium* plantations, but the decision was made to extend this to *Eucalyptus* instead of *Acacia* with Sinarmas, because this is now their primary genus.

RAPP

Sites were selected from the 2012 Pre Harvesting Inventory (PHI) assessment by RAPP Planning department. A total of 12 compartments were selected to represent a range in stand productivity potential. To ensure that the observed productivity was associated as much as possible with site characteristics rather than age or stocking levels, the 12 stands were selected to have similar stocking levels and ages. The source of the genetic material planted at each site was also extracted from the relevant management database. Within each compartment, a 600 m^2 rectangular plot of well stocked stand was selected for the assessment. At the centre of each plot, a soil profile pit (1 m x 1 m x 2 m) was excavated, and the soil was described. Within each plot, 10 soil cores (0-10 cm, 10-20 cm and 20-40 cm depth) were sampled using a soil auger and a composite sample by depth was analysed for soil chemical and physical properties. All of the trees in each plot were individually assessed for height (up to the canopy top) diameter (DBH) at 130 cm from ground surface. Tree measurement and soil sampling were conducted during March to September 2013. Top Height of each plot was defined as mean height of 6 trees with biggest DBH within each plot. Tree volumes were calculated using a company-derived volume equation. Effective rooting depth of each plot was determined as the maximum depth in the profile where medium and coarse roots were commonly occurring. Plot slope was measured at the centre of the plot.

The plantations across the 12 sites were all established in 2008. Seedlings/cuttings were planted manually with initial stocking of 1667 trees ha^{-1}. Basal fertilizers were applied at planting, at a rate of 70 g of triple super phosphate, and 40 g of muriate of potash per tree. We assumed that the standard operating procedure for weed control was followed, which requires 6 chemical control operations within the first 2 years. However, we had no independent record to verify that the SOP was applied at each site. Site elevations were recorded using a hand-held GPS (Garmin 76CSX).

An exploratory correlation analysis between various site/soil attributes and plot productivity (including top height and plot volume) was conducted in Excel.

Silviscan study

The impact of P fertilizer treatment on wood quality attributes (basic density, modulus of elasticity and microfibril angle) was assessed on a subset of plots in South Sumatra. A total of three cores from each of the two different phosphorus treatments from each site were collected for SilviScan™ rapid wood analysis. 12 mm cores were taken at breast height (1.3 m) with a manual corer before being sent for analysis at CSIRO, Melbourne Australia. All cores were taken from the southern side of the tree and extended to at least halfway into the tree trunk to represent a single radius. Trees to be sampled were randomly selected within each of the different treatments, where each treatment was a 5 x 5 tree plot (25 trees), with only the inner 3 x 3 trees (9 trees) available for sampling. Table 6 below shows the various sites sampled and required number of cores from each.

Table 6. Site descriptions and numbers of sampling cores taken.

Site Name	Plant year	Productivity	Treatments	No. Cores
Lematang	2008	Low	2	6
Gemawang	2008	High	2	6

Samples were collected in July 2013 when the trees were 5 years old. Core samples were dehydrated after collection using a series of ethanol treatments to prevent cell wall collapse. After the dehydration steps the cores were posted to CSIRO, Melbourne for analysis.

Downes et al (1997) provided the basic sampling theory and sampling methodology to be used in this project. The degree of variation and the level of heritability for different wood properties are unique, thus the ideal number of samples required will vary depending on the properties being assessed. Due to time and financial restrictions, and the assumption of low variability due to genotype this study only analysed a total of 12 core samples, at the time it was considered enough samples to provide for an adequate interpretation of treatment and site effects on wood properties.

Nitrogen mineralization study

The influence of tree species on soil nitrogen mineralization was assessed at three paired sampling plots, each with adjacent *A. mangium* and *E. pellita* plantations. The ages of *E. pellita*, at sampling were 5, 11 and 17 years. Soil samples were extracted from the upper 10 cm of soil using cores constructed from 50 mm PVC tubing. Nine pairs of soil cores were collected from each plot, with one of each pair extracted on day 0, and one on day 28. Aerobic incubation was conducted at 30° C for the 28 days.

5.1.3 Objective 3

The treatments adopted and the species planted were aligned with the interests of those partners who chose to participate. Five demonstration plantations were established, two with the support of MHP (both at Subanjeriji), two with Sinarmas (one at Perawang in Riau; one at Sintang in West Kalimantan [Finnantara]), and one with FORDA (at Gunung Kidul in Central Java). Apart from the trial in Sintang, the plantations were grown from establishment by the project; in Sintang, an area of plantation in its first year of growth was used. Locations of the demonstration experiments are shown in Fig. 6. The species planted were *Acacia mangium* (Subanjeriji, Perawang), *Eucalyptus pellita* (Subanjeriji, Perawang, Sintang) and *Acacia auriculiformis* (Gunung Kidul). At all sites, unthinned plots represented a pulpwood regime, including in some instances with and without weed control (Perawang, *A. mangium* at Subanjeri). At all sites except Perawang, saw-log regimes which include thinning and pruning are represented, although thinning to date has only been completed in the *A. mangium* at Subanjeriji. The intended treatments have also been completed at Perawang. All treatments except those allocated to weed retention at Subanjeriji were replicated.

Fig. 6 – Locations of demonstration experiments

The spacing at planting adopted for all demonstration trials was 3 × 3 m except at Finnantara (3 × 2.5 m). Each whole plot consisted of 11 × 11 = 121 trees with two buffer rows within each whole plot; thus there was a total of 49 measured trees in the net plot (Table 7). There were four types of treatment, and not all treatments were applied at all sites. Where treatments were replicated, there were either two or three replications. Weed control and at-planting fertiliser applications followed standard operational practice.

- Treatment #1: Pulpwood regime;
- Treatment #2: Saw-log regime – final stocking 600, 400 or 200 stems ha^{-1});
- Treatment #3: Treatment #2 with post-planting N fertiliser (*E. pellita* only);
- Treatment #4: Pulpwood regime with weeds retained.

Inputs for the saw-log regimes were as follows:

- Singling and form-pruning if needed and as necessary;
- 1st thinning to 600 stems ha^{-1} at DBH = 8-9 cm (for pulpwood) at age 1.5 years;
- 2nd thinning to 400 stems ha^{-1} at DBH = 11-12 cm (for small saw-logs) at age 2.5+ years;
- 3rd thinning to 200 stems ha^{-1} at DBH = 15-16 cm (for small saw-logs) at age 3.5+ years.

2nd and 3rd thinning treatments involved multiple thinnings, first 600, then to 400, then to 200 stems ha^{-1}. Thinning focused on the removal of trees that were suppressed or of poor form, and in a way that resulted in an even as possible distribution of retained trees.

Table 7: Plot sizes, treatments and tree numbers for plots established at 3 m × 3 m spacing and thinned to either 600 or 400 stems ha^{-1}.

Treatments (stems ha^{-1})	#Tree numbers per plot^{-1} Gross	 Net
1111	121	49
600	65	26
600→400	44	17
Plot size (ha)	0.109	0.044
Dimensions (m × m)	33.0 × 33.0	21.0 × 21.0

Sawing trials

Logs for the sawing trial were harvested in 2012, from an *E. pellita* stand that was then 10 years old. Twenty trees of good form that would each produce at least one 4-m basal log with a small-end diameter under bark of at least 15 cm were harvested from the larger size classes. The basal log was cut to a 4-m length; the diameter at the base and top of each log was accurately measured and used to calculate log volume; log straightness was also measured. A 5-cm thick disc from the base of the log was removed to calculate heartwood proportion and sapwood width.

End-splitting at both ends of the log was assessed by measuring the length of each split. Coloured paint combinations were applied to the cut ends to uniquely identify each log; subsequent measurements made on sawn boards could then be traced accurately back to the harvested tree; the cut ends were sealed with wax to arrest further end-splitting. The trees were stored using a standard procedure; end-splitting was remeasured just ahead of sawing and a digital photograph taken of both cut ends of each log with a scale.

A subsample of eight logs of DBH between 21 cm and 27 cm were randomly selected for the detailed laboratory measurements. Six additional logs were also measured, but only for calculation of percentage recovery of green sawn timber; these were allocated to spacers in the stack. The six remaining trees were allocated to buffer boards in the stack so that edge effects did not affect the drying of the boards used for detailed measurements. Each log was back-sawn following the standard commercial procedure to maximise the recovery of sawn boards. An agreed sawing pattern was adopted that minimised variation in board size. The centre cant was sawn into 3-to-4 boards of standard size, about 100 × 25 mm. The outer sections were then sawn into similar size or smaller boards, about 75 × 19 mm. Each log yielded between 6 and 10 boards. The orientation of the board in relation to the base of the log, and the side as it came off the saw were recorded.

The number, length, width and thickness of boards sawn from each tree were measured to calculate sawn green-volume recovery. Each board was scored for distortion: twist, spring, bow; and defects: end-splitting (length and number), knots (total and dead); wane; surface checking; rot. For air-drying, a stack was constructed under shelter. A single spacer (four per level) was used between each layer; three spacers were used at ground level to ensure good clearance and ventilation. The boards from the eight trees selected for intensive assessment were placed in the middle of the stack with at least two buffer boards on either side and at least one at the base and top of the stack. Each layer was either of the larger or smaller boards to ensure even compression on all boards. Additional weight was added at the top to ensure the boards near the top were firmly compressed.

The boards were reassessed as above approximately 30 weeks later in early October 2012. The latter part of the drying period was during the dry season. In addition, a Delmhorst Instrument Co. RDM-3 wood moisture meter was used to record the surface moisture content in the middle of either side of each board. As *E. pellita* is not one of the species programmed in the instrument, the constants for *E. tereticornis* were used.

Sawmill Capacity Survey

The requirement of this study was to answer the question: what saw-milling capacity already exists in the growing regions and is there a market to realise small-holder investment in saw-log silviculture? A survey form was prepared which addressed saw-log prices and costs, log sizes, and species and volumes processed. Two small saw-mills in South Sumatra answered the survey. It was not possible to visit any sawmills in Riau Province. Part of the advice received from Sinarmas Forestry was that wood supplies to saw-mills in Central Sumatra at that time were dominated by the illegal sector, and that currently there was no shortage of native-species logs, although this was expected to change.

5.1.4 Objective 4

GIS-based risk analysis of mortality

This was a desktop exercise utilizing pre-existing company data from Pre harvest Inventory assessments. The choice of location was made by the company and the GIS work was carried out by company staff and students in the operational division of RAPP with statistical analyses conducted by Marcus Hardie and Ross Corkrey at the University of Tasmania.

Estate Information

The trial estate occupies around 11,000 ha. The mean annual rainfall (1996 - 2003) is 2880 mm, with average rainfall exceeding 130 mm in all months. Inventory data were provided on the condition that: (i) they are commercially sensitive and must remain confidential, and (ii) there would be no explicit link between a set of data and ownership or precise geography in the presentation of results, (iii) spatial analysis was to be conducted internally by company staff in Indonesia, (iv) transferred data would not contain geographic co-ordinates.

Inventory data

Within the trial estate, *A. mangium* was planted at 3 x 2.5 meters spacing, a stocking rate of 1333 trees per ha. Since July 2011, a Pre-Harvest Inventory (PHI) has provided data on tree growth and mortality approximately 1 year before harvest. Typically each compartment has in the order of 10 - 20 PHI sampling plots, equivalent to approximately 2.0 - 2.5 % of the compartment area, depending on forest homogeneity. PHI plots consist of a geo-referenced, circular 11.28 meter radius area (0.04 ha) in which each tree is assessed for production including; diameter at 1.35 meters, max height of the 5 tallest trees, stems per ha (live and dead), standing dead trees, standing live trees (THA), merchandisable wood volume (Mvol), and likely cause of mortality including; wind, *Ganoderma*, monkey, elephant, frost, and *Ceratocystis* from recently deceased or infected trees at the time of assessment.

Topographic analysis

The digital elevation model (DEM) was derived from manual spot height 50 m x 100 m surveys of the entire estate using a Trimble Geo XT GPS calibrated to local benchmark (determined by differential GPS) and hand held inclinometer. Terrain analysis was conducted in SAGA, attributes included; valley bottom flatness (MrVBF), topographic slope (TS), topographic wetness index (TWI), topographic position index (TPI), valley depth (VD), normalised height (NH), mid slope position (MSP), and profile curvature (PC). Terrain attribute maps were exported to ARCGIS as tiff files and reclassified for analysis.

Soil analysis

Soil mapping was conducted in 2005 at 1:10,000 scale at the USDA family level (Soil Survey Staff 1998). Profile description and sampling was conducted on a 200 metre grid using Standard Guidelines for Soil Profile Description (FAO 1990), chemical analysis was conducted according to Soil Survey Laboratory Methods Manual (Soil Survey Laboratory Staff 1992). For each soil polygon, soil attributes including; depth, pH, CEC, C:N ratio, base saturation, sand %, clay %, silt %, colour, total nitrogen, total carbon, and Bray phosphorus were estimated for both the A and B2 horizons by averaging values from soil sampling sites within each polygon. In soil polygons for which no sampling was conducted, soil attributes were assigned values from the nearest polygon of the same family unit. Spatial analysis of soil properties assumed profile characteristics and soil chemistry apply equally within and between all polygons of the same family level.

Spatial Association

Soil and topographic attributes were determined for each PHI plot in ARCmap by intersection of the geo-referenced 0.04 ha PHI plot area with the soil and topographic data layers. Where intersection resulted in mixed attributes, values within the 0.04 ha plot area were averaged and calculated from the proportional area of each value. All attribute values were then recoded back to original index values in Excel.

Statistical analysis.

The effect of soil type on THA, Mvol and the cause of mortality was determined using one-way analysis of variance in SPSS v22, with Bonferroni post test at $p = 0.05$. The influences of soil and topographic attributes on THA and Mvol were analysed using stepwise linear regression in SAS 5.1 ($p<0.15$ to enter and stay in the model). Potential relationships between THA and Mvol with the soil and topographic attributes were also explored using a range of non-linear models in SPSS v 20. The possibility that relationships between THA, Mvol and mortality may exist with near maximum soil and topographic values was explored by Quantile regression for the 90th quantile using the *proc quantreg* and *proc quantselect* procedures in SAS 9.3 (Koenker and Bassett 1978).

As most soil and topographic attributes were not normally distributed and generally could not be improved by log or square root transformation, analysis was also conducted using a combination of non- parametric Spearman correlation in SAS 5.1, and partition analysis using the decision tree, bootstrap forest and boosted tree procedures in JMP PRO v11.

Examination of the biology, reproduction, population genetics and dispersal of Ganoderma philippii

The spore germination and mating type components were based on laboratory work at CFBTI, carried out by David Page, Desy Puspitasari, Morag Glen and Caroline Mohammed. Basidiospores were collected opportunistically by suspending filter papers under sporocarps while still attached to *A. mangium* or *Eucalyptus* trees or stumps and leaving overnight. Heru Indrayadi also supplied additional basidiospore collections.

Basidiospore germination:

As an axenic method of germinating basidiospores of *Ganoderma philippii* has not previously been published, an experiment to determine suitable conditions for basidiospore germination was conducted. Factors tested included basidiospore density, nutrient media and media additives such as ethanol and sawdust.

Ganoderma mating systems:

Basidiospores from two sporocarps of *G. philippii,* two sporocarps of *G. australe* and one sporocarp of *G. mastoporum* were germinated and monokaryon isolates obtained. Ten monokaryons from each sporocarp were paired in all sibling combinations and scored for formation of clamp connections and nuclear migration by fluorescent microscopy.

Reactions were scored as compatible if clamp connections and dikaryon formation were observed, semi-compatible if clamp connections were observed without nuclear migration, or incompatible if clamp connections were not observed. Some incompatible pairings also produced macroscopically visible reactions such as a barrage or a clear zone between the two isolates.

Two studies were planned for the population analyses; the first study is based on isolates collected from *Acacia mangium* plantations in the previous ACIAR root-rot project, FST 2003/048 and will test the hypothesis that genetic diversity of *G. philippii* increases as the rotation number increases. This will help in determining the contribution of sexual vs. asexual reproduction in the spread of *G. philippii*. The isolates have been revived, DNA extracted and sent to Australia and microsatellite analysis of these samples is underway.

The second study is based on two trial sites established by RAPP. The Baserah and Logas trials were established to examine the effects of destumping on root-rot incidence and the susceptibility of four different host species. These plots were offered to the ACIAR project at the conclusion of RAPP's study and were considered excellent sites to be included in the study of *Ganoderma philippii* population genetics. Each site contained 100-tree plots of *Acacia mangium, A. auriculiformis, Eucalyptus pellita* and *E*. hybrid, with 6 replicates of each treatment (species x destumping = 8 treatments). This provided the opportunity to examine gene flow among the different host species and to consider the potential for host adaptation, as well as looking at genetic diversity in subsequent rotations at the same site.

We surveyed and sampled the plots to obtain *G. philippii* isolates before the sites were harvested, and again after replanting. The fieldwork required a large team effort from RAPP, CFBTI and the University of Tasmania. Isolations were carried out in field accommodation or at CFBTI. Baserah was replanted to *Eucalyptus* and Logas was to be replanted to *Acacia* but delays in paperwork prevented this occurring in time for a post-harvest resampling within this project. A second pre-harvest sampling at Logas was conducted in April 2015, just prior to the harvest, with the expectation that it may be possible to conclude this study in a future project. All isolates are maintained at CFBTI and DNA was extracted at CFBTI and sent to the University of Tasmania for microsatellite analysis.

Development of microsatellite markers. The availability of next-generation sequencing technologies has expedited the discovery of microsatellite loci for population genetic studies without prior DNA sequence knowledge. In this study, DNA was extracted from *G. philippii* mycelium and sequenced on a Roche GS FLX. Shotgun sequences were screened for simple sequence repeat motifs of 2-6 bp, with at least four repeats, producing a file of 856 potential microsatellite sequences. A subset of 54 sequences that had sufficient sequence on both sides of the microsatellite locus to allow primer design and that did not contain additional microsatellite or mononucleotide repeats was selected for primer design. Primers were designed with a universal tail to allow labelling with fluorescent marker. Primers were screened against three isolates of *G. philippii* from geographically separate locations.

Pot trials assessing relative host susceptibility to various pathogens under different conditions (e.g. nutrient status, pH)

The experiments were conducted in large plastic pots (50 cm diam.) at Arara Abadi. Three soil types that are commonly found in the hardwood plantation estate in Sumatra were used in this study (Table 8). Pathogen inoculum was prepared by autoclaving pieces of *Acacia* wood, approximately 10 cm length by 3-4 cm diameter and incubating with one of the fungal isolates (Table 9) at 25 °C for 6 weeks. *Eucalyptus pellita* clone EP0077AA was grown from tissue culture and *Acacia mangium* was grown from seedlings, and both were 3 months old at the start of the experiment.

Table 8: Soils used in pot experiments.

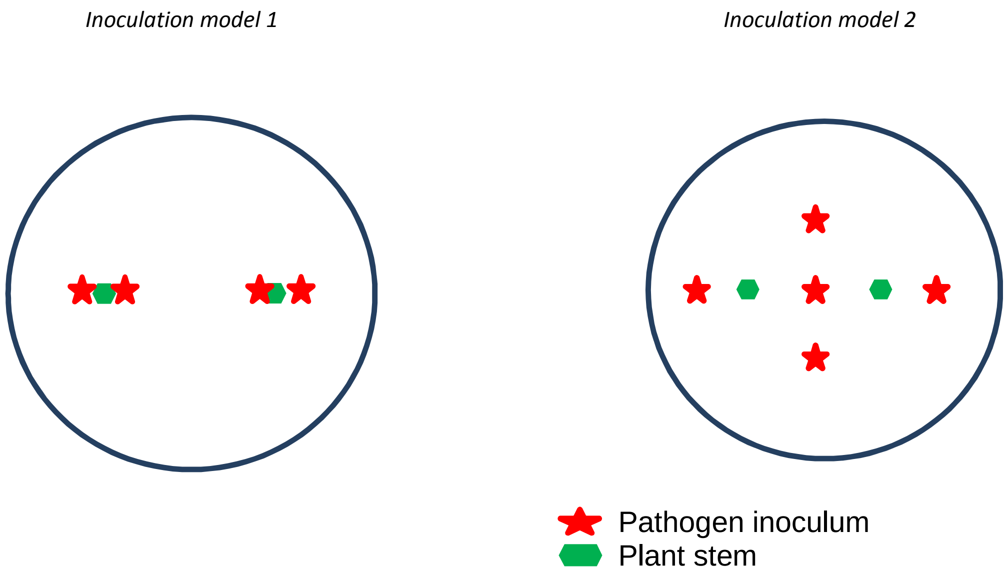
Soil	Texture	Source
R41	Sandy clay loam-sandy loam: sand >45%, clay 18-34%	Minas Rasau Kuning District P. RSKA175A
R51	Loamy sand-sand; clay <18%	Minas Rasau Kuning District Kampung Nias area
Peat	Ombrogenous deep peat (>3 m)	Minas Rasau Kuning District BF9

Table 9: Fungal isolates used in pathogenicity tests.

Species	*Isolate*	*Origin*	*Date isolated*
G. philippii	*5-D-3-C-12(M).3*	*Deras*	
G. philippii	*6-LS-3-D-56(M).3*	*Logas South*	
P. noxius	*4-D-2C-105(M)-A.2*	*Deras*	
P. noxius	*LC-RK-11C-36.1*	*Rasau Kuning*	

Two trees of the same species were planted in each pot, approximately 36 cm apart. Standard practice when conducting pathogenicity tests at Sinarmas is to place the pathogen inoculum immediately adjacent to the tree roots, but to allow the soil to have some effect on the interaction it was considered necessary to place the inoculum block farther away from the roots. Two modes of inoculation were therefore used; (1) two inoculum blocks were placed vertically in each planting hole, touching the seedling roots just below the soil surface and (2) five inoculum blocks per pot were placed vertically at a distance of 10-20 cm from the trees, just below the soil surface (Figure 7). Pots were rain-watered and monitored for symptoms and tree deaths on a weekly basis for 50 weeks.

Figure 7: Schematic diagram of the two different inoculation methods.



Eight additional pots of each soil type were used to check survival of the pathogen in the absence of plants. These pots each had 24 inoculum blocks covered with soil and 2 blocks per isolate were removed monthly and re-isolation of the pathogens attempted from the harvested blocks.

Histological investigations of differences between less and more susceptible hosts

Sample collection

Infected *A. mangium* root samples were obtained from a pot trial that examined the pathogenicity *G. philippii* in 6-month-old seedlings. Infected *E. pellita* root samples were collected from a pathogenicity pot trial and from a naturally infected young plantation tree. All samples were collected from Riau province, Sumatra, Indonesia.

Sample preparation and microscopic examination

Samples were washed before preserving in modified Davidson's fluid (30% formaldehyde solution (37-40%), 15% ethanol, 5% glacial acetic acid and 50% distilled water) and imported into Australia under import permit IP12004229. In the laboratory, specimens were initially fixed in 2.5% (v/v) glutaraldehyde in 0.1 M phosphate buffer pH 7.2 under vacuum for 30 mins followed by 12 hr in fresh fixative at 4 °C. Following two buffer washes each of 20 mins, the tissue blocks were dehydrated in an ascending acetone series and taken through three changes of 100% acetone each for 4 hr before being infiltrated with Spurr's resin (Spurr 1969) and polymerized at 70 °C for 8 hr. Thin sections, 4-5µm, were cut and transferred to a drop of sterile distilled water on a clean glass microscope slide and gently heat-fixed to the glass. The slides were then immersed in 0.1% (w/v) Toluidine Blue O in 1% sodium borate solution for 60 s, rinsed in distilled water, decolourised in 70% ethanol for 30 s, rinsed again in distilled water and air dried before being mounted in Euparal (Australian Entomological Supplies, NSW, Australia) beneath a coverslip. Images were captured with a Leica DFC420 photosystem mounted on a Leica DMLB compound microscope fitted with standard bright field optics. Digital images were managed with Leica Application Suite software version 3.6.0.

5.1.5 Objective 5

In vitro assessment of biocontrol (BCA) antagonism.

1. **Dual cultures on agar media and wood blocks**

The growth of both pathogens and BCAs in single and dual cultures on standard media was observed. Previous studies on malt or potato dextrose agar media showed that *Ganoderma philippi* grows slowly in comparison to *P. noxius* and various BCA isolates and is thus easily outcompeted in dual cultures (whatever the BCA) if subculture plugs are placed onto a plate simultaneously.

Plugs of *G. philippii* mycelium were therefore placed on agar medium and incubated for 1 week before BCA plugs were placed at a distance of 4 cm from the edge of the pathogen inoculum. In the screening of *P. noxius* plugs from both isolates (i.e. the pathogen inoculum and BCA) were placed on the agar simultaneously, at a distance of 4 cm.

Three confrontation screening trials were carried out; two with agar media and one with wood blocks;

i. The ranking of 20 candidate BCA isolates according to their biocontrol activity. Dual cultures were set-up in every possible combination between one isolate of *G. philippi*, one of *P. noxius* and 20 BCA isolates from 7 different species (Table 10). Single cultures of each pathogen were set-up as controls. The medium was Oxoid 2% malt extract agar amended with sawdust. The observations made included growth data of mycelium growing from each inoculum plug every day for 7 days; the nature of the interactions between isolates (macro and microscopic observations).

ii. The outcomes of the first trial (in respect to the ability of BCA isolates to reduce the growth of pathogen agar cultures) were validated by setting up dual cultures on Oxoid potato dextrose agar. Every possible combination was set-up between two BCA isolates with the highest level of BCA activity and one less promising BCA isolate, two isolates each for *G. philippi* and *P. noxius*. Control cultures of the pathogen isolates were also set-up.

iii. Dual cultures or confrontations were set up on sterile rubber wood blocks (6 x 3 x 0.5 cm) contained in petri dishes. Three methods for establishing the pairings were used, as follows:
    a. BCA and pathogen agar introduced onto wood block simultaneously.
    b. Pathogen incubated on the wood-block for one week before introducing the BCA.
    c. BCA incubated on the wood-block for one week before introducing the pathogen.

Three BCA isolates with good biocontrol activity as demonstrated in the cultural screening trials were used for the wood block experiments i.e. *Phlebiopsis* (Pb8), *Cerrena* (Cr6), and *Phlebia* (Pl3). The two pathogen isolates were the same as those used in the cultural trials i.e. Gp1 (*G. philippii*) and Pn2 (*P. noxius*). Every possible combination was set up and replicated three times (=59 wood block cultures).

Table 10: Twenty candidate biological control agents used in these experiments.

Species	Isolate	Code
Phlebiopsis sp. 1	LC-RK-11A-4	Pb1
Phlebiopsis sp. 1	LC-RK-11A-6	Pb2
Phlebiopsis sp. 1	LC-RK-11A-32	Pb4
Phlebiopsis sp. 1	LC-RK-11A-37	Pb5
Phlebiopsis sp. 1	LC-RK-11B-3	Pb6
Phlebiopsis sp. 1	LC-RK-11B-16	Pb8
Phlebiopsis sp. 1	LC-RK-11C-18	Pb9
Phlebiopsis sp. 1	LC-RK-11C-34	Pb10
Phlebiopsis sp. 1	LC-RK-11C-35	Pb11
Cerrena sp.	7-L-4-B-20(M)-A.1	Cr1
Cerrena sp.	7-L-4-B-15(W)-A	Cr2
Cerrena sp.	6-SU-2-B-55(W)-B.2	Cr3
Cerrena sp.	7-SU-3-B-55(W).1	Cr4
Cerrena sp.	7-SU-3-B-77(M)-B.2	Cr5
Cerrena sp.	7-S-4-A-25(M)-A.1	Cr6
Cerrena sp.	LC-RK-11B-4	Cr7
Phlebia brevispora	7-SU-3-E-3(FB)-B	Pl1
Phlebia sp. 1	T175B1 (L-T17-B.1)	Pl2
Phlebia sp. 2	E8898-A	Pl3
Phlebia sp. 3	FB1A2 (BS-FB1-A.2.3)	Pl4

Production of BCA oidia

Five experiments were carried out to investigate oidial production, storage and colonisation on wood blocks.

i. Ranking of the 20 different candidate BCA isolates of *Phlebiopsis*, *Cerrena* and *Phlebia* (see Table 10) according to their level of oidia production.

Twenty small bottles each containing 10 ml of water were autoclaved. When cool, six mycelial plugs from a single petri dish of each isolate were added to the bottle, shaken gently and allowed to sit for 1-2 hours with occasional gentle shaking. From each bottle, 20 ul was pipetted onto each of three petri dishes and spread with a cooled, sterile glass spreader. After three days, the number of colonies on each plate was counted and recorded. The colonies were allowed to grow long enough to confirm that the colonies are those of the BCA species and not contaminants.

ii. Testing the influence of media on oidia production.

The two best performing *Phlebiopsis* and *Cerrena* isolates in terms of oidial production were selected for testing the influence on oidial production of different media. Any *Phlebia* isolates that produced oidia in experiment 1 were tested on different media. The BCA isolates were plated onto 3 plates each of PDA, MEA and MEA + sawdust. The cultures were incubated for 1 week and then each isolate x medium combination was tested for oidia production as in experiment 1. If an isolate only produced a low number of oidia it was tested again after 2 weeks.

iii. Comparing oidia production by cultures of different ages

The plates prepared for experiment 2 were retained selecting for each isolate its best-performing medium. Eight isolates (3 replications of each isolate) were tested for oidia production as described above after 2 weeks, 4 weeks, 8 weeks and 12 weeks.

iv. Assessing the longevity of oidia in water, sucrose solution, vegetable oil and mineral oil

10 ml bottles were prepared containing sterile water, sucrose solution, vegetable oil and mineral oil (6 bottles for each substrate). One isolate of each species was selected from experiment 2 and plated out (i.e. one isolate of *Phlebiopsis*, one of *Cerrena*, one each of any *Phlebia* species that produced oidia). The oidial counts on the plates were monitored. As soon as there was a good level of oidial production six plugs from each plate were put into a bottle of each liquid, shaken gently and left to sit for 1-2 h with occasional gentle shaking. From each bottle, 20 ul was plated onto 3 MEA plates and spread with a sterile glass spreader. After 3 days incubation at room temperature, the number of colonies on the plates were counted (allowing sufficient growth to identify the colonies). This step was repeated at day 4, day 8, weeks 2, 4, 6, 8, 12 and 16.

v. The colonisation of wood blocks with oidia preparations in oil, sucrose and water.

Rubber wood blocks and acacia branch segments (cut into small enough pieces to fit into a glass petri dish) were sterilised; three blocks were prepared for each isolate x liquid combination (up to 72 blocks of each wood). 100 ul from each bottle of oidial suspension was pipetted onto the top of 3 rubber wood and 3 acacia wood blocks (the oidial suspensions from trial iv were used at the same time as the oidia were plated onto agar medium). The blocks were incubated at room temperature and observed weekly (under a dissecting microscope initially, until growth was macroscopically visible), taking notes and photographs.

Pot-trial to verify BCAs are non-pathogenic and assess effectiveness of reducing plant mortality in soil

The performance of potential BCAs was tested by placing inoculum of BCA with pathogen inoculum in 20 cm polybags in which seedlings of *A. mangium* were grown and recording tree deaths. *Acacia mangium* seedlings, 5-7 weeks old were grown in 20 cm diam. polybags, containing soil, pathogen inoculum and BCA inoculum, maintained in shade houses for 12 months, with symptoms and deaths recorded weekly.

Nine potential BCA isolates (Table 11) were tested using two inoculation methods, against four pathogen isolates (Table 11), with five replications of each treatment. One trial was established by Sinarmas and one by RAPP, using the same pathogen isolates and a mixture of BCA isolates (Table 12)

Table 11: Isolates of pathogen and BCA used in the polybag trials

Species	Isolate	Code	Company
Phlebiopsis sp.	LC-RK-11A-4	Pb1	Sinarmas
Phlebiopsis sp.	LC-RK-11A-6	Pb2	RAPP
Phlebiopsis sp.	LC-RK-11C-18	Pb9	Sinarmas, RAPP
Cerrena sp.	LC-RK-11B-4	Cr6	Sinarmas
Cerrena sp.	7-SU-3-B-55(W).1	Cr4	Sinarmas
Cerrena sp.	7-SU-3-B-77(M)-B.2	Cr5	RAPP
Phlebia brevispora	7-SU-3-E-3(FB)-B	Pl1	Sinarmas
Phlebia sp. 1	T175B1	Pl2	Sinarmas, RAPP
Phlebia sp. 2	E8898A	Pl3	RAPP
Ganoderma philippii	6-LS-3-D-56(M).3	Gp1	Sinarmas, RAPP
Ganoderma philippii	5-D-3-C-12(M).3	Gp2	Sinarmas, RAPP
Phellinus noxius	PHA-007	Pn1	Sinarmas, RAPP
Phellinus noxius	LC-RK-11C-36.1	Pn2	Sinarmas, RAPP

Pathogen inoculum was prepared by soaking rubber wood blocks, 6 x 6 x 3 cm, in water for 24 h before autoclaving for 2 h at 121 °C. After cooling the blocks were removed from the water and repackaged into autoclavable plastic bags, autoclaved for 20 min then inoculated with mycelia of the pathogen and incubated at room temperature for 3-4 weeks.

Two types of inoculum were prepared for the BCA isolates. Woodblock inoculum was prepared as for the pathogen inoculum. Sawdust inoculum was prepared by placing 1 kg sawdust in autoclavable bags with 1.2 L water and autoclaving for 2 h at 121 °C. After cooling, two petri dishes of agar inoculum were cut into approx. 1 cm squares and mixed into the sawdust. Bags were incubated at room temperature for 3-4 weeks.

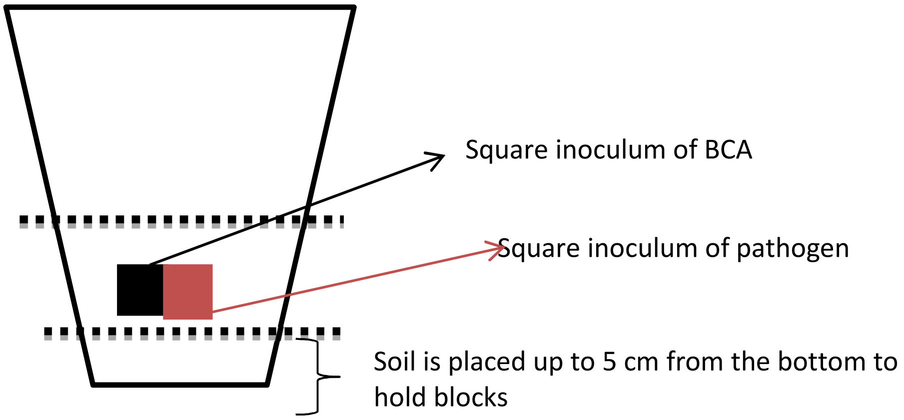
BCA inoculation method 1 (sawdust inoculum)

Sawdust colonized with BCA was mixed in a 1:4 ratio with potting soil, three seedlings planted into each 2 cm diam. polybag in the sawdust/soil mixture and, after two weeks, pathogen inoculum blocks were slipped down the side of the polybags to a depth of approx. 10 cm.

BCA inoculation method 2 (wood block inoculum)

A layer of soil, approx. 5 cm deep, was placed in the bottom of each polybag. The pathogen and BCA inoculum blocks were placed close together, side-by side, forming one 6 x 6 x 6 cm cube (Fig. 8), on top of the soil layer and covered with soil, 1 cm above the top of the blocks. After two weeks, 10-15 g of Osmocote was added, followed by another this layer of soil before three seedlings were planted in each polybag.

Fig 8. Wood block inoculation method



Controls, including BCA inoculum alone and pathogen alone, were established using wood-block inoculum and *A. mangium* seedlings or *E. pellita* cuttings. The *E. pellita* controls were included to test the pathogenicity of the BCAs against this host species. Polybags were maintained in shade-houses, in a randomized complete block design, and trees were monitored for symptoms including wilting, yellowing of leaves, and death. When mortalities occurred, the roots were removed and examined for signs of infection to confirm the cause of death.

Harvesting and re-isolation from BCA and pathogen wood-blocks.

One complete replicate of all treatments was harvested after 9 months, roots inspected for signs of infection and re-isolation attempted from all inoculum wood-blocks (BCA and pathogen). The remaining polybags were harvested at the end of the trial.

Field test of successful BCAs

Candidate BCA isolates for the stump trials were grown at CFBTI (Table 12), in petri dishes containing PDA, PDA plus sawdust and on rubber wood blocks. The agar medium and wooden blocks were chopped up and mixed with sterile water to make an oidia suspension 1-2 h before application of oidia to stumps.

Table 12: Candidate BCA isolates used in stump trials at Teso West and Rasau Kuning

Species	Isolate	Code	Oidia concentration (ml^{-1})
Phlebiopsis sp.	LC-RK-11A-4	Pb1	2,500
Phlebiopsis sp.	LC-RK-11C-35	Pb11	5,000
Cerrena sp.	7-L-4-B-20(M)-A.1	Cr1	>10,000*
Cerrena sp.	LC-RK-11B-4	Cr7	-**
Phlebia sp. 1	T175B1	Pl2	125
Phlebia sp. 2	FB1A2	Pl3	15

**Too many to count in the petri dish*

***Plates contaminated*

Stump trials were conducted at two locations (Table 13). Eight blocks of 7 trees were felled, leaving stumps 40 cm high, to allow a 10 cm disc to be sliced from the stump at the time of sampling. Each BCA was randomly allocated to a stump within each of the 7-tree blocks and applied to freshly cut stumps as an oidia suspension.

Table 13: Site details for oidia stump trials

Location	Tree species	Age (years)	Rotation	No. of treatments *
Teso West	*Acacia mangium* FAM003	3.5	?	9
Rasau Kuning	*Eucalyptus pellita*	4	1st (after 3 *A. mangium)*	7

**including controls (water only)*

After 10 weeks, a slice of approximately 10 cm was removed from the top of the stump and transported to CFBTI. A vertical slice was taken through the middle of the log and samples removed for fungal isolation and DNA extraction at depths of 5 mm, 5 cm and 10 cm.

For fungal isolation, slivers of wood were plated onto PDA plates and incubated at room temperature. Samples of mycelium were cut out of the agar and stored at -20 °C until DNA extraction. DNA was extracted and BCA species confirmed by species-specific PCR.

Primers were developed for preferential amplification of each of the four candidate BCA species, *Phlebiopsis* sp., *Cerrena* sp., *Phlebia* sp. 1 and *Phlebia* sp. 2, in a manner similar to those developed for *Ganoderma philippii* (Yuskianti et al., 2014). Isolates were tested with each species-specific primer set.

A trial to test the efficacy of BCA isolates applied as wood-block inoculum in the planting hole was established in Compt B001 at Logas. This site has a history of high levels of *Ganoderma* root rot. The trial included nine treatments; seven ACIAR candidate BCA isolates (Table 14), two RAPP candidate BCAs (not shown) and a control (uninoculated wood-block). Plots were 25 trees (5 x 5) with 20 replications. The trial was established in October-November 2014 and first assessment took place in April 2015 at six months of age.

Table 14: Candidate BCA isolates used in the field trial

Species	Isolate	Code
Phlebiopsis sp.	LC-RK-11A-4	Pb1
Phlebiopsis sp.	LC-RK-11C-35	Pb11
Cerrena sp.	7-L-4-B-20(M)-A.1	Cr1
Cerrena sp.	LC-RK-11B-4	Cr7
Phlebia sp. 1	T175B1	Pl2
Phlebia sp. 2	E8898A	Pl3

5.1.6 Objective 6

Objective 6 aimed to better understand the knowledge, social experiences and conditions of small landholders in managing short-rotation plantations and how these plantations impacted the lives and livelihoods of small landholders. We aimed to establish effective knowledge transfer systems to ensure all technical research can be fed back to smallholder growers.

As part of their corporate social responsibility programs, paper and pulp companies in Indonesia have engaged at different levels with the local communities. Instead of focusing on general corporate social responsibility programs, this objective focussed on the partnership arrangements between the industries and small land holders where small land holders had agreed to use their own land to grow acacia for pulp production. These small land holders could receive financial support and technical advice from the companies. This type of partnership produced significant benefits for the company as well as the individual growers because it increased the land-base from which the industries could grow trees, and at the same time it helped build rapport with the local communities.

Short-rotation plantations can also be independently adopted by farmers. Objective 6 also included a selection of these farmers as they are able to directly implement changes to the management of their farm. Therefore, we looked across two community forestry schemes and sought to address two questions:

- What is the social profile of small landholders who are involved in the partnership with the companies?
- What livelihood impacts have the partnerships produced for participating and non-participating smallholder farmers?

All research work was approved with ethical clearance from CSIRO social science human research ethics committee (and from the University of Western Australia human research ethics committee for Activity 2). Verbal consent was sought from participants before the survey began. Each respondent was also provided with an information leaflet detailing the study and various contact numbers for his or her future reference.

Activity 1. West Kalimantan: Impacts of company-community partnerships on local livelihood.

Methodology: The two research questions were addressed by a livelihood impact assessment in West Kalimantan. We conducted two-stage face-to-face interviews with smallholder growers who chose to join a partnership with Finnantara Intiga and those who did not join. A total of 101 interviews were conducted in the first stage. All surveys were conducted in Bahasa Indonesia by five native Indonesian speakers. Each survey took approximately one hour to complete. Depending on the participation type, monetary compensation was given to people who completed surveys. Respondents who had to sacrifice their working hours to complete surveys were compensated Rp 50,000 (about AUD$5). Otherwise, respondents were given Rp 25,000 (about AUD$2.50). All respondents stated that they were willing to be re-interviewed.

The researchers returned to West Kalimantan four months after the first survey to re-interview these 101 respondents. Only 53 of first survey respondents were available for re-interview due to access constraints. Some villages were only accessible by boats and the boats were not in operation when the researchers returned. Some farmers were away from their usual place of residence during the second interview. In all, 59 new respondents were recruited in the second stage.

For both stages of the study, we utilised convenience sampling techniques to recruit respondents. As part of the study agreement, the company Finnantara Intiga and their advice on road accessibility was used to recruit potential respondents. In line with the local custom, verbal permission was sought from either informal or formal village leaders before the study commenced. At all times at least two interviewers arrived at the designated village with one of the company community extension officers who had made initial contact with village leaders. The company extension staff left the village as soon as introductions were made between the village leader and the study interviewers.

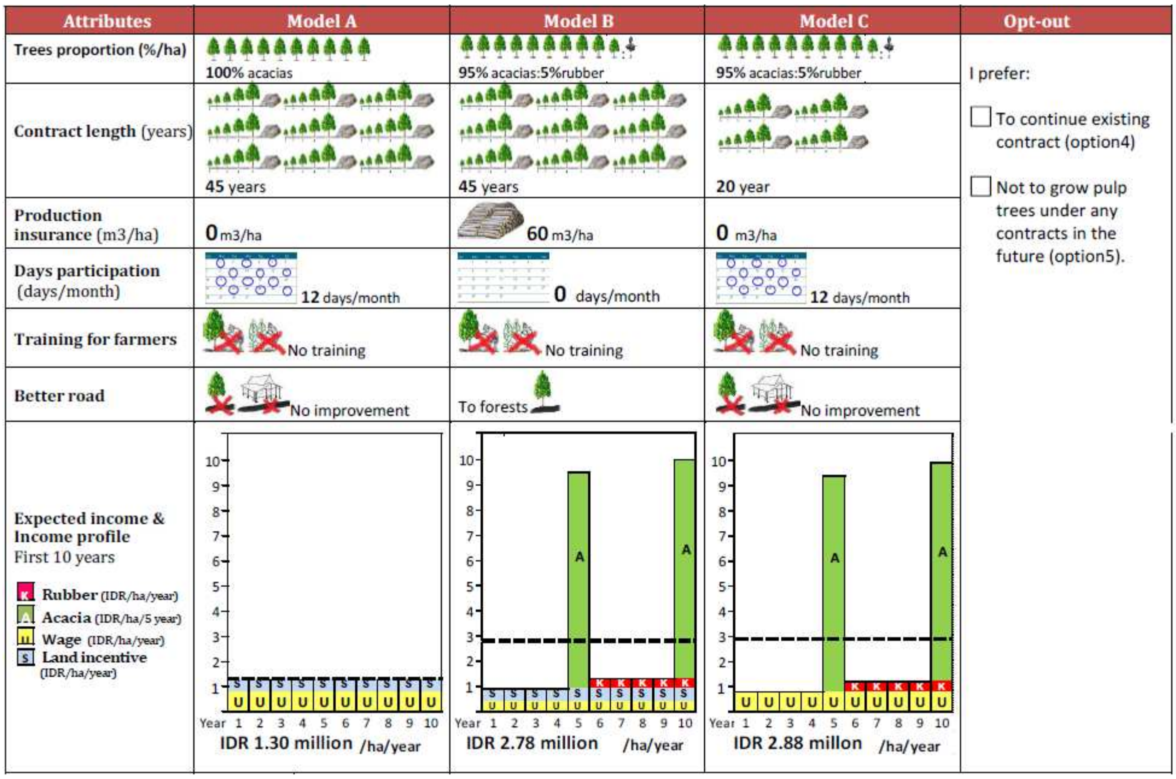
The interview was conducted in two-stages to ensure the quality of data collected and reduce the likelihood of respondents' fatigue. The interview in the first stage of the study focussed on profiling the respondents and obtaining the details of the partnership itself. The second stage was aimed at obtaining information on perceived changes in the partnership and farmer preferences on the partnership arrangements.

Activity 2. Conditions (or attributes) of partnership most important to smallholder farmers.

Choice experiments were also implemented as part of Objective 6 study to understand how small growers make their decisions to join Company-Community Partnership (CCP) schemes ***(Activity 2)***. The study was undertaken by the PhD candidate Dwiko Permadi. Two existing partnerships that were examined included PT Finnantara Intiga in West Kalimantan and PT Musi Hutan Persada in South Sumatera. In summary, the choice experiments aimed to find out what contract attributes are most influential to farmers' decisions to join the CCP schemes?

Methodology: Choice experiments are one of the stated preference methods used in economic valuation of non-marketed goods and services, which allows the results to be used in cost benefit analysis, demand analysis and economic simulations. The choice experiment study was conducted in three locations: West Kalimantan, South Sumatera and Yogyakarta, during August – September 2014, which involved 485 respondents. In this research, respondents were presented six sequential choice sets and asked their preference to select one option that according to them gives the highest utility among different options/models. Figure 9 shows one example of the choice sets given to respondents.

Figure 9. An example of choice sets presented to the respondents in West Kalimantan and South Sumatera, Indonesia. The question: imagine you have 1 ha private land and have rights to decide which option to select: which one do you prefer the most?



Attributes	Model A	Model B	Model C	Opt-out
Trees proportion (%/ha)	100% acacias	95% acacias:5%rubber	95% acacias:5%rubber	I prefer: ☐ To continue existing contract (option4) ☐ Not to grow pulp trees under any contracts in the future (option5).
Contract length (years)	45 years	45 years	20 year	
Production insurance (m3/ha)	0 m3/ha	60 m3/ha	0 m3/ha	
Days participation (days/month)	12 days/month	0 days/month	12 days/month	
Training for farmers	No training	No training	No training	
Better road	No improvement	To forests	No improvement	
Expected income & Income profile First 10 years K Rubber (IDR/ha/year) A Acacia (IDR/ha/5 year) U Wage (IDR/ha/year) S Land incentive (IDR/ha/year)	IDR 1.30 million /ha/year	IDR 2.78 million /ha/year	IDR 2.88 millon /ha/year	

Activity 3. Gunung Kidul farmers and short rotation plantations.

Activity 3 of Objective 6 sought to address the following three research questions with stakeholder and farmer workshops in Gunung Kidul region

- What factors motivate farmers to adopt short-rotation plantations independently?
- What livelihood impacts can short-rotation plantations provide for these farmers?
- What support mechanisms exist to encourage farmers to uptake short-rotation plantations?

Methodology: Gunung Kidul was selected because the farmers are known locally to be active tree growers. Tree growing in the region was encouraged by the Indonesian government in the 1960s as part of a re-greening program. Tree growing has stayed in the culture of Gunung Kidul farmers and become a way of farming for those with farmland. Traditionally, teak is grown in the region. As teak takes at least 15 years to harvest profitably, there is a move to diversify tree growing to include shorter rotation tree species.

In total, nine workshops were conducted in Gunung Kidul: three workshops for forestry stakeholders and six for farmers.

Stakeholder workshop participants were chosen on the basis that the stakeholders must work with farmers. They included social forestry researchers (n=5), government forestry officers (n=8), and extension staff from non-profit organisations (n=5). Except for social forestry researchers, all other stakeholder participants were compensated for their time and fuel to attend the workshops. Social forestry researchers were invited to attend as part of their work commitments with a separate ACIAR project (ie. FST/2008/030 “Overcoming constraints to community based commercial forestry in Indonesia”).

Farmers were selected from the three southern regions of Gunung Kidul where acacias were historically preferred due to poorer soil conditions. They included (1) Jlumbang hamlet, Giripurwo village in Purwosari sub-district (n=20); (2) Palgading hamlet, Giripanggung village in Tepus sub-district (n=20), and (3) Jeruken hamlet, Girisekar village in Panggang sub-district (n=19).

We approached forestry extension staff to gain access to each hamlet leader. To encourage participation from female farmers, two separate workshops were organised in each hamlet: one for males and another for females. The hamlet leaders were asked to randomly choose local farmers to participate. Again, farmers were compensated for their participation in the workshops.

Each workshop included three main activities: (1) general discussion, (2) two or three survey questionnaires and (3) one institutional mapping exercise. Each workshop took up to three hours to complete.

Table 15 shows the basic population statistics of the three sub-districts selected for Activity 3.

Table 15 – Basic population statistics of the 3 subdistricts sampled for Activity 3

	Purwosari	Tepus	Panggang
Area in km^2	71.76	104.91	99.80
Population	19,601	32,282	26,839
No of villages	5	5	6
No of hamlets	32	83	44
Size of woodland/smallholder forests (ha)	2,302	5,704	2,215
Size of water pond, national forest (in ha)	672	148	2,269

Activity 4. Desktop review of policy arrangements.

Finally, a desktop review of the broad policy context surrounding small outgrower farmers and tree crops in Indonesia was conducted for **Activity 4.** This policy review was aimed to provide recommendations to create effective partnerships using available literature.

Methodology: A literature review and desktop analysis was conducted, approaching policy options in terms of understanding relational and contextual factors linking smallholders, forestry companies, and other forestry stakeholders. The international literature on social forestry is vast. We restricted our search for relevant literature to publications that focused on Indonesia, that either reviewed existing literature or presented integrative frameworks, and which was in English (since the researcher available was only able to speak English).

6 Achievements against activities and outputs/milestones

Objective 1: To assess the potential for E. pellita (and hybrids) as a second-rotation crop to benefit from the higher soil N derived from A. mangium grown in previous rotations and to manage the risk and consequence of pathogen build-up.

No.	Activity	Outputs/ milestones	Completion date	Comments
1.1	Establish and maintain core field experiments	2-3 core sites selected	December 2011	Completed 2011/12
		Core sites established	Due: February 2012 Anticipated: May 2012	Completed 2011/12
		Core site maintenance	Ongoing/as-needs basis	Sites are well maintained
		Measurement of tree productivity and root rot incidence	Due at 0.5, 1, 2, and 3 years after establishment	All sites have been measured as per the measurement schedule.
1.2	Validation of CABALA capacity to predict productivity of both species	Preliminary CABALA testing against 2 year data (objectives 1 and 2)	Due: May 2014, Revised: January 2015	Achieved within revised time schedule
		Revised parameters and/or reworked CABALA model in response to prelim. validation	Due: January 2015	Preliminary validation completed, but some issues with clonal variation mean that modelling is less meaningful than originally hoped for predicting volume growth.
		Final CABALA validation against 3 year data (objectives 1 and 2)	Due: April 2015	Completed (note caveat above), and we will be able to get more confidence in the model outputs once the trees at our intensively monitored sites are closer to rotation age.
1.3	Development of lookup tables and growers manual	Lookup tables developed and ready for inclusion in growers manual	Due: May 2015	Model-based lookup tables are not going to be as valuable as first hoped. The variation between clones and sites (eg. 2-fold difference between E. pellita clones at Lipat Kain) overwhelms the finer scale of information that models may have been able to provide. Information on the drivers of this variation is more important than understanding the fine-scale resource dynamics, and lookup tables based on empirical data will be more valuable than model outputs for this purpose.
		Revised growers manual	Due: May 2015	Growers manuals for *A. mangium* and *E. pellita* were released and are available on the project website (www.pohoncepattumbuh.com).

PC = partner country, A = Australia

Objective 2: To explore and extend the interactions between site edaphic properties, soil fertility, water availability and effects of management on productivity

No.	**Activity**	**Outputs/ milestones**	**Completion date**	**Comments**
2.1	Site characterisation at a range of sites with variable productivity, climate, soil, previous rotation history	Up to 30 sites selected (including outgrower farms)	Due: December 2011 Anticipated: December 2012	Completed
		Soil profiles described	Due: May 2012 Anticipated: May 2015	Soil profiles have been described at all sites.
		Soil chemistry completed	Due: October 2012 Anticipated: June 2015	Soil chemistry completed at all sites
		Quantitative analysis of relationship between site characteristics and productivity	Due: December 2012 Anticipated: December 2015	This has been completed for RAPP (see draft report: Sabar et al.), and Sinarmas. Both studies were presented at the final review/workshop.
2.2	Establishment of satellite experiments to compare *A. mangium* and *E. pellita* productivity under a range of conditions	Subset of 10 sites from activity 2.1 selected	January 2012	Reduced scope was addressed in 2011/12 report
		Sites established	Due: March 2012 Anticipated: July 2012	Completed in 2011/12 in South Sumatra, and in July 2012 in Riau.
		Measurement of tree productivity and root rot incidence	At 0.5, 1, 2, and 3 years after establishment	Measurements have been made, and were reported on at the final review. Draft paper by Maralop et al. details an interesting study into the management impacts on disease in *A. mangium* and *E. pellita*.
2.3	Value-adding to existing experiments	Wood sampling for isotopic analysis for water stress	Due: March 2012 Anticipated: July 2012 New anticipated: July 2014	Wood cores have been sampled from key sites. A full Silviscan analysis has been undertaken instead of isotopic analysis to better understand the impact of treatments on wood properties. Water stress is now being addressed separately through the instrumentation established at the core sites, and manuscript preparation is in progress (Hardie et al., Mendham et al.).
		Full-rotation assessment of responses to P fertilizer in already existing experiments	January 2013	Not achieved due to ceratocystis-linked premature deaths of trees in all of these experiments.

PC = partner country, A = Australia

Objective 3: To provide management options for enhancing profitability through smallholder plantation systems producing wood for both pulp and timber

No.	**Activity**	**Outputs/ milestones**	**Completion date**	**Comments**
3.1	Explore best-bet management options to maximise value of standing crop	Six sites, 4 in Central and 2 in South Sumatra selected (A, PC	January 2012	RAPP chose not to participate in this part of the project. In total five sites were established: SinarMas – 2 sites, one at Arara Abadi in Riau (**Arara; *A. mangium and E. pellita***), the second near Sintang in West Kalimantan (**Finnantara; *E. pellita***); Musi Hutan Persada – 2 sites, both at Subanjeriji in South Sumatera (**MHP1; *A. mangium* & MHP2; *E. pellita***); FORDA – 1 site in Central Java (**Gunung Kidul; *A. auriculiformis***). Except at **Arara** (pulpwood only), all sites include sawlog and pulpwood treatments. At some sites, a “weeds-retained” treatment is present.
		Singling and form pruning treatments applied as necessary; allocation of treatments; 1st growth measurements; maintenance schedule established (A, PC)	July 2012	**Arara** : There were large changes in survival between age 12 and age 18 months in both the *A. mangium* (<60%) and *E. pellita* (<80%). In the former, this was because of further disease ingression (mainly *Ceratocystis*); in the latter because of J-rooting and windthrow. Poor rooting of the eucalypt clones used by the company is a widespread problem at Arara; the effect of the containers on root development appears to be an unknown. At age 3 y, the surviving acacias have been irretrievably damaged by monkeys. Mean DBHob of the eucalypts (clone EP5147AA) at age 3 y was 12.8 (weed-free) and 12.5 (weeds-retained) cm. **MHP1**: 1st-lift pruning to 1.5 m was undertaken in June 2013; 2nd-lift pruning to 2.5 m in September 2013 and 3rd lift-pruning to 4.5 m in May 2014. The thinning program was completed in September 2014. At age 3 y, mean dbh in the Sawlog-400, Sawlog-600; Pulpwood-1111 and Pulpwood-1111-no weeding was 15.8, 17.4, 14.3, and 14.7 cm, respectively. Survival in the Pulpwood-1111 regime had declined from 76 to 55% from age 15 months to age 4 y because of losses to *Ceratocystis*. **MHP2**: The growth and survival of this plantation was compromised by intense weed condition which was not brought under control until August 2013 (age 7 months). Agreed-to activities (additional weed control, restocking and 1st-lift pruning) were unfortunately not undertaken. Pruning to 4 m and 1st thinning to 600 stems/ha has been undertaken in the saw-log regimes. In February 2015 (age 2 y), mean DBHob in the Sawlog-200, Sawlog-400, Sawlog-600 and Pulpwood-1111

				treatments was 11.6, 11.6, 10.7 and 10.6 cm, respectively. Survival in Pulpwood-1111 was 75.5%. **Gunung Kidul**: A qualitative assessment suggests that intercropping has had a positive effect on tree form without seriously compromising tree growth. The mean height and DBHob of the trees across the trial at age 14 months was 3.4 m and 2.9 cm. Differences between the four seedlots appear to be emerging (DBHob ranges between 2.5 and 3.4 cm). **FINNANTARA**: The three plots dedicated to a saw-log demonstration trial were form-pruned in March 2014.
		Thinning treatments applied (A, PC)	July 2013	**ALL TRIALS**: All thinning treatments are on schedule and have been completed at **MHP1** (no thinning treatments at **Arara**). See above for status
3.2	Integration	Incorporation of knowledge into CABALA to allow prediction of thinning effects	March 2015	Preliminary work with CABALA has been completed. Further development not pursued at this stage due to larger differences between clones than need to be modelled.
		Inclusion of high value sawlog option in the growers manual	May 2015	Completed, manual released in January 2015
3.3	Demonstrate best bet management options	Run field days and disseminate outcomes for at least 20 smallholders per site (A, PC)	December 2014	Field day for local farmers was held at Gunung Kidul in February and in South Sumatra in June 2015.

PC = partner country, A = Australia

Revised activities and timelines* ***Objective 4: To investigate the site factors and/or host properties which reduce the risk of root-rot incidence and/or severity***

No.	Activity	Outputs/ milestones	Completion date	Comments
4.1	GIS-based risk analysis of mortality in relation to soil and topographic factors.	Scope of project, data requirements, roles and responsibilities outlined, agreement on protocols for data access signed.	Completed	Preliminary literature review on disease risk assessment, mapping and methodology has been completed. Protocols for transfer of sensitive information have been developed. This project will focus on 20 compartments in the North Logas estate, which includes 13 USDA soil units. PHI is available for 900 2nd rotation and 180 3rd rotation plots.
		Develop suitable database at the plot scale to interrogate the incidence of mortality with soil/terrain attributes.	Completed June 2014	Company sensitivity about data sharing, problems in access to and communications with operational staff contributed to delays in getting to this stage and this will impact on completion dates of subsequent activities.

		Analysis of GIS/mortality data.	August 2014	Preliminary analyses indicate that relationships between mortality and certain soil/terrain attributes are significant, but the complexity of the interactions requires more detailed data that are at present not available.
		Preparation of a scientific paper on the influence of soil/terrain features on mortality and disease of *A. mangium.*	December 2014	A manuscript has been written and will be submitted for publication after internal review.
		Development of a preliminary mortality risk decision support tool.	December 2014	Results obtained indicate that a decision support tool is not possible until more detailed data is available.
4.2	Examination of the biology, reproduction, population genetics and dispersal of *Ganoderma philippii*	Collection of viable basidiospores, determination of the conditions required for germination and isolation of monakaryon cultures.	Completed	This study is the first to describe simple, reliable protocols for in-vitro germination of *G. philippii* basidiospores (manuscript written and submitted for publication). Germination of *Ganoderma philippii* has been problematic in the past, with the only published report indicating that ingestion by a particular insect was required to promote germination. The addition of ethanol to growth media stimulates the germination of *G. philippii* basidiospores.
		Determination of the mating system of *G. philippii.*	Completed	*G. philippii* has a bifactorial, tetrapolar mating system similar to other *Ganoderma* species. This promotes outcrossing and the generation of genetic diversity. A paper is at advanced draft stage.
		Development of microsatellite markers for *G. philippii.*	Completed	454 shotgun sequencing of *G. philippii* genomic DNA facilitated the development of forty primer pairs targeting simple repeat sequences (microsatellites). Half of these have been screened, with eight loci determined to be polymorphic. Another two loci require further optimisation for reliable PCR amplification.
		Survey and sampling of two RAPP ex-trial sites examining the effect of destumping on root-rot incidence in four host species.	Initial sampling completed.	Root-rot incidence in eucalypts appears to be increasing in successive rotations, as also occurred with *A. mangium,* indicating possible host adaptation. This study will examine gene flow among isolates from different hosts in close proximity.

		Survey and sampling of two RAPP ex-trial sites following harvest and replanting.	Delayed	One of the sites (Baserah) was planted with eucalypts and a preliminary survey revealed a low level of disease incidence. A second survey in early 2015 revealed a high incidence of red root rot in coppiced stumps and a higher disease incidence in other plots also. These samples are being fast-tracked for molecular work to determine whether the stump infections are likely to have arisen from stump colonisation by basidiospores. The other site (Logas South) was inadvertently omitted from the harvesting schedule and while permission has been granted, delays in processing the paperwork have meant that the second site still has not been harvested and replanted. A second sampling has been carried out at Logas in March/April 2015 and the remaining trees will be harvested very soon.
		Revival and DNA extraction of isolates from different rotations of A. mangium obtained in the previous root rot project .	September 2014	DNA from the isolates has been extracted and imported into Australia.
		Population genetic analysis, using microsatellite markers, of collections from different rotations and from RAPP ex-trial site.	December 2014	Microsatellite analysis of the pre-harvest population at Baserah has been completed and shows a highly diverse population.
4.3	Pot trials assessing relative host susceptibility to various pathogens under different conditions (e.g. nutrient status, pH)	- Supporting literature review & experimental plan in journal article format (A, PC)	Completed	Draft report in preparation
		- All materials obtained and trials underway (PC)	Completed	The pot trial at Arara has concluded, and results indicate that soil type affects root rot incidence. RAPP have included an additional trial in parallel with the BCA polybag trials, looking at a different soil type and we expect these results to be incorporated with the Arara experiment.
		> Journal articles submitted for publication (A, PC)	June 2014 & June 2014	Draft prepared.
4.4	Histological investigations of differences between less and more susceptible hosts	- Supporting literature review & experimental plan in journal article format (A, PC)	August 2011	Draft prepared.

		Protocol developed for micro-anatomical examinations	June 2014	Field-infected roots at the early infection stage were sampled in March 2012. These have been preserved in fixative and brought to Australia. Protocols have been tested on uninfected roots. Further material has been obtained from pot trials being conducted by Arara Abadi and RAPP. Initial results have been obtained from infected roots and additional samples have been collected. Quarantine restrictions have meant that root samples collected for the histological work need to be 'fixed' using chemical fixing agents. This fixing process limits the range of selective stains that can be used for the visualisation of fungi in the root sections, so optimisation of staining procedures has taken additional time. This optimisation is now complete and the sections are being examined.
		Microscopic examination of all samples completed	December 2014	Many pictures taken of fungal mycelium invading the root tissues, both in *A. mangium* and *Eucalyptus.*
		Journal article describing the root infection process and any anatomical differences associated with root-rot susceptibility differences submitted for publication (A, PC)	February 2014	Delayed due to availability of people with relevant expertise. First draft almost complete (submission in August 2015).

PC = partner country, A = Australia

*Objective 5: To characterise potential biological control agents discovered during project FST2003/048 to facilitate industry commercial development and application**

No.	**Activity***	**Outputs/Milestones**	**Expected date of completion**	**Comments**
5.1	In vitro assessment of biocontrol (BCA) antagonism	Activity of BCAs against *G. philippii* and *Phellinus noxius* has been confirmed.	Completed	*Phlebiopsis* sp. kills off the pathogens, whereas there is some survival of pathogen isolates after confrontations with *Cerrena* sp. The *Phlebia* spp. are not strongly competitive in vitro.
		Determination of best medium and growth stage for oidia production by BCAs	Completed	Oidia production is greater for *Phlebiopsis* and *Cerrena* spp. than for *Phlebia* sp. Results vary and not all factors relating to oidia production are understood – growth on woody substrates may help to revive oidia production capability.

		Development of a formulation to preserve oidia for storage and transport.	Completed	Survival up to 6 weeks has been achieved, potentially longer. Survival for 6 weeks will allow commercial application at a much reduced cost compared to the current practice of using colonised wood blocks.
5.2	Pot-trial to verify BCAs are non-pathogenic and assess effectiveness of reducing plant mortality in soil	Pot trials established and being monitored.	Completed	Oral presentation on biological control given at IUFRO Acacia conference, Hue, Vietnam in March 2014.
		Sampling and re-isolation from inoculum blocks from one complete set of replicates.	Completed	Results of re-isolation from BCA and pathogen blocks indicates that *Phlebiopsis* and *Cerrena* are able to outcompete *G. philippii* and *Phellinus noxius* in wood blocks in the soil, despite the low rate of infection and death in the control pots. DNA species confirmation is still required to finalise results.
5.3	Field test of successful BCAs from 5.2	Discussions have commenced re number of sites, replications etc.	Completed	All trials established
		Production of oidia for inoculation is currently being optimised and a suitable formulation for storage, efficient transport and application is under development.	Completed	Sufficient oidia were obtained for establishment of two field trials and one shade-house ‘simulated stump’ experiment. Colonisation of wood blocks in vitro by oidia has been demonstrated.
		‘Simulated stump’ trial to determine the concentration of oidia that will prevent colonisation of freshly cut stumps by basidiospores of *G. philippii.*	Completed	Colonisation by BCAs was successful, however this experiment has been compromised by the lack of germination of *Ganoderma philippi* basidiospores. The basidiospores took 2 weeks to germinate *in vitro* compared to 1-2 days for previous collections. Consequently, none of the stumps, including control stumps, were colonised by *Ganoderma philippii.* Data from this trial can be used to augment the field stump trials.
		Field trial to determine the ability of oidia to colonise stumps of freshly cut *A. mangium* and *E. pellita* under field conditions.	Completed	The trials have been harvested and re-isolation and direct PCR tests indicate that all BCA species are able to colonise eucalypt and Acacia stumps. Further work to optimise oidia concentration and application is required
		Field trial using wood blocks colonised with three different BCA species (RAPP).	Completed	Field trial established.
		Assessment of field trial will take place at 1 year old	Completed	The 1 year-old assessment has been completed, data yet to be analysed though incidence of tree deaths is low.

		Field trial using wood blocks colonised with *Cerrena* sp.	Abandoned because of damage caused by other agents.	A field trial established by Arara has been compromised by other agents including *Ceratocystis*, elephants and monkeys.

PC = partner country, A = Australia

*Original activities and timelines for Objectives 4 and 5 are given in the Appendix

Objective 6: To assess smallholder understanding of the tree cropping system, and use this information to develop and test models of intervention to facilitate adoption

No.	Activity	Outputs/ milestones	Completion date	Comments
6.1	Assessment of the capacity of smallholders to adopt new or improved acacia farming practises	Designed questions for interviews	July 2011	Questions have been designed and submitted for CSIRO ethics clearance.
		Administer the interviews	December 2011	As highlighted in earlier reports, the effort that was planned in Riau has been redirected to West Kalimantan, where there are high numbers of small landholders who grow acacia in partnership with Sinarmas. We have now completed 101 face-to-face interviews in West Kalimantan.
		Data analysis on all interviews	January 2012 Anticipated June 2014	This activity was completed in June 2014.
		Report on the results of the semi-structured interviews	April 2012. Anticipated August 2014	This activity was delayed for reasons noted above, but was completed and a report was written entitled: Acacia Plantations in West Kalimantan - Impacts on community livelihood.
		Contact and build rapport with informal leaders in each village who are well respected by everyone in the community	Ongoing	This activity is occurring as planned in South Sumatra. We have started this in West Kalimantan and Gunung Kidul. Hamlet leaders are open for the project to continue work with them. Researchers noticed that some hamlets had not received any assistance in farming compared to others.
6.2	Examination of the current social forestry partnership arrangements between the local industry and the small land holders	Designed questions for interviews	July 2011	Interview questions are ready and approved by the CSIRO Ethics committee.
		Administer the interviews	December 2011 Revised date: August 2013	Completed as per the revised plan in South Sumatra Details on partnership arrangements were captured in the first interview. Second interviews with local farmers

				were also completed in West Kalimantan.
		Data analysis on all interviews completed	April 2012 Revised date: December 2013	Completed, as per the revised plan in South Sumatra and West Kalimantan
		Report on the nature of the partnership arrangements	July 2014	On track to deliver according to plan. Preliminary results reported to inter-project workshop in Yogyakarta, February 2014. Report on company-community partnerships in West Kalimantan was published in August 2014. The results from the second interviews are to be published in a journal paper under preparation.
		Provided recommendations for changes in partnership to one that is mutually beneficial for both parties	July 2014	On track to deliver according to plan. Preliminary results reported to inter-project workshop in Yogyakarta, February 2014. In West Kalimantan, a brief on the recommendations was provided to the forestry company in June 2015. A desktop review on partnership arrangements was also published as a CSIRO technical report in March 2015.
6.3	Assessment of the feasibility and long-term viability of creating a demonstration site as a means of communicating with small land holders in South Sumatra	Designed questions to scope farmers' preferred communication method with the researchers	July 2011	Addressed in 2011/12 annual report
		Developed criteria for assessing the best communication method	January 2012	
		Report on the best communication method	April 2012	Addressed in 2011/12 report
		Implementation of the preferred communication method	September 2012	Two new demonstration plots have been established in Gunung Kidul and West Kalimantan.
6.4	Development of strategies and guidelines to effectively engage smallholders for knowledge exchange so they can increase the productivity of their plantations (through adoption of better farming practises)	Workshops held with farmers to inform research outcomes and exchange ideas	September 2014	Completed in June 2015 in South Sumatra. This was completed in West Kalimantan. Exchanges were held with industry stakeholders to influence decision makers on their partnership arrangement with the local community
		Farmers adopting practises	May 2015	Farmer awareness in South Sumatra and Gunung Kidul is the closest that we have come to achieving this. In West

		recommended by the research		Kalimantan and South Sumatra, farmers are disinterested because of their culture and limited market opportunities. Less resources have been targeted towards these areas since our understanding of this improved. Farmers attending the demonstration site in Gunung Kidul asked for seedlings to grow acacias on their farm. Management practises for acacia mangium need to be adapted to suit farmers who grow *Acacia auriculiformis* in Gunung Kidul.
		Guidelines developed from the experiences of direct engagement with the growers	May 2015	Draft report available from studies in South Sumatra. A journal paper looking at institutional support for farmers to grow acacia is currently being prepared. A desktop review with recommendations on establishing effective partnerships was published in March 2015.

7 Key results and discussion

The key scientific outcomes are in the process of being written up into scientific publications. Below is a summary of the key outcomes within each objective.

7.1 Objective 1

Objective: To assess the potential for E. pellita *(and* E. pellita *x* grandis *hybrid) as a second/third-rotation crop to benefit from the higher soil N derived from* A. mangium *grown in previous rotations and to manage the risk and consequence of pathogen build-up.*

7.1.1 RAPP Core and Satellite experiments

This study was undertaken at RAPP by Sabar Siregar, Alun Wibowo, Wawan, and Adiwirman

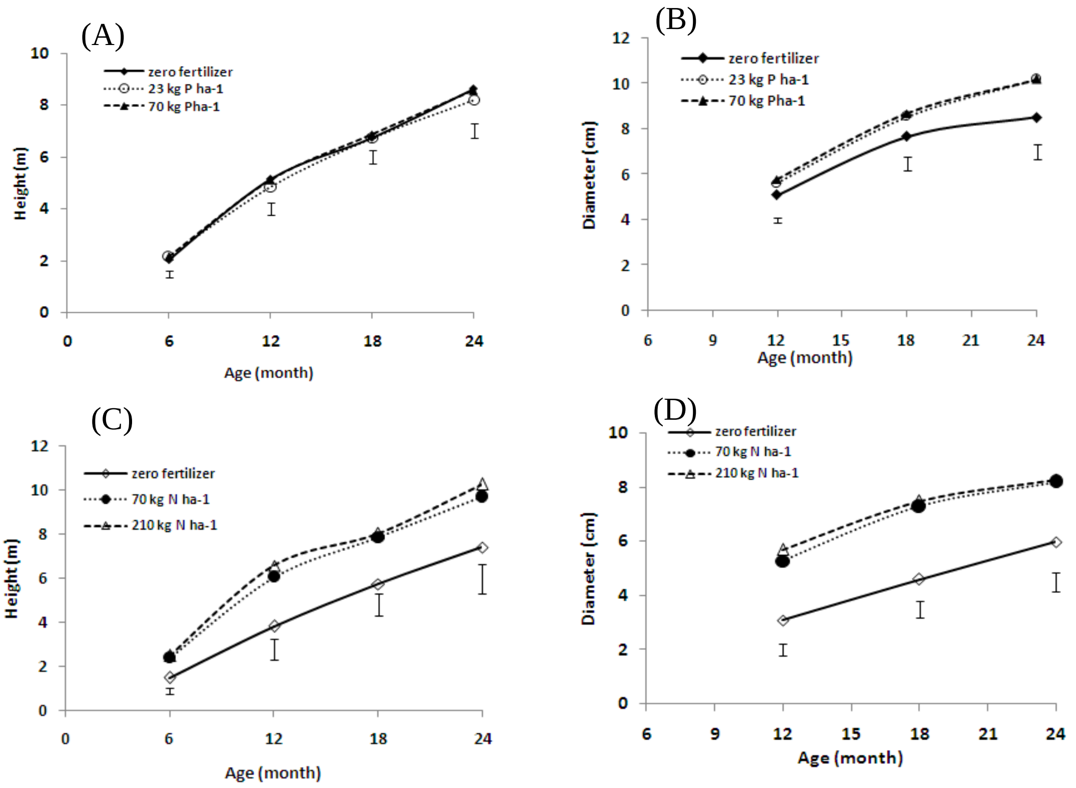
Survival

Fertilizer application with P or N did not significantly affect survival of either species (data not shown). Up to age 24 months, mortality of *A. mangium* was predominantly due to root disease and stem vascular wilt disease while that of *Eucalyptus* was more due to wind fall.

Growth and Volume

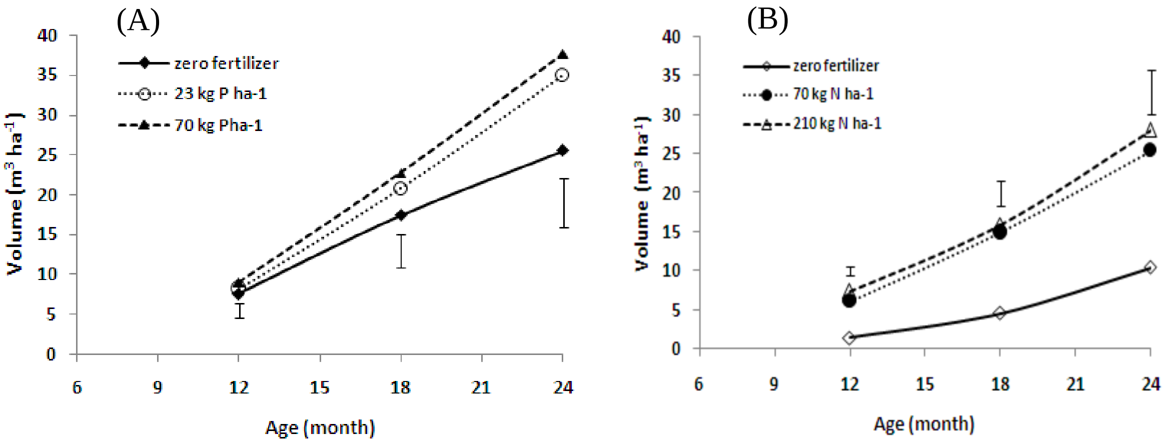
Fertilizer application significantly increased the height of the *E*. hyrid (EH) trees by 31-39% (Fig. 10c), but not of the *A. mangium* (Fig. 10a). Fertilizer application significantly increased diameter and standing volume of both species compared to zero fertilizer, by 20% for *A. mangium*, and by 37-38% for EH. However, increasing the rate of P (*A. mangium*) or N (*EH*) beyond the initial amount had no effect on growth or stand volume.

Figure 10. (A) Height and (B) Diameter (at breast height) of *A. mangium*; (C) Height and (D) Diameter (at breast height) of EH affected by fertilization. Note that basal P was applied in the N-fertilized EH plots. Vertical bars in the graphs are LSD$_{(0.05)}$



Fertilizer application increased the standing volume of each species, significantly for *A. mangium* only from age 18 months (Fig. 11a). At age 24 months, the fertilized *A. mangium* treatments had 37-49% greater standing volume than the zero fertilizer treatments. EH standing volume was 150-170% greater in fertilized compared to the zero fertilizer treatment (Figure 11b). Higher P or N rates above the first treatment level did not result in significant further increases in the standing volume of each species.

Figure 11. Influence of fertilizer on standing volume of *A. mangium* (A) and EH (B). Note that basal P was applied in the N-fertilized EH plots. Vertical bars represent LSD$_{(0.05)}$ between treatments at each measure time.



Growth and volume responses to fertilizer in this study were similar to those reported by Hardiyanto and Wicaksono (2008) and Hardiyanto and Nambiar (2014) in South Sumatra. They also found that application of P resulted in a significant increase in stem diameter and volume of *A. mangium*. Localized application of P (mixed with soil in the planting hole) increased its availability to the roots as soon as they started to grow, promoting a rapid response, and supporting early growth before the trees start to access P from other sources; either the endogenous soil/litter P, or through retranslocation within their foliage. Lack of response to higher rates of P application in *A. mangium* was also found by Mendham et al. (2010) across 13 sites in South Sumatra, where application of no more than 10 kg/ha P was sufficient to support maximum growth rates at all sites. Lack of response to higher P application rates has been hypothesized to be because of increased capacity of larger trees to source P from soil and litter sources, because of the extensive fine root system that develops with acacias.

Lack of response to higher rates of N application in EH was similar to that reported by Smethurst *et al.* (2004) in Tasmania for sites on ex-legume-based pasture, where *E. nitens* trees did not respond to N fertilizer. However, they found that ex-native-forest sites did respond to N application, and up to 500 kg N ha^{-1} (in a split-dose) was required to obtain maximum yield at some of these sites. In our experiment, retention of harvesting slash alone resulted in around 120 – 186 kg N ha^{-1} being retained in the slash, most of which is available to plants over the first 12 months, when much of the slash decomposition occurs. These factors, combined, suggest that nitrogen may be not a limiting factor for eucalypts established after 2 rotations of *A. mangium*, but it needs to be recognised that soil availability of N may decline over multiple eucalypt rotations (Mendham et al., 2004, Wibisono et al., 2015), so N responses need to be monitored over the longer term to ensure that optimal productivity is maintained.

Tree Biomass

As with standing volume, fertilizer application also significantly increased the biomass of the trees and each biomass component for both *A. mangium* and EH (Table 16 and Table 17). Again, the response only occurred for the lowest rate of fertilizer in each experiment. Fertilizer application increased standing above ground and calculated root biomass of *A.*

mangium by 57-81% and 50-75% respectively. Fertilization increased EH stand biomass by 96-103% and 85-95% respectively for above ground and root biomass.

Table 16. Effect of fertilizer application on tree and stand biomass of *A. mangium* at 24 months. Figures in the same column followed by the same letter are not significantly different at LSD$_{(0.5)}$

Treatment	Stem	Bark	Branches	Leaf	Total above-ground	Root
Tree biomass (kg/tree)						
Zero Fertilizer	10.8 a (68)	1.0 a (6)	2.5 a (16)	1.6 a (10)	15.8 a	
23 kg P ha^{-1}	18.7 b (72)	1.6 b (6)	3.6 b (14)	2.0 b (8)	26.1 b	
70 kg P ha^{-1}	18.6 b (72)	1.6 b (6)	3.6 b (14)	2.0 b (8)	25.8 b	
Stand biomass (t/ha)						
Zero Fertilizer	13.7 a (68)	1.3 a (6)	3.2 a (16)	2.1 a (10)	20.3 a	5.5 a
23 kg P ha^{-1}	22.9 b (72)	1.9 b (6)	4. 5 b (14)	2.5 ab (8)	31.8 b	8.3 b
70 kg P ha^{-1}	26.6 b (72)	2.2 b (6)	5.1 b (14)	2.8 b (8)	36.8 b	9.6 b

Table 17. Effect of fertilization on tree and stand biomass of *EH* at 24 months. Figures in the same column followed by the same letter are not significantly different at LSD$_{(0.5)}$. Numbers in brackets are % of total above ground biomass.

Treatment	Stem	Bark	Branches	Leaf	Total above-ground	Root
Tree biomass (kg/tree)						
Zero Fertilizer	8.2 a (67)	1.2 a (10)	2.0 a (16)	0.9 a (7)	12.2 a	
70 kg N ha^{-1}	17.8 b (70)	2.4 b (10)	3.5 b (14)	1.5 b (6)	25.3 b	
210 kg N ha^{-1}	18.6 b (71)	2.6 b (10)	3.6 b (13)	1.6 b (6)	26.4 b	
Stand biomass (t/ha)						
Zero Fertilizer	13.6 a (67)	1.9 a (9)	3.2 a (16)	1.4 a (9)	20.2 a	5.6 a
70 kg N ha^{-1}	28.0 b (70)	3.8 b (10)	5.4 b (14)	2.4 b (6)	39.7 b	10.4 b
210 kg N ha^{-1}	29.3 b (71)	4.0 b (10)	5.6 b (13)	2.5 b (6)	41.5 b	10.9 b

As tree growth responded significantly to fertilizer application, tree biomass also increased commensurately. However, fertilizer application also changed the proportions of biomass in the different tree components. For *A. mangium*, a 67-97% increase in stem biomass with fertilizer application also led to a higher proportion of biomass in the stem from 68% to 72% (4% proportional increase), while fertilizer application to EH increased the stem biomass by 105-115%, and increased the proportion of stem from 67% to 71%. This shift to higher proportion of stem biomass resulted in commensurately lower proportions of biomass in both branches and leaves in both species.

Estimated root biomass of both *A. mangium* and EH also increased significantly after fertilization. However, individual tree root:shoot ratio was significantly reduced by fertilization due to higher increased in aboveground biomass especially contributed by stem biomass increase (Table 18 and Table 19). Higher rates of P or N fertilizer did not appear to influence root:shoot ratio in either species.

Table 18. Effect of fertilizer application on tree biomass and estimated root:shoot ratio (R:S) of *A. mangium* at 24 months. Figures in the same column followed by the same letter were not significantly different at LSD$_{(0.5)}$

Treatment	Tree Biomass (kg/tree)		Root:Shoot ratio
	Above-ground	Root	
Zero Fertilizer	15.8 a	4.3 a	0.28 a
23 kg P ha^{-1}	26.1 b	6.8 b	0.27 b
70 kg P ha^{-1}	25.8 b	6.9 b	0.27 b

Table 19. Effect of fertilizer application on tree biomass and estimated root:shoot ratio (R:S) of EH at 24 months. Figures in the same column followed by the same letter were not significantly different at LSD$_{(0.5)}$

Treatment	Tree Biomass (kg/tree)		Root:Shoot ratio
	Above-ground	Root	
Zero fertilizer	12.2 a	3.4 a	0.29 a
70 kg N ha^{-1}	25.3 b	6.6 b	0.27 b
210 kg N ha^{-1}	26.4 b	6.9 b	0.27 b

Fertilizer application significantly increased leaf specific area of *A. mangium*, but did not significantly influence the individual leaf area, while for EH, the application of fertilizer significantly increased both the individual leaf area and leaf specific area (Table 20). EH had a higher leaf specific area compared to *A. mangium*. Increasing the rate of fertilizer beyond the base level in each species did not affect leaf characteristics further.

Table 20. Effect of fertilizer application on leaf characteristics of *A. mangium* and EH at 24 months. Figures in the same column for each species followed by the same letter are not significantly different at LSD$_{(0.5)}$

Treatments	Dry Weight (g/leaf)	Leaf Area (cm/leaf)	Leaf Specific Area (cm^2/g)
A. mangium			
Zero Fertilizer	0.87 a	92.3 a	107.3 a
23 kg P ha^{-1}	0.86 a	94.2 a	113.3 b
70 kg P ha^{-1}	0.81 a	90.6 a	114.8 b
E. hybrid			
Zero Fertilizer	0.41 a	42.6 a	117.3 a
70 kg N ha^{-1}	0.36 a	48.8 b	162.2 b
210 kg N ha^{-1}	0.40 a	53.0 b	156.3 b

Leaf biomass of the stand was between 2.1 and 2.8 t/ha for *A. mangium* and 1.4 to 2.5 t/ha for EH at 24 months, and in combination with their respective leaf specific areas, leaf area index of *A. mangium* was 2.2 to 3.2 and of EH was 1.6 to 3.9. The unfertilised EH had the lowest LAI, but when fertilized, it had a higher leaf area index than *A. mangium*.

Fertilizer application increased stem growth efficiency (i.e. the ratio of stem biomass to leaf biomass) in both species. Stem growth efficiency of *A. mangium* was 6.5, 9.2, and 9.5 t wood per t of leaf for treatments zero fertilizer, 23 and 70 kg P/ha, respectively. Stem growth efficiency of EH was 9.7, 11.6 and 11.7 t wood per t of leaf respectively for zero fertilizer, 70 and 210 kg N ha^{-1}. EH showed a higher stem growth efficiency than *A. mangium*.

Nutritional Status of the trees

Fertilizer application tended to increase nutrient concentration in young fully developed leaves of both species (Table 21). Phosphorus fertilization increased *A. mangium* foliar P and K concentration but there was no effect on foliar N, Ca, and Mg concentration. Foliar concentration of K and Mg in fertilized EH was significantly higher than in unfertilized trees, however there were no significant differences in foliar concentrations of N, P or Ca.

Table 21. Foliar nutrient concentration in *A. mangium* and EH in relation to fertilizer application. Note that figures in the same column for each species followed by the same letter are not significantly different at LSD$_{(0.05)}$.

Treatment	Leaf phase	Foliar concentration (%)				
		N	P	K	Ca	Mg
A. mangium						
Zero fertilizer	Young Green	2.61 a	0.127 a	0.93 a	0.269 a	0.219 a
23 kg P ha^{-1}	Young Green	2.99 a	0.108 a	1.18 b	0.387 a	0.198 a
70 kg P ha^{-1}	Young Green	2.96 a	0.141 b	1.24 b	0.485 a	0.206 a
Zero fertilizer	Old (yellow)	1.33 b	0.017 c	0.344 c	0.258 a	0.165 b
23 kg P ha^{-1}	Old (yellow)	1.51 b	0.020 c	0.652 c	0.372 a	0.176 b
70 kg P ha^{-1}	Old (yellow)	1.54 b	0.023 c	0.661 c	0.416 a	0.175 b
E. hybrid						
Zero fertilizer	Young Green	1.54 a	0.10 a	0.67 a	0.34 a	0.19 a
70 kg N ha^{-1}	Young Green	1.80 a	0.11 a	0.96 b	0.41 b	0.25 b
210 kg N ha^{-1}	Young Green	1.74 a	0.11 a	0.87 b	0.30 a	0.23 b
Zero fertilizer	Old (yellow)	0.73 b	0.03 b	0.37 c	0.32 a	0.17 c
70 kg N ha^{-1}	Old (yellow)	0.62 b	0.02 b	0.54 c	0.40 b	0.22 d
210 kg N ha^{-1}	Old (yellow)	0.65 b	0.02 b	0.48 c	0.37 a	0.21 d

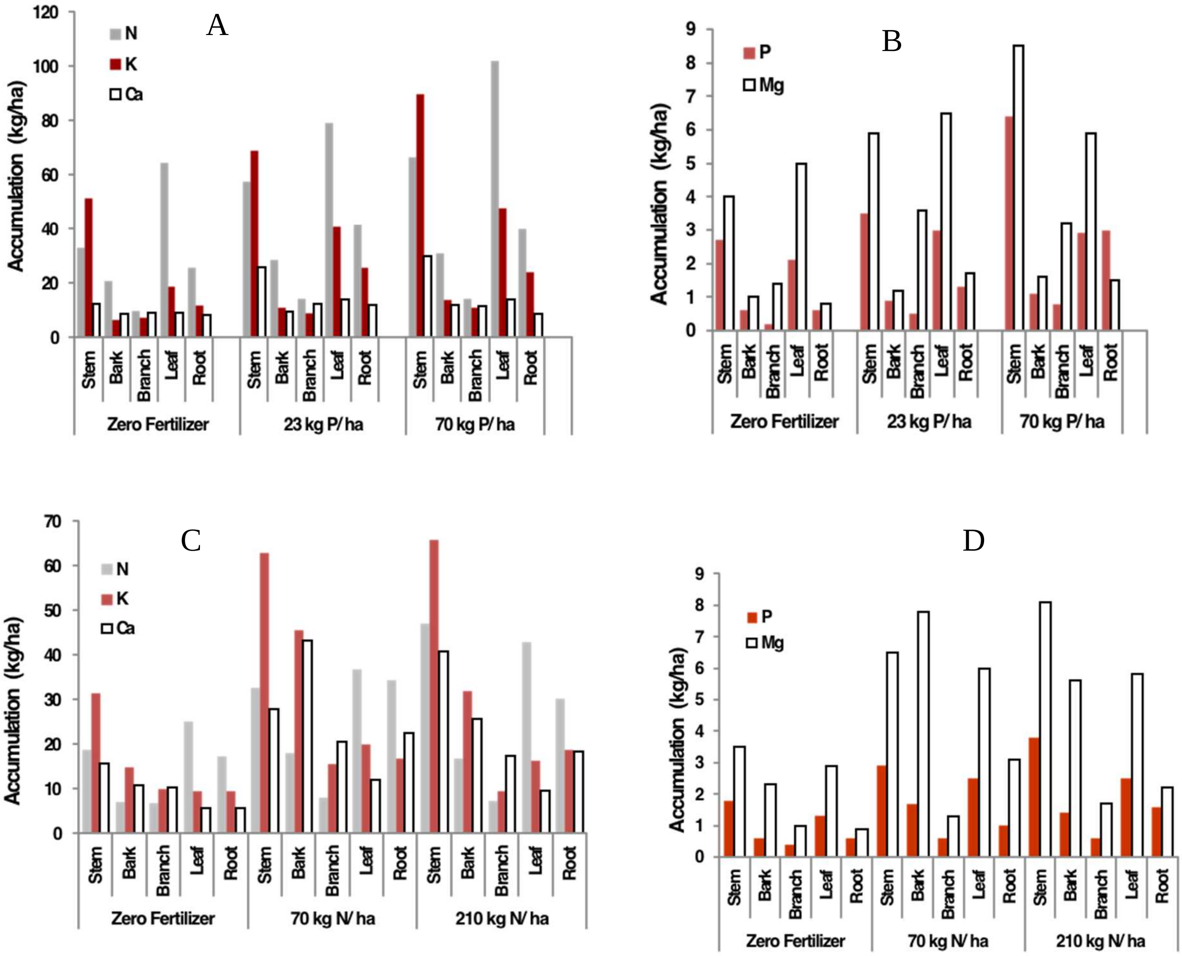
In both *A. mangium* and EH foliage, P had the highest proportional retranslocation (Table 22). Fertilizer application significantly reduced P and K retranslocation rate in *A. mangium*. However, in general, the retranslocation rate of nutrients was reduced by fertilizer application in both species.

Table 22. Foliar nutrient retranslocation in *A. mangium* and EH in relation to fertilization. Note that figures in the same column for each species followed by the same letter are not significantly different at LSD$_{(0.05)}$. Retranslocation was calculated using the methodology of Gonçalves et al. 2004.

Treatment	Foliar nutrient retranslocation (%)				
	N	P	K	Ca	Mg
A. mangium					
Zero fertilizer	45.5 a	85.5 a	62.5 a	4.2 a	18.9 a
23 kg P ha^{-1}	46.9 a	80.1 b	45.3 b	4.2 a	6.9 a
70 kg P ha^{-1}	47.9 a	83.1 ab	45.8 b	2.3 a	11.5 a
E. hybrid					
Zero fertilizer	61.0 a	85.4 a	54.0 a	4.2 a	13.9 a
70 kg N ha^{-1}	60.9 a	84.8 a	40.1 a	3.1 a	7.0 a
210 kg N ha^{-1}	64.7 a	84.4 a	44.7 a	1.9 a	10.5 a

Fertilizer application significantly increased the accumulation of nutrients in all biomass components for both species, reflecting the main effect of fertilizer in increasing the biomass (Fig. 12). In *A. mangium*, N was the nutrient that was most accumulated in all of the biomass components, except for the stem, while in the eucalypts, potassium tended to be the most accumulated nutrient, except in the leaves and roots, where nitrogen had the highest accumulation. Despite having a lower total biomass compared to stem, branches and roots, the leaves had the highest accumulation of nitrogen under all treatments. P accumulated most in leaf and stem, as did Ca and Mg. Potassium accumulated most in stem.

Figure 12. Biomass nutrient accumulation in *A. mangium* (A) and (B) and in EH (C) and (D).



7.1.2 Sinarmas Core and Satellite Experiments

This study was undertaken at Sinarmas by Rianto Maralop, Edison Sianipar, Liberty Pangaribuan, Agung Setyawan, Fadjar Sagitarianto, and Budi Tjahyono

Soil characteristics before planting

The soil was an Ultisol (Typic hapludults), formed from a parent material of sandy sediments (Rachim, 2007), with a relatively acidic nature and high sand content (Table 23). The low pH may be due to a combination of soil age and high rainfall in the region, which is likely to have led to intensive leaching of base cations. Carbon (C) in the surface 0-10 cm was moderate to high, and while it declined with depth, it was still around 1.5% in the 20-50 cm soil layer. Nitrogen (N) total in the 0-50 cm layer was relatively low, with C:N ratios between 23 and 59. Soil texture was relatively uniform in all layers, namely sandy clay loam to sandy loam. Sand concentration was high (over 60%) due to the soil's derivation from sandy sediments. The texture of the soil can greatly influence the availability of both macro and micro nutrients (Marschner, 1997). Available phosphorus was also low (less than 10 mg/kg), and is probably also influenced by the high iron and aluminium content typical of Ultisols.

Table 23. Soil chemical characteristics (sampled before planting)

Depth range (cm)	pH (1:2.5, water)	Organic C (%)	Total N (%)	Sand (%)	Silt (%)	Clay (%)	Available P (mg/kg)
0 -10	4.04-4.47	2.91-4.63	0.11-0.20	70-75	8-12	17-19	3.33-5.76
11-20	4.01-4.48	1.50-2.66	0.05-0.08	67-72	9-12	18-21	1.28-3.31
21-50	4.15-5.67	1.18-1.65	0.02-0.06	67-72	7-12	18-22	0.38-1.09

Tree growth and survival

Experiment 1: ex-*E. pellita* site

Survival of *A. mangium* was less than that of *E. pellita* (clone EP5147AA) at the age of 35 months (Table 24, Fig. 13). The height of *A. mangium* trees was not significantly different to that of the EP5147AA trees, while DBH of *A. mangium* was significantly bigger than the EP5147AA. While the remaining number of live trees in the *A. mangium* plots was lower, the size of these trees was sufficient to ensure that the *A. mangium* plots had as much (or more, albeit non-significant) volume compared to the experimental *E. pellita*. In contrast, the *E. pellita* #EP0077AA clone had much higher survival and standing volume compared to both the experimental *A. mangium* and EP5147AA.

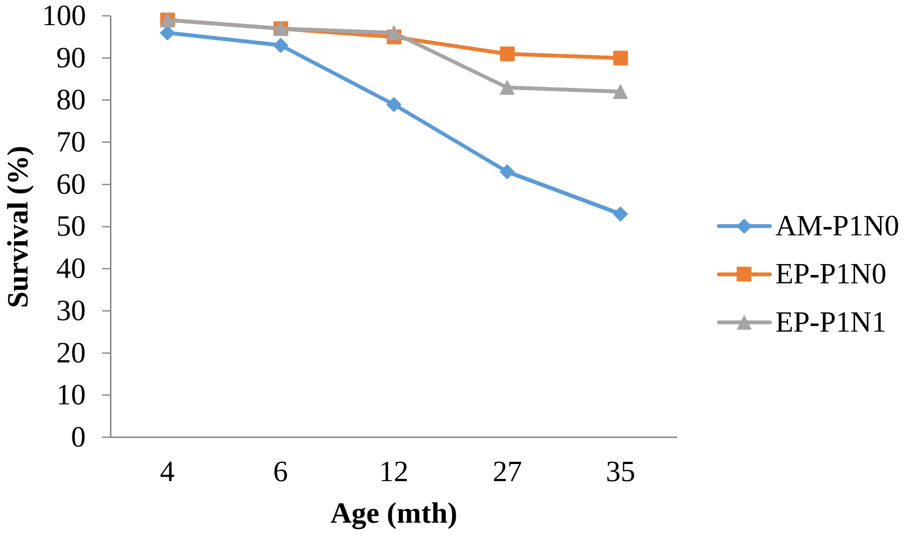
The causes of mortality are discussed later, but the low survival of *A. mangium* was predominantly attributable to the *Ceratocystis* sp pathogen. The affected plants show symptoms of wilting, followed by leaf desiccation and death. The infected trunks became brown or black, hardened, dry, and there was often evidence of the hole-boring *Ambrosia* beetle, which may be a vector for *Ceratocystis* sp.

Table 24. Growth of the tree until the age of 35 months in Experiment 1 (ex-*E. pellita*)

	Age	T1	T2	T3	EP0077AA
	(months)	AM-P1N0	EP-P1N0	EP-P1N1	(border)
Survival (%)	4	96	99	99	
	6	93	97	97	
	12	79	95	96	
	27	63b	91a	83ab	96
	35	53b	90a	82a	94
Height (m)	4	1.79b	2.26a	2.36a	
	6	2.74b	3.36a	3.37a	
	12	6.43a	6.64a	6.27a	
	27	14.61b	14.06a	14.09a	16.22
	35	17.50a	17.39a	17.58a	18.39
DBH (cm)	12	7.02a	5.09b	5.07b	
	27	12.68a	9.33b	9.45b	10.65
	35	14.39a	10.58b	10.69b	12.00
Volume (m^3/ha)	12	21.9	11.3	10.8	
	27	104.9	75.3	70.5	135.1
	35	138.2	124.3	117.3	169.8

Notes: - Means with the same letter in each row are not significantly different at DMRT (α=5%)
- Fertilization regime for EP0077AA : RP 380 g + NPK 150 g per tree

Figure 13 – Comparison of treatment effects on survival



The experiment was established on a site that had a previous rotation of *E. pellita,* and the soil had a relatively low N status (Table 23), so we anticipate that this site would be among the more likely to demonstrate a response to N fertilizer if it was required to maximise productivity of *E. pellita* in this environment. This hypothesis is based on the theory that *Eucalyptus* plantations require N in many environments to promote maximum growth, which contrasts with the N requirement of acacias, which are able to fix N from the atmosphere (Bouillet *et al*, 2006).

We found that application of N of up to 165 g/tree (equivalent to 126 kg N/ha) did not significantly improve productivity of EP5147AA. This result suggests that the N supply from the soil and decomposing slash and litter is sufficient to support the growth EP5147AA, for at least the first 3 years following re-establishment. This was despite the fact that the soil N (Table 23) levels were relatively low according to the criteria of Soil Research Institute Bogor (2009). Although these criteria are general in nature, and based on the results of our study, it is apparent that a total soil N concentration in the 0-10 cm layer of 0.1% to 0.2% was sufficient to support maximum growth rates of EP5147AA. This might be partly due to the retention of crop residues (slash) on site at harvest. Decomposing slash has potential to provide sufficient N to support early plant growth, especially given the high decomposition rates experienced in the warm and wet environment in Riau. We did not assess the N content of slash or the dynamics of its release, but demand on the soil N reserves may be relatively low while the slash is decomposing. Gonçalves *et al* (2008) reported that N retained in litter and slash on site after harvest of 7-year-old *E. grandis* in Brazil amounted to 187 kg/ha, most of which would have been mineralised within the first 12 months (Deleporte *et al*. 2008). Gonçalves *et al* (2008) also suggested that high N mineralization from slash was the cause of there being little or no response to N fertilizer in Brazil.

Whilst the standing volume of the *A. mangium* plots was higher than that of the EP5147AA plots at age 3, the lower volume of the *E. pellita* stand can be offset by the higher pulp yield of *E. pellita* wood compared to *A. mangium* wood. The pulp productivity of *A. mangium* is 1 tonne of pulp from 4.9 tonnes of wood, while for EP5147AA it requires only 3.35 tonne. If a recovery of 80% is assumed due to timber loss factor and proportion of bark in the volume estimate, then the plantation pulp productivity of *A. mangium* (in treatment 1) was only 7.70 t/ha/y, compared to 10.2 t/ha/y for EP5147AA in Treatment 2.

The operational planting of trees around the experiment provided an interesting comparison of the difference between clones, as they were planted at the same time and had a similar intensity of management to Treatment 2. The operational planting of clone EP0077AA had much higher standing volume than either the *A. mangium* or EP5147AA in our experiment (Table 24). EP0077AA is a clone from Sinarmas commercial forestry and partners that has demonstrated high and consistent performance on a variety of land types. The survival of EP0077AA, at 94%, was very high compared to that in the experimental plots, suggesting it is more resistant to pests and diseases, including *Ganoderma* sp and *Ceratocystis* sp. EP0077AA also has a better rooting structure, is not as easily uprooted. The difference in growth rates between EP0077AA and EP5147AA demonstrates that there is large variation in the *E. pellita* genome, and that there is potential scope for further improvement and site/clone matching. Thus, the volume-productivity of *A. mangium* at 35 months was higher than clone EP5147AA, but lower than clone EP0077AA.

Interestingly, the canopy depth was not significantly influenced by species or treatment at age 27 months, while at 35 months the canopy of *A. mangium* was deeper than that of EP5147AA in Treatment 2 (Table 25). Nitrogen treatment had significant impact on the canopy depth of EP5147AA at age of 35 months, suggesting that an N limitation on growth may manifest later in the rotation. If N does become limiting, the trees tend to compensate by reducing the leaf area to maintain a stable N concentration in the remaining leaves, resulting in canopy lift. The canopy depth can also be an indicator of limitation of other resources such as water or light, as leaves are shed once they become limiting.

Table 25. Canopy depth at the age of 27 and 35 months

Treatment	Canopy depth (m)	
	27 months	35 months
T1 - AM-P1N0	5.40	5.14a
T2 - EP-P1N0	5.41	4.06b
T3 - EP-P1N1	5.06	4.95a

Experiment 2 (ex-A. mangium site)

There was a trend for higher survival in the eucalypts compared to the acacias at the 34-month measure. Interestingly, survival of the naturally regenerated *A. mangium* (wildling, T1) was not higher than that of the nursery-derived seedlings of *A. mangium* (T2 and T3) at age 34 months, and the average tree height and diameter were lower, resulting in a lower standing volume (Table 26) compared to the nursery-grown seedlings. The *A. mangium* wildling treatment was included in the design because of anecdotal evidence that naturally regenerated acacia has a greater resistance to disease than nursery-grown seedlings. It has been hypothesised that the survivors are selected from millions of regrowth seedlings per hectare, and are therefore better adapted to the site. However, we demonstrated that the *A. mangium* wildlings in our experiment were still quite susceptible to mortality, with around 61% loss by age 34 months. *A. mangium* mortality across all treatments was mainly due to *Ceratocystis* sp. disease, and the causes of mortality are discussed in more detail below.

Table 26. Survival and height of the trees up to age of 34 months in Experiment 2 (ex-*A. mangium*)

Treatment	Survival (%)					Height (m)				
Age (months):	4	6	12	24	34	4	6	12	24	34
T1 (AW+P1N0)	99	93	91	72	39	0.36a	0.91a	3.60a	10.56a	15.47cde
T2 (AM+P0N0)	100	99	92	69	53	1.10b	2.07b	5.16bc	12.05c	16.09abc
T3 (AM+P1N0)	99	96	85	57	41	1.33c	2.39c	5.45c	12.45cd	16.15abc
T4 (AM+P2N0)	100	99	87	53	37	1.48d	2.72d	5.84d	12.35cd	15.83bcd
T5 (EP+P0N0)	92	89	84	75	73	1.37cd	2.38c	5.43c	12.12c	14.77e
T6 (EP+P1N0)	99	93	88	72	68	1.80e	3.01e	6.65e	13.45e	17.20a
T7 (EP+P2N0)	97	91	89	71	63	1.98f	3.43f	7.28g	13.53e	16.39abc
T8 (EP+P0N1)	95	93	89	81	81	1.29c	2.09b	4.86b	11.32b	14.59e
T9 (EP+P1N1)	89	85	80	68	60	1.89ef	3.27f	7.16g	13.52e	16.79ab
T10 (EP+P2N1)	96	89	84	68	59	1.82e	3.01e	6.75ef	12.98de	16.26abc
T11 (EP+P0N2)	96	96	92	89	84	1.40cd	2.49c	5.93d	12.25c	15.08de
T12 (EP+P1N2)	99	99	89	72	65	1.92ef	3.23f	7.03fg	13.22e	16.78ab
T13 (EP+P2N2)	99	91	84	72	71	1.98f	3.37f	7.22g	13.64e	16.89a
EP0077AA				96	94				16.22	18.39

Note: figures are followed by the same letter in the same column were not significantly different (DMRT, α =5%)

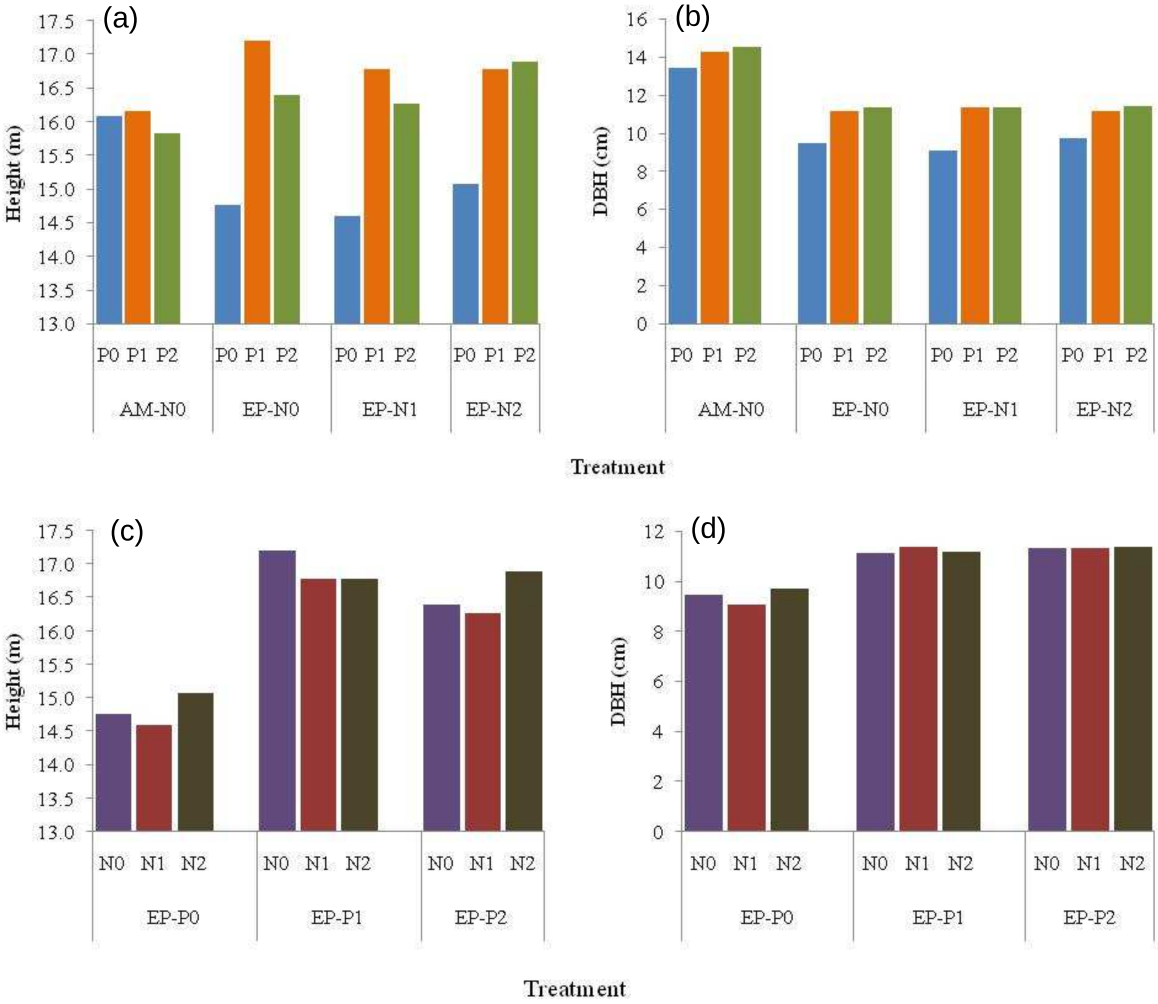
Table 27 - Tree diameter, volume and MAI up to age 34 months in Experiment 2 (ex-*A. mangium*)

Treatment	DBH (cm)			Volume (m^3/ha)			MAI (m^3/ha/y)	
Age (months):	12	24	34	12	24	34	24	34
T1 (AW+P1N0)	3.22a	9.32b	12.93c	3.52	53.01	75.38	26.5	26.6
T2 (AM+P0N0)	5.42d	10.82c	13.39bc	13.12	74.39	126.56	37.2	44.7
T3 (AM+P1N0)	5.94e	11.38c	14.26ab	15.11	68.89	100.96	34.5	35.6
T4 (AM+P2N0)	6.76f	12.17d	14.48a	20.53	70.79	90.69	35.4	32.0
T5 (EP+P0N0)	3.85b	7.72a	9.44e	4.76	36.96	69.26	18.5	24.4
T6 (EP+P1N0)	4.92c	9.15b	11.13d	9.88	55.07	102.54	27.5	36.2
T7 (EP+P2N0)	5.38d	9.14b	11.33d	13.11	54.29	93.42	27.1	33.0
T8 (EP+P0N1)	3.31a	7.26a	9.05e	3.34	33.39	71.64	16.7	25.3
T9 (EP+P1N1)	5.30cd	8.95b	11.36d	11.20	50.16	90.08	25.1	31.8
T10 (EP+P2N1)	5.08cd	9.16b	11.32d	10.19	50.32	85.05	25.2	30.0
T11 (EP+P0N2)	4.05b	7.86a	9.72e	6.27	46.30	86.17	23.2	30.4
T12 (EP+P1N2)	5.21cd	8.95b	11.17d	11.88	51.84	96.74	25.9	34.1
T13 (EP+P2N2)	5.30cd	9.26b	11.38d	11.83	57.21	106.98	28.6	37.8
EP0077AA		10.65	12.00		135.12	169.8	67.6	59.9

Note: figures are followed by the same letter in the same column were not significantly different (DMRT, α =5%)

Phosphorus fertilizer treatments tended to significantly increase the growth of *A. mangium* trees up to age 34 months, especially in terms of diameter (Tables 26 and 27). The diameter of *A. mangium* at the high rate of P application (400 g ERP/tree, equivalent to 82 kg P/ha) was significantly higher than that in the P0 treatment. Phosphorus fertilizer treatment also significantly increased the growth of EP5147AA, either with or without N fertilizer, but there was no significant improvement in growth achieved by increasing the quantity applied beyond the P1 level (14 kg/ha). There was no significant benefit of N fertilizer addition up to the age of 34 months (Figure 14).

Figure 14 – Comparison of main P treatment effects on height (a) and DBH (b) at age 34 months, and main N treatment effects on height (c) and DBH (d). This is a graphical representation of the data in Tables 26 and 27



From the results of the two experiments, it is clear that the *E. pellita* in our experiments (clone EP5147AA) did not respond to N fertilizer, either on ex-*Acacia* or ex-*Eucalyptus* sites (Table 28). Given that the soil at these sites had relatively low N status, the hypothesis that *E. pellita* may be more responsive to N fertilizer on ex-*Eucalyptus* sites was not proven. It is likely that the N cycling in soil and from decomposition of slash and litter is sufficient to support maximum productivity of EP5147AA. However, this needs to be monitored into the future, as other studies demonstrated that (1) there is an impact of N treatment on canopy depth at age 3, (2) soil N availability can decline under eucalypt plantations, and (3) higher productivity stands (such as those with EP0077AA) may put higher demands on the endogenous N supply, and (4) We are only able to report on response up to half of the rotation age here (3 years).

Phosphorus treatment had significant impact on EP5147AA canopy depth at age of 34 months in Experiment 2 (Table 29, Fig. 15), with significantly deeper canopies in the *Acacia* plots compared to the *E. pellita* plots. The lower productivity of the *E. pellita* P0 treatment was also associated with shallower canopies, but this was not the case in the acacia stands, where the higher P treatments were associated with greater volume of wood, but similar canopy depths. Canopy depth can be a useful indicator of the productive potential of a stand, and can be influenced by factors such as resource limitation (water or nutrients), or pest/disease incidence and severity. For example, one clone (EP0005AA) is highly susceptible to *Botryosphaeria* sp, which causes significant leaf loss and subsequent lack of capacity for the stand to grow rapidly. However, the lack of response of canopies to N in our experiment is further evidence that N was not the key limitation for the EP5147AA trees in our experiment.

Table 28. Comparison of tree growth at the 2 different sites

Site	*EP5147AA*						*A. mangium*		
	N influence			P Influence			P Influence		
	Ht	DBH	DOC	Ht	DBH	DOC	Ht	DBH	DOC
Ex-*E. pellita*	NS	NS	S						
Ex-*A. mangium*	NS	NS	NS	S	S	NS	NS	S	NS

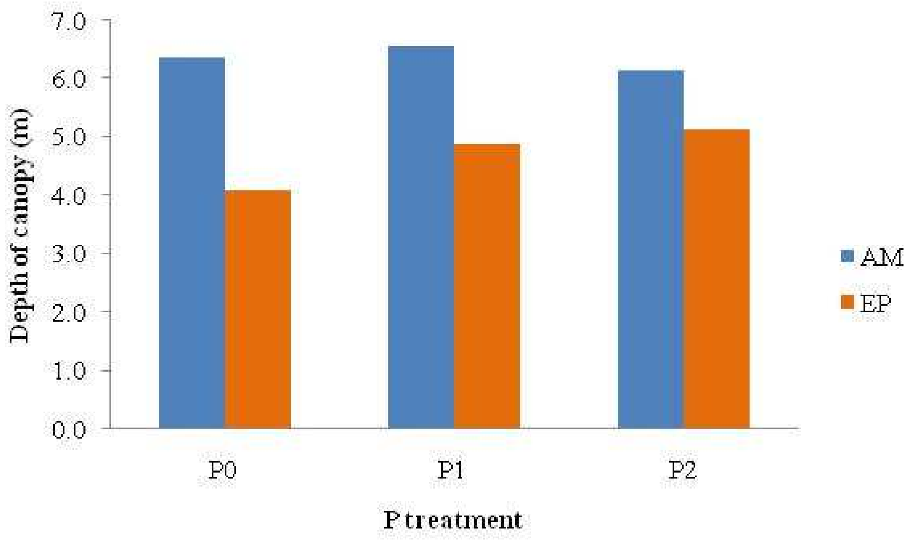
Note : Ht : tree height; DBH : diameter breast height; DOC : depth of canopy; NS : not significant S : significant

Table 29. Canopy depth in Experiment 2 (ex-A. mangium site)

Treatment	Canopy depth (m)	
	24 months	34 months
T1 (AW+P1N0)	6.06	6.60a
T2 (AM+P0N0)	6.33	6.37a
T3 (AM+P1N0)	6.87	6.56a
T4 (AM+P2N0)	6.01	6.14a
T5 (EP+P0N0)	5.30	3.81e
T6 (EP+P1N0)	5.54	4.56cd
T7 (EP+P2N0)	5.69	5.32b
T8 (EP+P0N1)	5.09	4.28de
T9 (EP+P1N1)	5.99	5.05bc
T10 (EP+P2N1)	5.82	5.10bc
T11 (EP+P0N2)	5.24	4.17de
T12 (EP+P1N2)	5.81	5.08bc
T13 (EP+P2N2)	5.90	4.97bc

Note: values at 34 months followed by the same letter were not significantly different (DMRT, α =5%)

Fig. 15 – Main effect of P treatment on canopy depth in A. mangium and E. pellita



Causes of mortality

One goal of this experiment was to determine the impact of species and management treatment on the incidence and severity of pests and diseases. On both of the experiments (ex-*Eucalyptus* site and ex-*Acacia* site), we found that the mortality of *A.*

mangium was significantly higher than that of EP5147AA (Table 30). Up to age 24 months, there was no mortality due to root rot in acacias, and only a low level in *E. pellita* (2.7%, likely to *Phellinus noxious*). However, by age 34 months, mortality of *A. mangium* due to root rot was high in Experiment 1 (9.3%). Previous experience tells us that *Ganoderma* is likely to cause significant mortality by the end of the rotation, especially for *Acacia* (Francis et al. 2014). *Ceratocystis* sp was already a significant cause of mortality (29.3% in *A. mangium* in Experiment 1). There were no symptoms of *Ceratocystis* infection in the EP5147AA. The *E. pellita* planting stock that was used in this experiment was subject to wind damage, predominantly due to a poor rooting pattern, typified by lateral rooting and few deep tap-roots. Further work is being conducted to understand the cause of the poor rooting pattern observed in EP5147AA.

Mortality due to *Ceratocystis* was only found in the *A. mangium* trees, but the disease has also been reported in *Eucalyptus*. Roux *et al* (2000) reported *Ceratocystis fimbriata* in *Eucalyptus* trees in the Congo and Brazil. Tarigan (2010) found that *C. manginecans* and *C. acaciivora* were the key species infecting *A. mangium* and *A. crassicarpa* in Riau-Indonesia. The results of these studies suggest that *Ceratocystis* present in our experiment was restricted to the *A. mangium*. However, while there is no evidence to date of *Ceratocystis* cross-infection from acacias to eucalypts, a threat remains that *Eucalyptus*-specific strains of *Ceratocystis* may become a problem in the future.

Table 30. Causes of mortality (%) in Experiment 1 (ex-Eucalyptus) at 24 and 35 months

Treatment	Root rot		Ceratocystis		Bacterial wilt		Wind throw	
Tree age (months):	24	35	24	35	24	35	24	35
T1 AM+P1N0	0	9.3	26.7	29.3	0	0	0	8
T2 EP+P1N0	2.7	6.7	0	0	0	2.9	4	0
T3 EP+P1N1	0	1.4	0	0	0	1.4	2.7	14.8

On the ex-*Acacia* site (Experiment 2), *A. mangium* mortality due to root rot was still relatively low at 24 months, at 1.3-4.0% (Table 31), but this had increased to 5.3-13.3% at 34 months (Fig.16), and is likely to increase further with age as the previous rotation at this site had suffered significant losses due to *Ganoderma philippi* root rot. Inoculum, in the form of hyphae and/or fungal spores are still present at the site after harvesting, especially if the stumps and roots of the harvested trees are left at the site, and the experience to date has been of increasing losses due to root rot over successive rotations. There was no mortality due to root rot disease in wildling *A. mangium* regeneration at 24 months, but at 36 months, mortality due to root rot had increased significantly to 13%. This treatment had close to the highest mortality overall at 36 months, predominantly due to wind damage.

The causes and levels of mortality had similar patterns in Experiment 1 and Experiment 2, with *Ceratocystis* being the main cause of mortality in *Acacia*, and wind damage in *Eucalyptus*. Few trees were affected by Bacterial Wilt Disease at 24 months, but at 36 months, the mortality due to Bacterial Wilt Disease was non-existent in the *Acacia*, and present but low (1.3-5.3%) in EP5147AA (Figure 16, 17). In general, mortality of both *A. mangium* and EP5147AA was higher in the ex-*A. mangium* site (Figure 18).

The application of P fertilizer tended to be associated with lower mortality of *A. mangium* due to root rot disease (albeit non-significantly), but it was also associated with an increase in mortality due to both *Ceratocystis* in acacias and wind damage in *Eucalyptus* at 36 months (Fig. 16). The mechanism for these effects is unknown, but may be associated with the development of a greater leaf area (in the case of wind damage), and/or increased palatability of the trees for the insect vector of *Ceratocystis*.

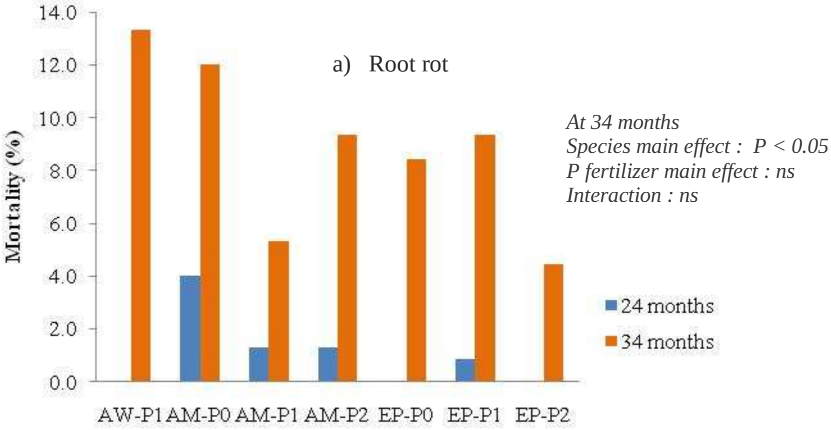
Application of N fertilizer did not significantly influence mortality due to disease, but it is interesting to note that there was a non-significant tendency for the trees in the higher N treatment (N2) to have lower mortality associated with root rot, bacterial wilt and wind damage.

Causes of mortality were similar between the ex-*E. pellita* and ex-*A. mangium* sites (Fig. 18), possibly suggesting that more than 1 rotation of *E. pellita* would be required to break the disease cycle, and/or that the *Acacia* wildling population that typically grows in an E. pellita rotation is sufficient to maintain the disease pressure on following rotations.

Table 31. Causes of mortality (%) in Experiment 2 (ex-Acacia) at 24 and 34 months

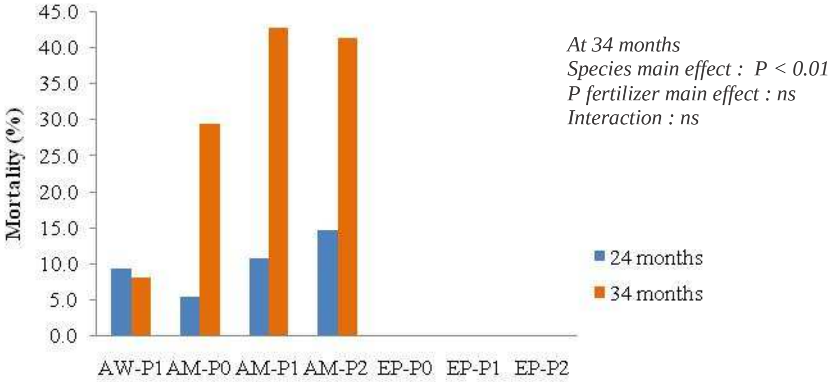
Treatment	Root rot		Ceratocystis		Bacterial wilt		Wind damage	
Age (months) :	24	34	24	34	24	34	24	34
T1 (AW+P1N0)	0.0	13.3	9.3	8.0	0.0	0.0	0.0	40.0
T2 (AM+P0N0)	4.0	12.0	5.3	29.3	0.0	0.0	0.0	4.0
T3 (AM+P1N0)	1.3	5.3	10.7	42.7	0.0	0.0	0.0	10.7
T4 (AM+P2N0)	1.3	9.3	14.7	41.3	0.0	0.0	0.0	12.0
T5 (EP+P0N0)	0.0	14.7	0.0	0.0	0.0	1.3	16.0	10.7
T6 (EP+P1N0)	1.3	10.7	0.0	0.0	0.0	5.3	9.3	16.0
T7 (EP+P2N0)	0.0	0.0	0.0	0.0	0.0	5.3	10.7	32.0
T8 (EP+P0N1)	0.0	5.3	0.0	0.0	1.3	5.3	9.3	8.0
T9 (EP+P1N1)	1.3	12.0	0.0	0.0	0.0	5.3	17.3	22.7
T10 (EP+P2N1)	0.0	6.7	0.0	0.0	0.0	4.0	16.0	30.7
T11 (EP+P0N2)	0.0	5.3	0.0	0.0	0.0	5.3	6.7	5.3
T12 (EP+P1N2)	0.0	5.3	0.0	0.0	0.0	4.0	8.0	25.3
T13 (EP+P2N2)	0.0	6.7	0.0	0.0	0.0	4.0	10.7	17.3

Figure 16 – Cause of mortality in species x P treatments, Experiment 2 (ex-A. mangium) at age 24 and 34 months



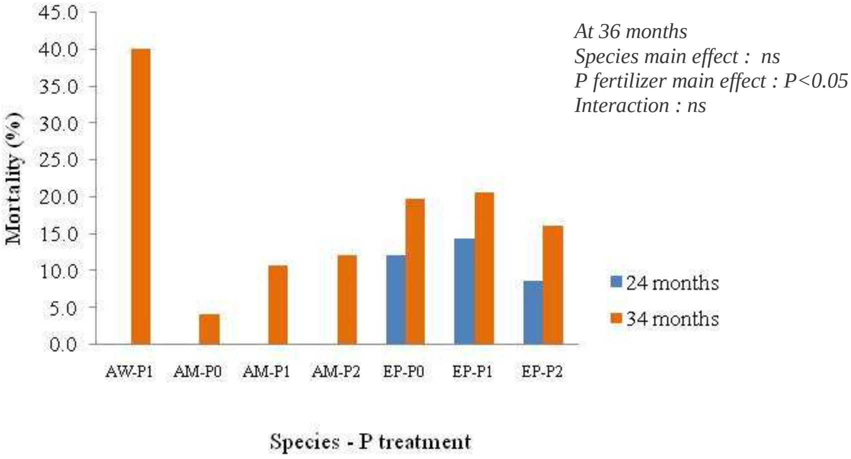
At 34 months
Species main effect : P < 0.05
P fertilizer main effect : ns
Interaction : ns

b) Ceratocystis



At 34 months
Species main effect : P < 0.01
P fertilizer main effect : ns
Interaction : ns

c) Wind damage



At 36 months
Species main effect : ns
P fertilizer main effect : P<0.05
Interaction : ns

Figure 17. Cause of mortality in species x N treatments, Experiment 2 (ex-A. mangium) at age 24 and 34 months. Note N treatment did not significantly influence any of the mortality levels

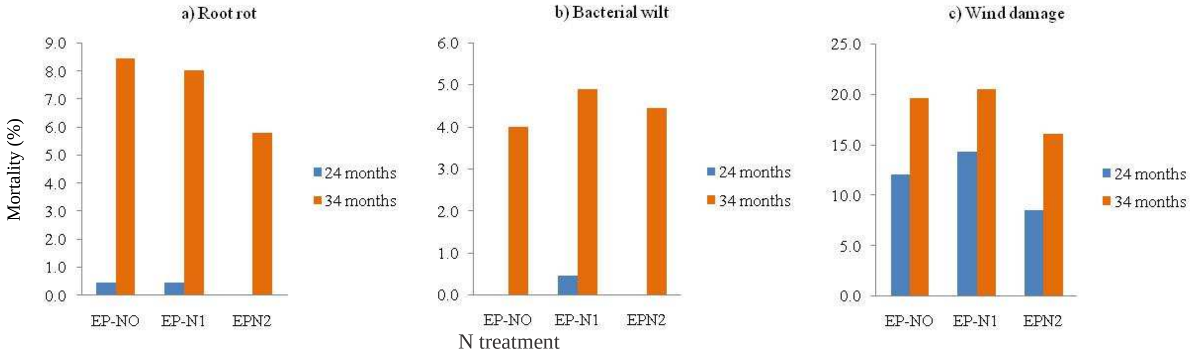
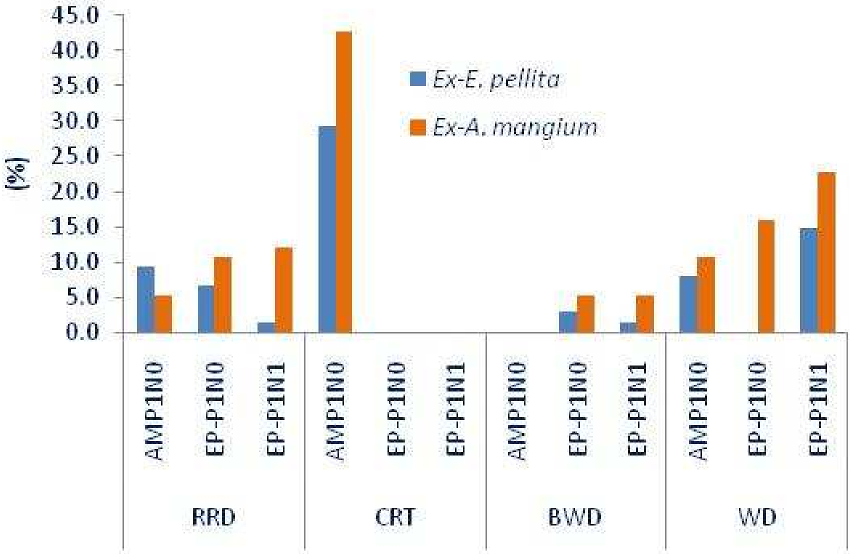


Figure 18. Comparison of mortality in 2 different sites; Root rot disease (RRD), Ceratocystis (CRT), Bacterial wilt disease (BWD) or wind damage (WD).



7.1.3 Musi Hutan Persada

This study was undertaken at PT Musi Hutan Persada by Alen Inail and Eko Hardiyanto.

Response to N and P fertilizer

Addition of N fertilizer did not significantly increase growth of *E. pellita,* either in the core experiment (Table 32), or in the satellite experiments (Table 33). However, there was a consistent though non-significant, trend for 7-13% higher productivity with high N application at each of the 3 experiments, suggesting that N fertilizer effect may have been evident if more replication was employed in the design. In contrast, the application of P fertilizer did significantly and substantially improve the growth of *E. pellita* ($P<0.001$); at 3 years of age the mean height, diameter and stem volume were 13.3 m, 12.4 cm and 77.1 m^3 ha^{-1} respectively in the plot receiving 30 kg P ha^{-1}, while in the unfertilized plot the mean height, diameter and stem volume were 10.8 m, 9.7 cm and 45.6 m^3 ha^{-1} respectively. At three years of age plots receiving P fertilizer had a standing volume that was 36-48% higher than those without P fertilizer. These growth responses to N and P application were consistent from 6 months to 3 years old.

Table 32. Growth responses to the application of N fertilizer at the core experiment at 3 years of age

Rate of N (kg ha-^{1})	Mean height (m)	Mean DBH (cm)	Volume (m^{3} ha^{-1})
0	11.7	10.6	57.5
40	11.9	11.3	61.1
120	12.4	11.1	65.3

Note: differences between rates of N for any growth variable were not significant

Table 33. Growth responses to the application of N fertilizer in satellite experiment at 3 years of age

Rate of N (kg ha-^{1})	Mean height (m)		Mean DBH (cm)		Volume (m^{3} ha^{-1})	
	Ex. Am	Ex Ep	Ex. Am	Ex. Ep	Ex.Am	Ex. Ep
0	14.5	14.8	13.1	12.7	95.2	92.2
120	15.4	15.2	13.8	13.0	101.9	97.4

Note: Am= Acacia mangium, Ep=Eucalyptus pellita

Response to K and Ca application

The application of K fertilizer did not significantly increase *E. pellita* growth, even though the treatment with K added had slightly better growth, with mean height, diameter and stem volume of 13.9 m, 13.0 cm and 87.9 m^{3} ha^{-1} respectively for the treatment receiving K fertilizer, while the mean height, diameter and stem volume for the treatments without K fertilizer were 13.8 m, 12.1 cm and 82.4 m^{3} ha^{-1} respectively. Similarly at three years of age, the treatment with added lime did not significantly increase standing volume of *E. pellita* compared to the control. The mean height, diameter and stem volume were 10.5 m, 9.9 cm and 47.9 m^{3} ha^{-1} respectively for the plot receiving 2500 kg ha^{-1} of hydrated lime, while the mean height, diameter and stem volume for the unfertilized plot were 10.7 m, 9.3 cm and 43.2 m^{3} ha^{-1} respectively. The lime treatments were not fertilized with P, and were not significantly different to all of the non-P-fertilized treatments.

Residual nutrients left from the previous rotation will greatly influence their availability in the next rotation. *A. mangium* stands have significant potential to leave additional N in the soil, litter and retained harvest residues. At the end of the first and second rotation, the potential N released from decomposed slash and litter was reported by Hardiyanto and Wicaksono (2006) to be 533-557 kg N ha^{-1} and 400-474 kg N ha^{-1}, respectively (Hardiyanto and Wicaksono 2006). *A. mangium* has also been reported to have a high capacity to fix atmospheric N. A study conducted at site located near the current experimental plot found that an *A. mangium* plantation was able to fix between 37 to 213 kg N ha^{-1} from the atmosphere, depending on P treatment and genotype (Wibisono et.al. 2015). This fixed N may be available for the next crop. The lack of significant response to N in the *E. pellita* in core and satellite experiments is possibly due to adequate residual N from the previous rotation of *A. mangium*. The site grown previously with one rotation of *A. mangium* and followed by a 10-year rotation of *E. pellita* was also able to support high growth rates of a 2nd *E. pellita* rotation without additional N requirement. Thus there was likely to be sufficient N available in the soil at this site to support at least 2 rotations of *E. pellita*. A nutrition study conducted in Riau, Central Sumatra on site formerly grown with two rotations of *A. mangium* found similar results where *E. pellita* did not show positive response to the addition of N fertilizer (Marolop, see Section 7.1.2 above). However, it is not yet known whether the available N on these sites will be sufficient to support high productivity of non-N-fixing species of *E. pellita* for the remainder of the current rotation, or over several rotations into the future.

The experiment was established on an Ultisol, a soil type which typically has low available P. Previous studies with *A. mangium* in the same region have demonstrated significant responses to P addition, but only a small amount of P (10 kg P ha^{-1}) was needed for maximum productivity (Hardiyanto and Wicaksono 2008, Mendham and Hardiyanto 2011). Growth responses to P addition have also tended to decline beyond age 4 years (Hardiyanto and Wicaksono 2008). Therefore, response later in the rotation needs to be assessed.

In this experiment no positive growth response to K addition at 70 kg ha^{-1} was found. Similarly there was no growth response to the addition of Ca as 2.5 t ha^{-1} lime even though the soils had low pH (4.4). It seems that the availability of K and Ca in the soil of experimental sites is sufficient to support the growth of current rotation of *E. pellita*. As the content of K and Ca in the soil has been found to decline over multiple rotations (Hardiyanto and Wicaksono 2008) cation availability may require greater management in later rotations. K deficiency has been widely reported in *Eucalyptus* plantations by the third rotation in Brazil and consequently K fertilizer application is recommended there to maintain high productivity (Gonçalves et al. 2008).

7.1.4 Cross-regional conclusions from Objective 1 studies

Across the experiments that we established, it is clear that the addition of P fertilizer is needed to achieve high productivity of all new *E. pellita* plantations. However, if the E. pellita rotation follows an *A. mangium* rotation, it is unlikely to require additional N. From the limited experience in South Sumatra, K and Ca fertilizer are also likely to not be required. However, the soil status of these nutrients, and the response of plantations to nutrient addition needs to be monitored into the future as part of the strategy to maintain productivity over several rotations.

7.2 Objective 2

Objective: To explore the interactions between site edaphic properties, soil fertility, slope, water availability and effects of management on productivity, and test if the relationships derived in South Sumatra are more generally applicable to other plantation regions within Sumatra.

7.2.1 RAPP Survey

This study was conducted at RAPP by Sabar Siregar, Alun Wibowo and Ahmad Hamid. Details of compartments chosen for this study and measurement results at plots within each compartment are shown in Table 34. At time of sampling the stand age ranged from 4.5 – 5.1 years, and stocking ranged from 983 to 1517 trees ha^{-1}. Stand volume was between 141 to 215 m^3/ha. (MAI of 29 to 44 m^3/ha/y). There was no relationship between age and stand volume across the 6-month age difference in this study (Figure 19) therefore we can assume that any variation in productivity between stands was independent of age.

Table 34 – Stand characteristics of the 12 *A. mangium* plantations used in this study

Site Number	Genetic Code	Sampling Age (year)	Plot Survival (%)	Plot Stocking (%)	Mean DBH (cm)	Mean Height (m)	Top Height (m)	Stand Volume (m³/ha)	MAI (m³/ha/y)
1	C3	4.9	76	1267	16.9	19.3	22.2	215.0	44.0
2	C7	4.5	63	1050	17.2	19.7	23.7	194.6	43.2
3	C6	4.7	91	1517	15.3	17.5	19.5	194.0	41.6
4	C1	4.9	78	1300	15.8	18.3	21.8	198.9	40.4
5	C2	5.1	84	1400	15.5	19.0	22.4	203.7	40.1
6	C1	5.0	61	1017	18.1	19.2	21.0	197.7	39.5
7	C3	4.9	68	1133	16.8	19.0	21.7	192.7	39.3
8	C1	5.0	73	1217	16.2	16.8	18.3	174.1	34.8
9	C5	5.0	71	1183	16.8	16.6	19.3	174.0	34.8
10	C4	4.8	70	1167	17.1	15.0	20.6	157.3	32.8
11	C2	5.0	59	983	16.5	19.0	21.6	155.9	31.2
12	C2	4.8	60	1000	16.2	16.1	19.1	141.5	29.3

There were 7 seedlots planted across the 12 compartments (Table 35), ranging from seeds originating from local Seed Production Areas (SPA) of proven provenances to vegetatively propagated material selected from individual families in progeny tests. Each seedlot had a calculated "genetic yield potential," of which there were 3 classes across the 12 sites. Analysis of the genetic yield potential (Fig. 20) demonstrated that there was a genetic basis to some of the variation that was observed in MAI, with the 'superior' genetic material having a higher MAI than the 'High Plus' material.

Figure 19 – Correlation between age and standing volume across the 12 sites

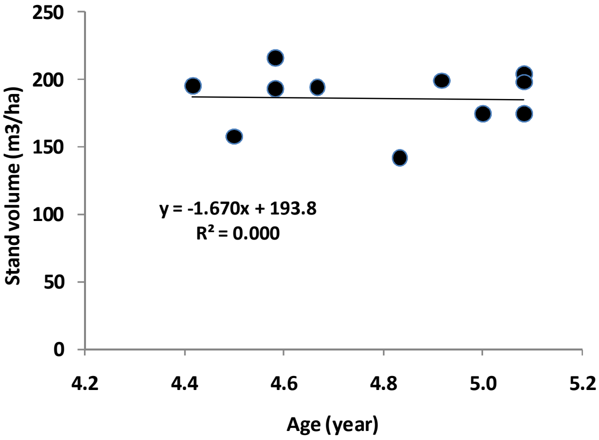
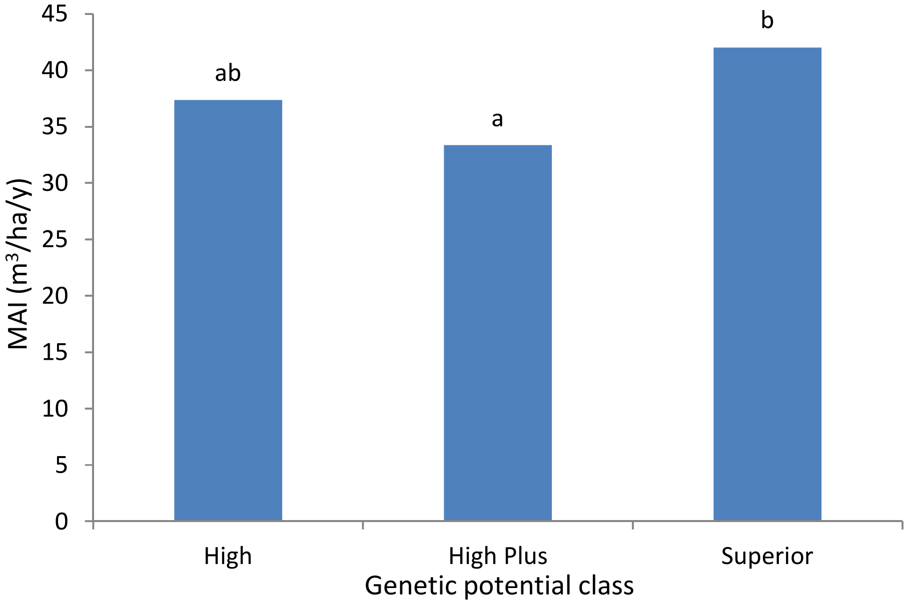


Table 35. Range of reported genetic potential of the selected seedlots

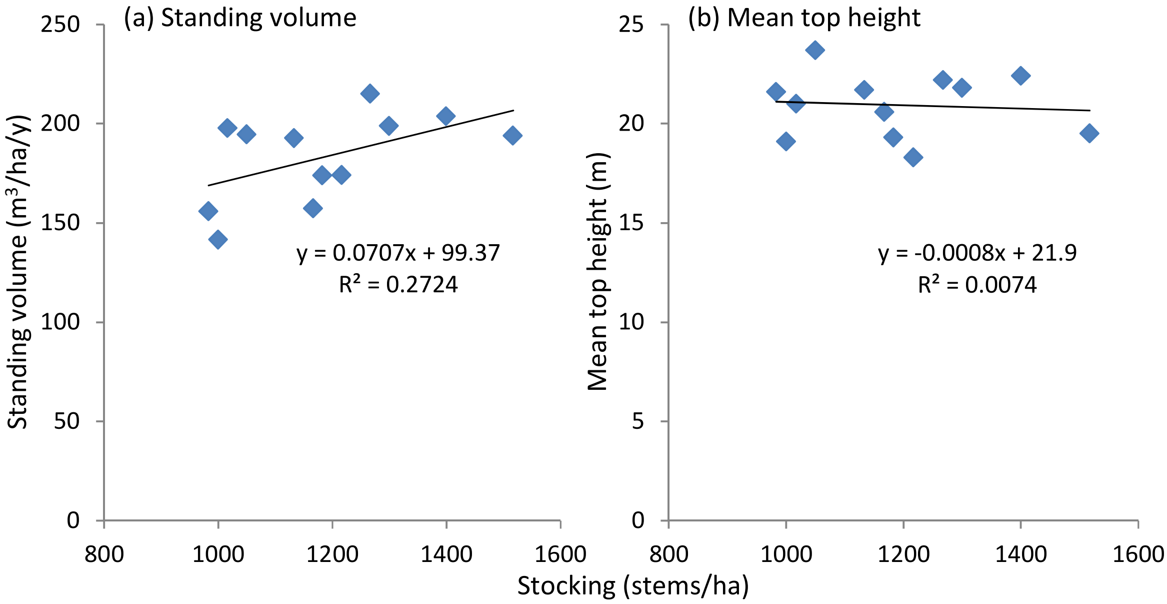
Seedlot	Sources	Genetic Potential Class
C1	Seed Production Area	High
C2	Clonal Breeeding/Seedling Orchard	High Plus
C3	Selected Family	Superior
C4	Clonal Breeeding/Seedling Orchard	High Plus
C5	Seed Production Area	High
C6	Selected Family	Superior
C7	Selected Family	Superior

Figure 20 – Yield of seedlots with different genetic potential across the site. Columns with the same letter were not significantly different (P<0.05).



Due to the intentional selection of stands with similar stocking rates across the sites in this study, there was only a weak positive correlation (R^2 = 0.27, P<0.1) between plot stocking and volume (Figure 21a). This indicates that stocking was not a significant factor influencing the volume of stands being studied, thus much of the variation in productivity was independent of stocking rate.

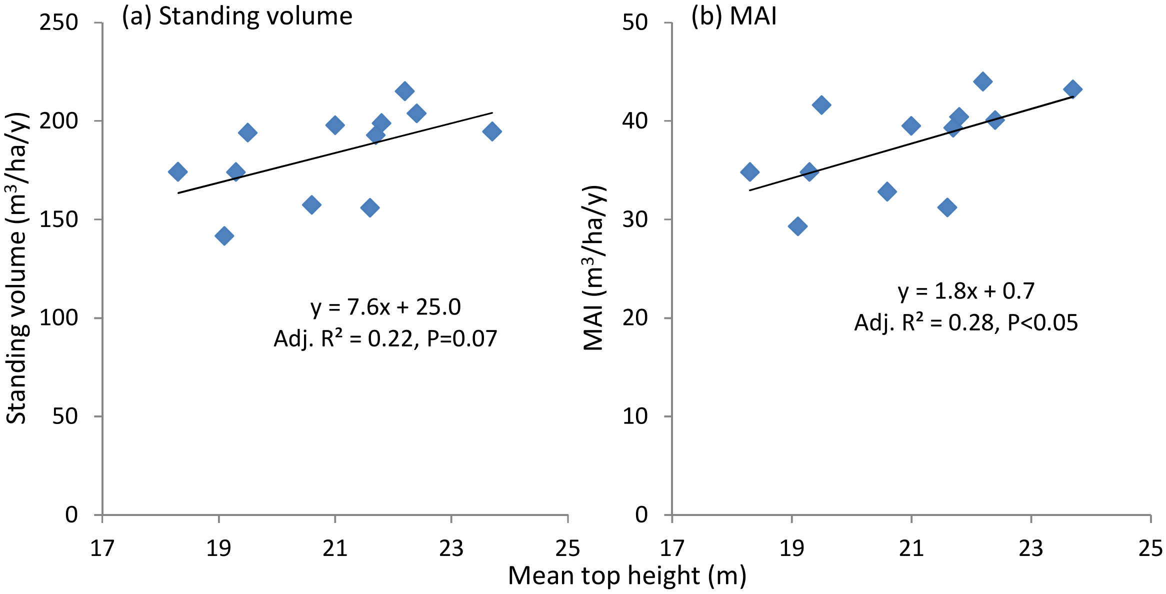
Figure 21 – Relationships between stocking and mean top height (a) and standing volume (b) of A. mangium across the 12 study sites



Top height had no relationship (R^2 = 0.007, P>0.1) with stocking of the stand (Figure 21b). It is worth noting that all plots had top heights within the range 18.3-23.7 m. Based on the top height (site index) classification of Lagura *et al.* (2012), the selected plots are categorised as very poor (<21 m) to average (23-25 m). Despite these classifications, the productivity levels were still high by world standards, with productivity at the 'very poor' sites ranging from 29.3 to 41.6 m^3 ha^{-1} yr^{-1}, the 'poor' sites (21-23 m) from 39.3 to 44 $m^3ha^{-1}yr^{-1}$, the single 'average' site (23-25 m) had an MAI of 43.2 m^3/ha/y (see Table 34), casting some doubt over the value of top height as a measure of site productivity. Indeed, Lagura *et al*. (2012) did not report any correlation between the Top Height (their Site Index) with actual stand productivity, so we suggest that Top Height is not a strong indicator of actual site productive potential.

There was a weak (almost significant) positive correlation between Top Height and stand volume (Adjusted R^2 = 0.22, P=0.07) and MAI (Adjusted R^2 = 0.28, P<0.05) (Figure 22).

Figure 22. Correlation between Top Height and standing volume (a) and MAI (b) of *A. mangium* across the 12 study sites



Relationships between site characteristics and stand productivity

Main site characteristics based on soil profile study is presented in Table 36.

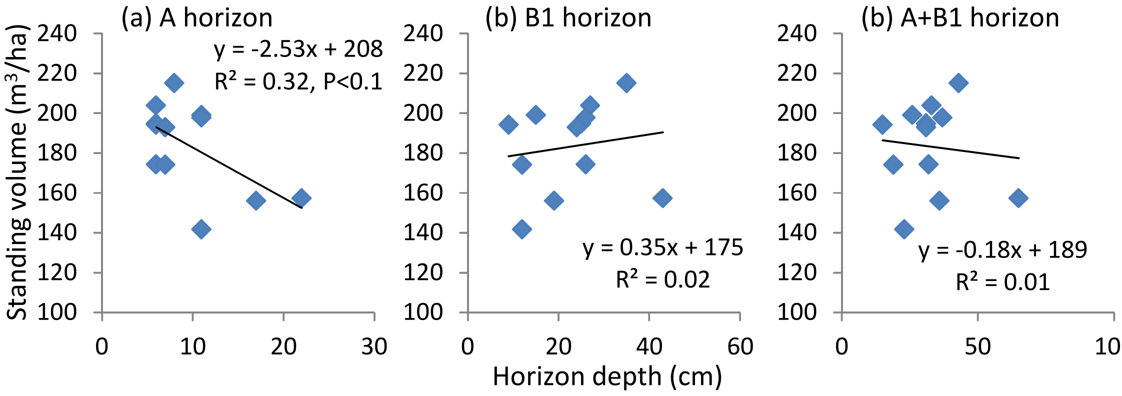
Table 36 –Site and soil characteristics of each of the 12 study sites

Site Number	Top Height (m)	Stand Volume (m^3/ha)	MAI (m^3ha/y)	Horizon thickness (cm) A	B1	Rooting depth (cm)	Plot slope (%)	Elevation (m)
1	22.2	215.0	44.0	8	35	86	7	74
2	23.7	194.6	43.2	6	25	64	16	140
3	19.5	194.0	41.6	6	9	116	4	84
4	21.8	198.9	40.4	11	15	64	12	103
5	22.4	203.7	40.1	6	27	74	4	98
6	21.0	197.7	39.5	11	26	114	6	41
7	21.7	192.7	39.3	7	24	75	8	84
8	18.3	174.1	34.8	6	26	129	13	60
9	19.3	174.0	34.8	7	12	48	32	97
10	20.6	157.3	32.8	22	43	20	0	48
11	21.6	155.9	31.2	17	19	86	6	119
12	19.1	141.5	29.3	11	12	23	0	65

Thickness of A and B1 horizons

There was a weak and negative correlation (R^2=0.32) between thickness of the A horizon and standing volume (Fig. 23), suggesting, somewhat perversely, that the highest productivity occurred in the sites with the shallowest A horizon. There were no relationships between the B1 or A+B1 horizon thicknesses and productivity of the stands (Fig. 23b,c).

Figure 23 – Relationships between standing volume and depth of horizons A (a), B1 (b) and A+B1 (c).



Rooting Depth

In addition to the weak correlation between the thickness of the A horizon and stand productivity, there was some evidence of a relationship between rooting depth and productivity (Fig. 24), with lower productivity observed at the sites with the shallowest rooting depths, but again, these relationships were not strong, and the site factors influencing rooting depth are still not clear. This relationship was mainly influenced by the 2 sites with the shallowest rooting depths, i.e. sites 10 and 12, which were related to impeded drainage and high water table, which was probably associated with the fact that they were within a run-on area with flat local topography. Evidence of high water tables and impeded drainage was also associated with a fluctuating water table shown by light greyish soil colour with iron mottling occurrence (reduced-oxidized intermittent condition). Rooting depth was not correlated with tree DBH, stocking or plot slope (Table 37).

Figure 24 – Relationship between rooting depth and standing volume (a) and MAI (b)

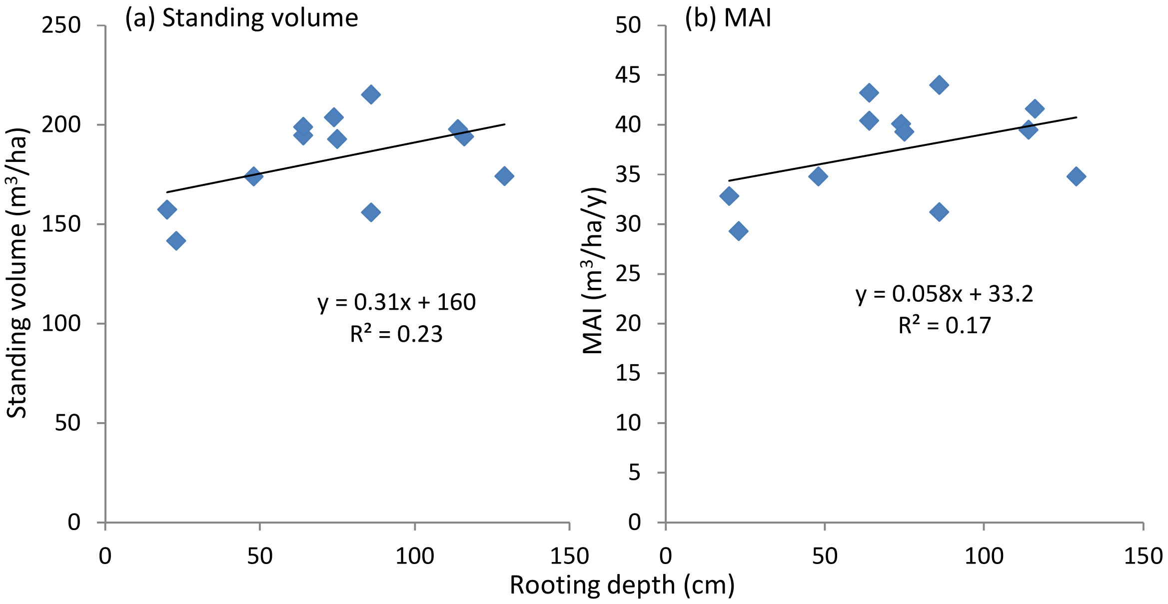
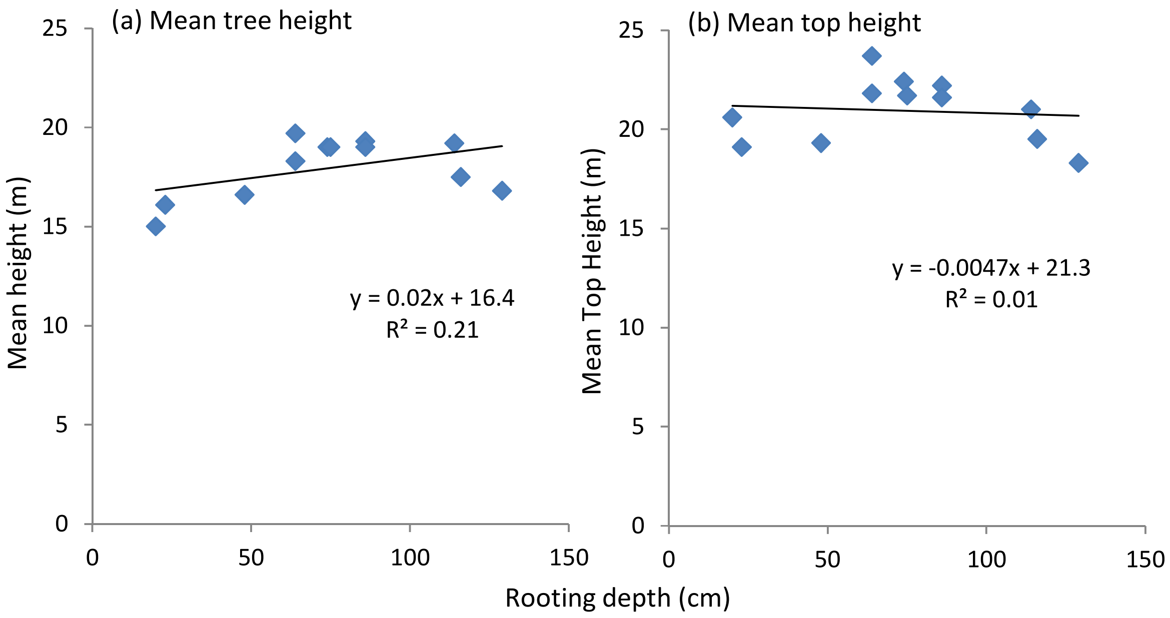


Table 37. Coefficient of determination (R^2) of linear relationships between rooting depth with DBH, plot slope and stocking. Relationships were not significant at P<0.05.

Correlation	R^2
Rooting depth with DBH	0.006
Plot Slope with Rooting Depth	0.001
Root depth with stocking	0.08

Rooting depth in the soil profile also had some relationship with mean tree mean height ($R^2 = 0.21$, Fig. 25a), but not with Top Height ($R^2 = 0.01$, Fig. 25b).

Figure 25. Relationship between of rooting depth and tree mean height (a) and Mean Top Height (b) of A. mangium.

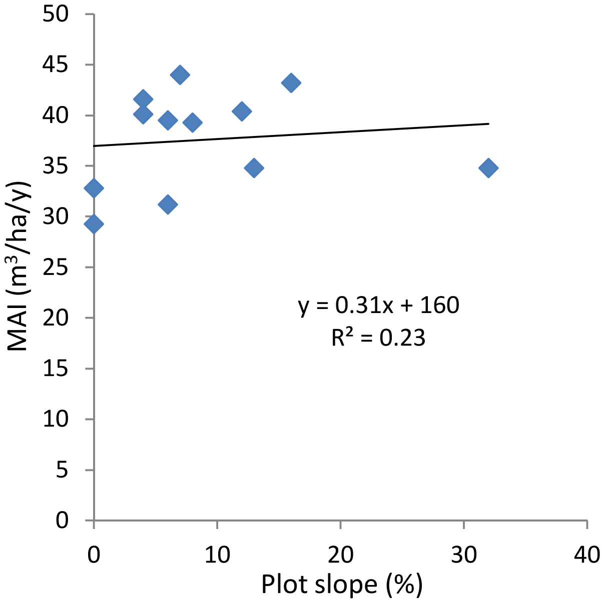


Plot Slope

Sampled plots in this study were mostly on mid or upper slopes, except for the 2 plots on flatter terrain (Sites 10 and 12). Plot slopes varied from 0 to 32%. Trend analysis showed that slope was weakly related to standing volume (Figure 26). Stand volume increased as slope increased up to around 10% slope, with but on the site with the steepest slopes, the stand volume was lower again.

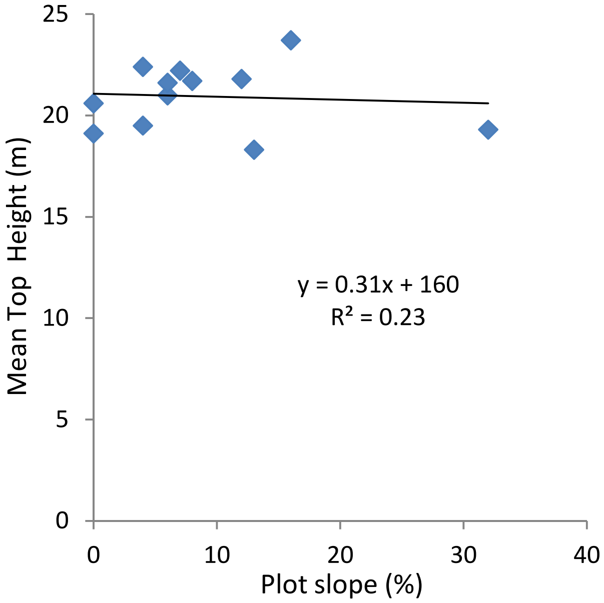
In this study, the flat sites and those with steep slopes (>30%) tended to have lower productivity than sites within 3-20% slope. Two plots in Ukui have 0% slope and clearly had a drainage impediment. Therefore, slope may also be indicative of the drainage characteristic of the site up to certain point. On the other hand, although one steeper site, in Teso West, has no drainage impediment, this steep slope (32%) may have exposed the stand to more difficult implementation of standard silvicultural practices (proper planting and maintenance), or perhaps exposed the site to greater damage during harvesting, which in turn affects the soil's capacity to support high growth rates. Water retention capacity on steeper slopes of a well drained soil could also be lower, contributing to less water availability during drier periods of the year compared to areas with shallower slopes. Badia *et al.* (2007) reported that tree height and basal area of pine and juniper in Spain was affected by slope in relation with water deficit. Steeper sites in that study had higher water deficit hence every 1° increase in slope, on average, reduced tree height by 10-25 cm depending on species.

Figure 26. Correlation between slope and MAI of *A. mangium*



The impact of slope on stand productivity was not reflected in the Top Height (Figure 27).

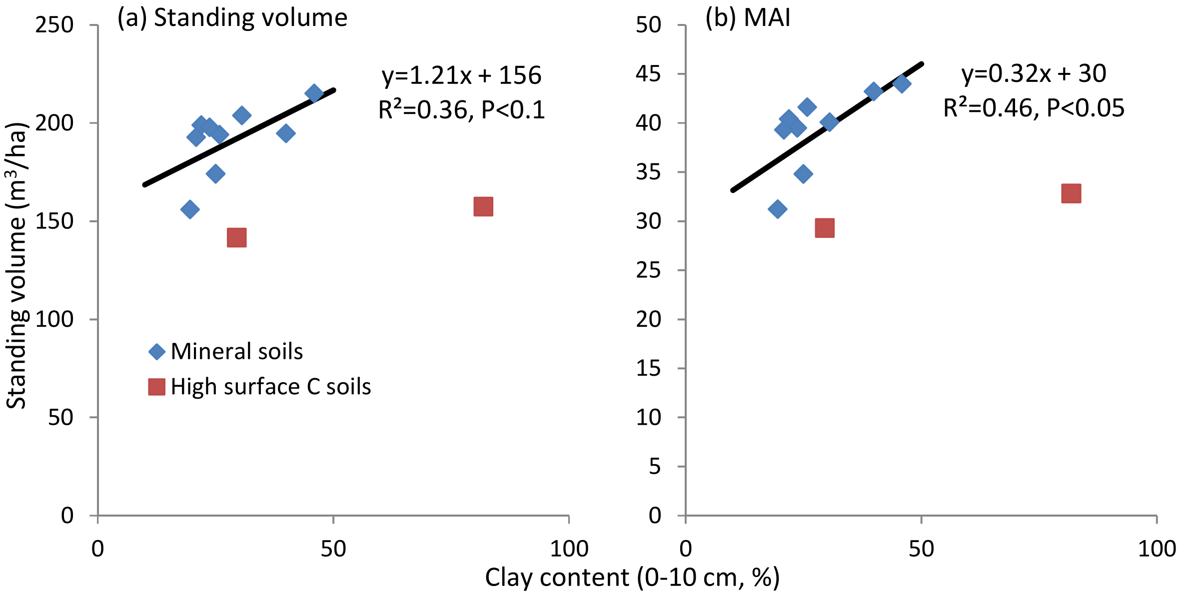
Figure 27. Correlation between slope and Top Height of *A. mangium*



Soil surface texture

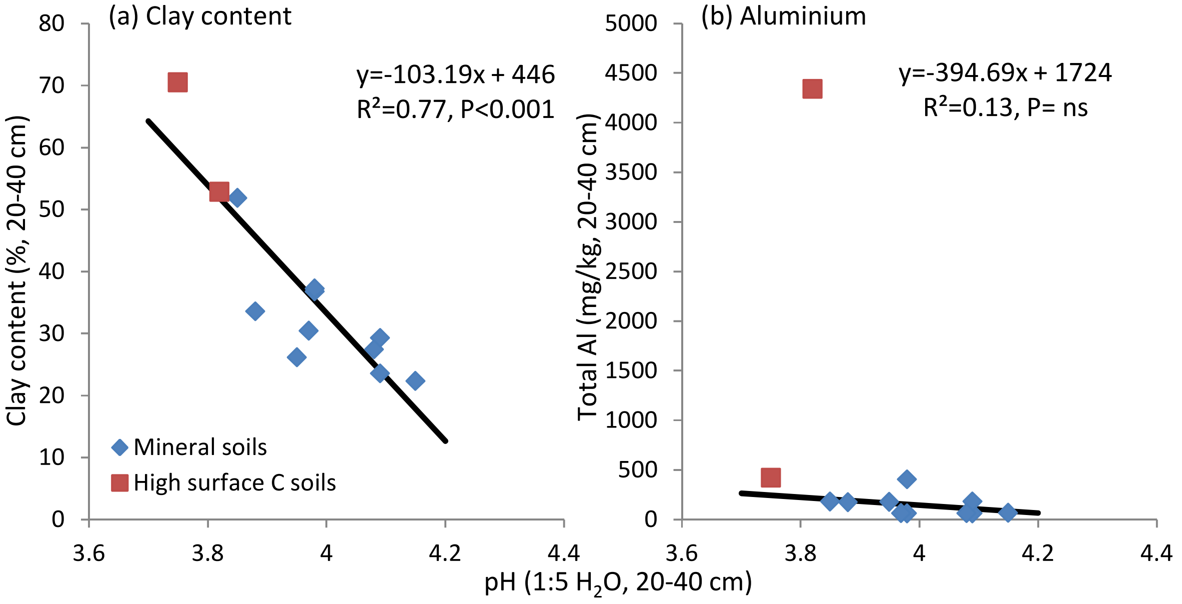
Across the 12 sites, there were no relationships between standing volume and surface clay content, but when the 2 sites with high surface soil carbon (sites 10 and 12 had peat-like characteristics in the surface soil, with organic carbon contents in the 0-10 cm depth range of 16.3% and 35.3%, respectively) were omitted from the relationships, there was a significant positive relationship between productivity and clay content, such that sites with higher clay content also had higher productivity (Fig. 28). There were no significant relationships between productivity and clay content in the deeper horizons (data not shown). Previous studies in Riau have found a relationship between surface soil clay content and P fixation capacity (Siregar, 2013), with higher P fixation in soils with higher clay content. Although we found no significant relationships between clay content and available P, the relationship between clay content and P fixation capacity may partly explain why the higher clay content soils had higher productivity, as their reserves of available P may be higher.

Figure 28 - Relationship between clay content and standing volume (a) and MAI (b). Soils with higher surface C (peat-like characteristics) were excluded from the regression analysis.



There were few relationships found between clay content and other soil properties, but one that stood out was the relationship between subsoil (20-40 cm) clay and pH (Fig. 29a), even though the range in pH was not great (3.75-4.15). This relationship did not readily translate to the total aluminium content, which was not significantly related to clay content, even with the high Al outlier omitted (Fig. 29b). A laboratory study in Riau has shown that P fixation by clay increased as clay content increased. Soil with clay content of 50%, for example, had the capacity to fix around 700 mg P kg^{-1} soil, or around 7 kg P ha^{-1} within 0-10 cm depth of soil (Siregar, 2013). So for this study, we hypothesised that soil with higher aluminium or clay content tended to make P less available to the plants, but perhaps still extractable using the Bray-P method hence showing a trend of higher extractable P.

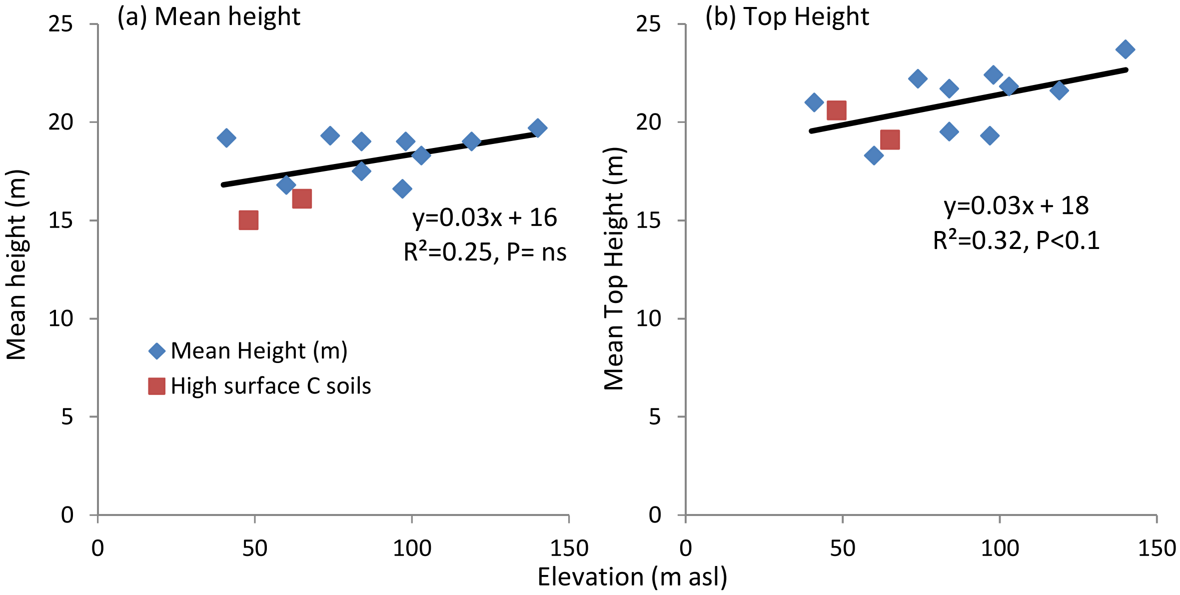
Fig. 29 – Relationships between subsoil pH and clay content (a) and total Al (b)



Site Elevation

The sites in this study were all at a relatively low elevation, ranging from 41 to 140 m above sea level. Mean Top Height was weakly related (R^2=0.32) to elevation (Fig. 30), but it was not related to stand volume (R^2 = 0.02), MAI (R^2 = 0.06) or stocking (R^2 = 0.00) (data not shown).

Figure 30 – Relationships between site elevation and mean tree height (a) and Mean Top Height (b).



Soil profile characteristics

Soil profile characteristics that were related to stand productivity are shown in Table 38. High productivity sites tended to have soil which was dark yellowish brown (10YR6/8) to brownish yellow (7.5YR4/4) in colour, had a friable to firm consistency, and a medium subangular blocky structure. Lower productivity sites tended to have poor drainage, were dark brown (7.5YR3/1) to white light gray colour (5Y8/1), and had a friable to firm consistency. Soil profiles representing the different stand productivity classes are shown in Fig. 31.

Figure 31. Soil profiles representing different stand productivity classes: (A) high productivity (MAI 44); (B) medium productivity (MAI 39); (C) low productivity (MAI 29)

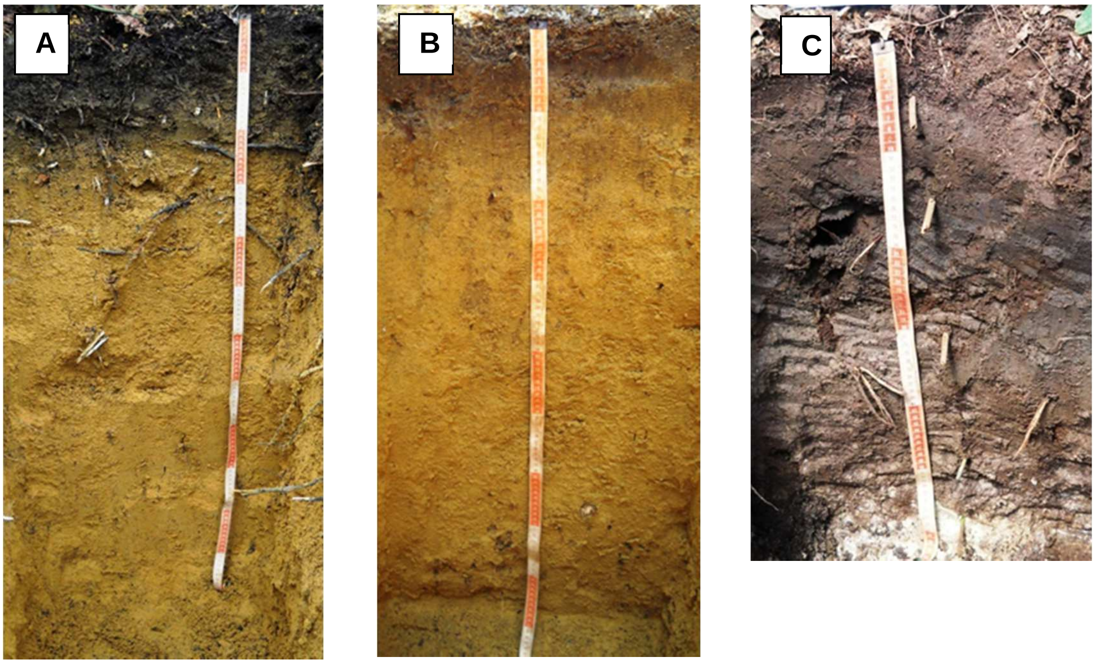


Table 38. Characteristics of soil profiles in different productivity class sites of *A. mangium* in Riau

Characteristics*	High Productivity Sites (MAI 40-44)	Medium Productivity Sites (MAI 34-39)	Low Productivity Sites (MAI 29-32)
Soil Colour	Dark yellowish brown to brownish yellow	Yellow to yellowish brown	Dark brown or White to light gray
Drainage	Good	Good	Poor to good
Texture	Sandy clay loam to clay	Sandy loam to clay	Silty clay to clay
Consistency	Friable to firm	Friable to firm	Friable to firm
Structure	Medium subangular blocky	Medium subangular blocky	Fine subangular blocky or sapric

** soil characteristics at about 40-50 cm depth*

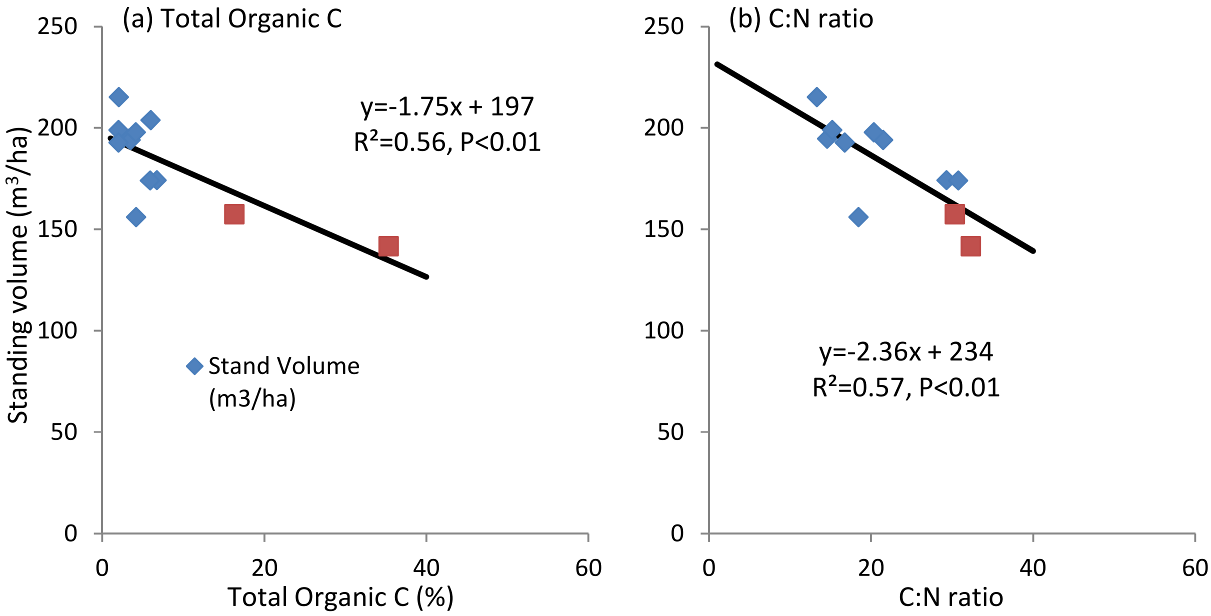
We found that sites with good drainage tended to have higher productivity, and this was associated with soil textures that were sandy clay loams, while the lower productivity poorly drained soils had silty clay to clay textures. Darker soil colour at two of the lowest productivity sites (sites 10 and 12) was probably attributable to their low-lying landscape position in a flood-plain, with a shallow water table leading to formation of thick organic matter layer (peat) on top of fine heavy clay, with light gray or white mineral soil substratum.

Our finding of drainage being a key factor associated with productivity was supported by other studies, including Laffan *et al*. (1998) who found that gray and orange mottles and thick very dark top soil were usually poorly drained and had lower productivity of *Eucalyptus nitens* in Tasmania. Similarly, Mendham and Hardiyanto (2011) reported that high productivity *A. mangium* sites in South Sumatra tended to have good drainage and red coloured soils while low productivity sites had a gley layer and tended to be brown-yellow in colour. The most prominent soil characteristic in South Sumatra that was related to productivity was the depth to plinthite (a layer of accumulation of clay with iron oxide mottles) which is impervious to water. The depth of plinthite layer was hypothesised to be an indicator of the rooting depth for *A. mangium* in South Sumatra. Although plinthite was not observed in Riau in the sites in this study, one of the lower productivity sites (Site 11) did have mottling in the mineral substratum below a thick organic layer indicating, which suggested a fluctuating water table. Impeded drainage at this site and the resulting low-oxygen environment much of the time may have resulted in the high accumulation of organic material on the soil surface.

Soil chemistry

Surface soil organic carbon was significantly related to standing volume (Fig. 32a), but the relationship was mainly influenced by the lower productivity peat-like soils at sites 10 and 12. The relationship showing lower productivity with higher surface soil C:N ratio (Fig. 32b) was more convincing across the whole dataset, as it was not unduly influenced by any of the individual sites. As discussed above, the poorer drainage at sites 10 and 12 may have resulted in both the lower productive potential and higher soil carbon. The C:N ratio can also be a good indicator of soil fertility, so it makes sense that the highest productivity sites had surface soil C:N ratios below 15.

Figure 32 - Correlation between standing volume of *A. mangium* and soil organic C (a) and soil C/N ratio (b) in the 0-10 cm depth range. Note that site 5 had a C:N ratio of 110, which was omitted from the relationship as it was well outside the normal bounds of soil C:N ratios (typically 10-40).



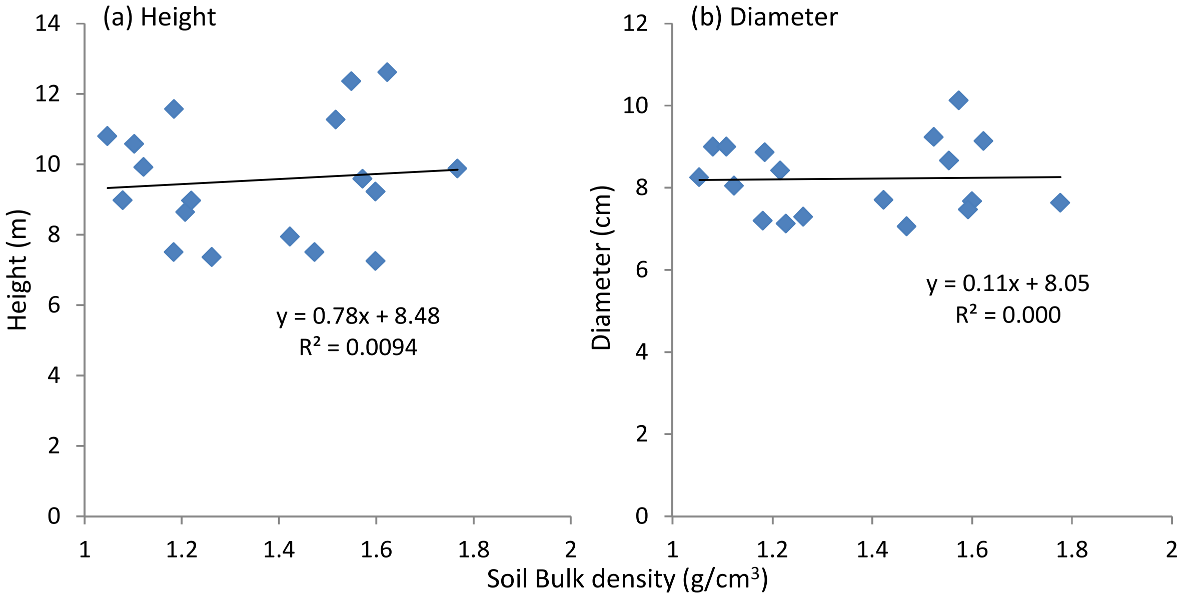
A. mangium productivity attributes were not significantly related to exchangeable soil cations (K, Ca, Mg) and CEC sampled at time of measurement (Table 39), but there were weak negative correlations with organic C, and with total soil N and extractable P at top 0-10 cm. Stand volume was not correlated with soil micro nutrient concentration (data not shown).

Table 39. Correlation between selected soil fertility measures and productivity attributes of A. mangium. Statistically significant (P<0.05) correlations were denoted: *

Surface soil attribute (0-10 cm)	Correlation coefficient (R) with:			
	Mean height	Stand volume	MAI	Survival
Organic C (0-10 cm)	-0.65*	-0.74*	-0.70*	-0.34
CEC (0-10 cm)	-0.59*	-0.47	-0.40	-0.27
Bray P (0-10 cm)	-0.44	-0.63*	-0.58*	-0.36
Exchangeable K (cmol +/kg)	-0.42	-0.14	-0.06	-0.04
Exchangeable Ca (cmol +/kg)	0.08	0.01	0.19	-0.27
Exchangeable Mg (cmol +/kg)	-0.27	-0.09	-0.01	-0.11

In order to explore the relationships between soil bulk density and productivity, we conducted an initial opportunistic survey in Nagodang Teso (L048, L047, and L051, total around 100 ha) in 2012 assessing soil BD in soil profiles after mechanical harvesting (single tire skidder) and assessed the productivity of the next rotation of *Eucalyptus pellita* in relation to the measured soil bulk density. We found that soil BD ranged from 1.00 to 1.60 g cm^{-3} at the 10-15 cm depth interval, but variation in bulk density was not able to explain variation in tree height or diameter in a plot of 150 m^2 around the soil pit (Fig. 33, Siregar *et al*., 2013). Soil BD measured at the soil profile has no correlation with plantation growth 2 years after planting (Figure 33). Whether or not *A. mangium* behaves the same as *E. pellita* in term of correlation with soil BD needs to be studied further.

Fig. 33 – Relationships between soil bulk density and E. pellita height (a) and diameter (b) at age 2 years



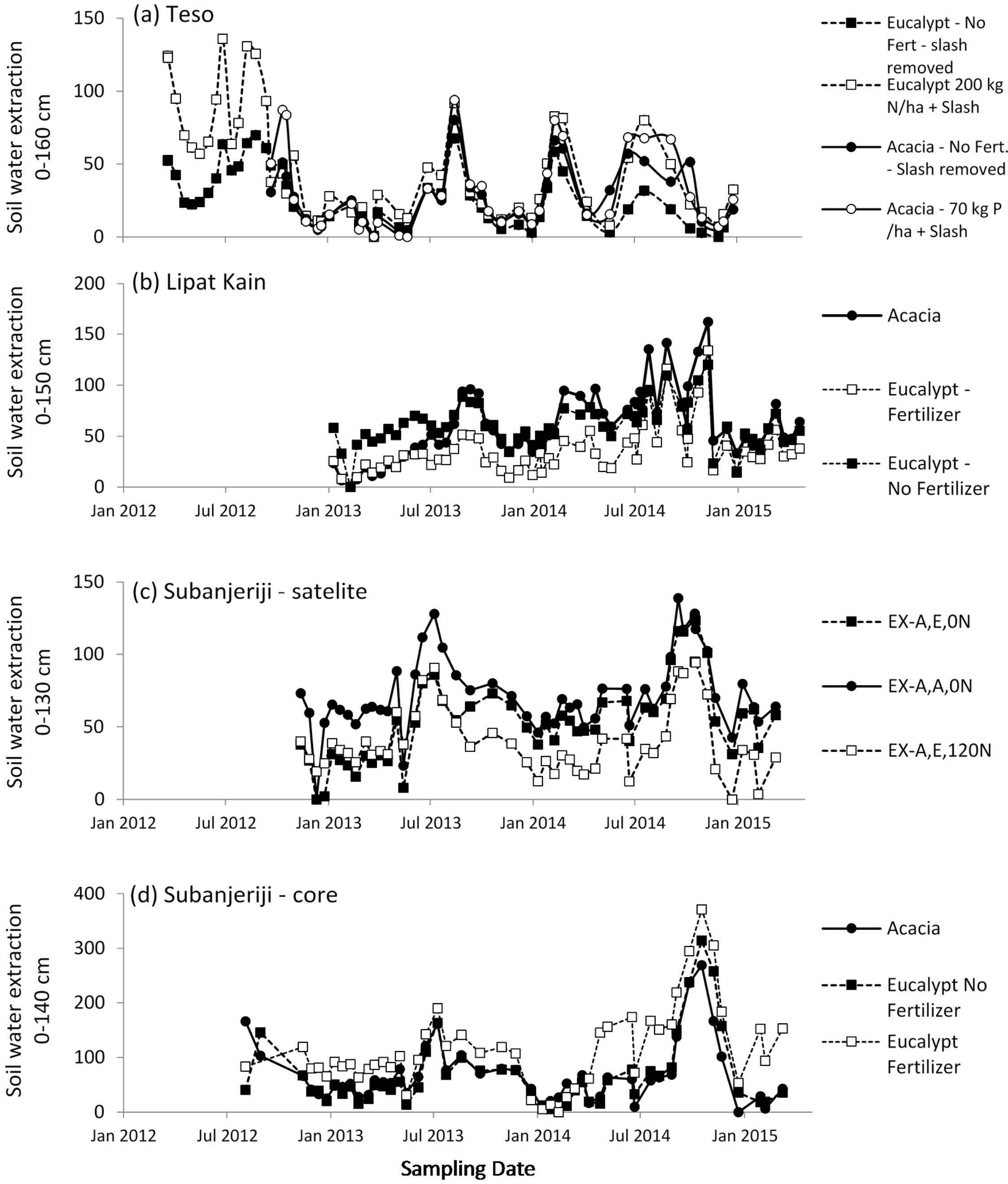
7.2.2 Treatment and site influences on soil water dynamics

This part of the study was led by Marcus Hardie and Daniel Mendham.

Effects of species and fertilizer on soil moisture and soil water extraction

Few differences in soil water extraction existed between species or nutrient treatments at any of the four sites. Throughout most of the monitoring period, soil moisture extraction to a depth of 140 cm depth remained less than 150 mm. The greatest soil water extraction occurred at the Subanjeriji core site between October 2014 and December 2014 (Figure 34). For example at Teso and Subanjeriji core sites soil water extraction was greatest for the fertilized *Eucalyptus* treatments, whereas at Lipat Kain and Subanjeriji satellite sites the *Eucalyptus* treatments with nitrogen fertilizer had the lowest soil water extraction. Substantial differences in the average soil water extraction existed between sites.

Figure 34: Average soil water extraction over time from (a) Teso E, (b) Lipat Kain, (c) Subanjeriji – satellite, (d) Subanjeriji –core.



Significant differences in water extraction between species/treatments within a site were slightly more common in the topsoil (0-30 cm depth) than the whole soil profile (0-140 cm depth), with a species effect on topsoil water extraction found at the Lipat Kain and Teso East sites, and also at the Teso East site from 0-100 cm depth. Significant differences in soil moisture between the two plantation species did not coincide with significant differences in soil moisture extraction. Fertilizer application did influence soil water extraction at 0-100 cm and 0-140 cm depth at the Teso East site but not at the other sites. Soil moisture data from the Teso east site was unable to be analysed using repeated measures due to bimodal data distribution (Table 40). The maximum amount of water able to be extracted from the soil profile (0-130 cm) differed between sites, but not between plantation species or fertilizer treatments.

Table 40: Effect of species, and fertilizer on cumulative soil moisture and soil water extraction

		Soil Moisture				Soil Water Extraction (log)			
Cum. Depth		Species	Fertilizer	Date vs Species	Date. vs Fert	Species	Fertilizer	Date vs Species	Date. vs Fert
0-30 cm	Lipat Kain	0.0001	NS	NS	NS	0.0025	NS	NS	NS
	Subanjeriji Core	NS	NS	NS	NS	NS	NS	NS	NS
	Subanjeriji Satellite	0.0083	NS	NS	NS	NS	NS	NS	NS
	Teso East	NA	NA	NA	NA	0.0001	NS	0.0001	NS
0-100 cm	Lipat Kain	NS	NS	NS	NS	NS	0.0019	NS	0.002
	Subanjeriji Core	NS	NS	NS	NS	NS	NS	NS	NS
	Subanjeriji Satellite	NS	NS	NS	NS	NS	NS	NS	NS
	Teso east	NA	NA	NA	NA	0.0043	NS	0.0001	NS
0-140 cm	Lipat Kain	NS	NS	NS	NS	NS	0.0061	NS	0.0001
	Subanjeriji Core	NS	NS	NS	NS	NS	NS	NS	NS
	Subanjeriji Satellite	0.0207	0.0081	NS	NS	NS	NS	NS	NS
	Teso east	NA	NA	NA	NA	NS	NS	0.0001	NS

NS not significant, NA data not available or not able to be normalised.

Repeated measures analysis demonstrated that at specific depths significant differences in soil water extraction existed between both plantation species and fertilizer treatments (Table 41). However significant differences in plantation species or fertilizer treatment were frequently not supported by a significant interactions between time (date) vs plantation species, or date vs fertilizer treatment interactions. Furthermore across the four sites, there was no clear consistent pattern of interaction between treatments and soil water extraction. At Lipat Kain all but one of the fifteen depths had a significant difference in soil moisture and soil water extraction, whereas at Teso East, no significant differences in either soil moisture or soil water extraction existed at any depth. The presence of significant differences in soil water extraction between treatments was attributed to spatial variance in soil properties and depth to ground water, which were not fully accounted for by replication and randomization of treatment plots.

Table 41: Influence of plantation species and fertilizer on soil water extraction by depth.Significance of relationship denoted by P<0.05 (✓), P<0.01 (✓✓), or not significant (NS).

	Lipat Kain				Subanjeriji Core				Subanjeriji Satellite						Teso East			
Depth cm	Plantation Species	Fertilizer	Date vs Species	Date vs fert	Plantation Species	Fertilizer	Date vs Species	Date vs Fert	Prior plantation species	Plantation Species	Fertilizer	Date vs Prior Species	Date vs Species	Date vs fert	Plantation Species	Fertilizer	Date vs Species	Date vs Fert
10 cm	✓	NS	NS	✓	✓	NS	NS	NS	NS	✓✓	NS	✓	✓	✓	NS	NS	✓✓	NS
20 cm	✓	✓	NS	NS	NS	NS	NS	NS	✓	NS	NS	NS	NS	NS	NS	NS	✓✓	NS
30 cm	✓	✓	✓	NS	NS	NS	NS	NS	NS	✓	NS	✓	NS	NS	NS	NS	✓✓	NS
40 cm	✓✓	✓	✓✓	✓	NS	NS	NS	NS	✓	NS	NS	NS	NS	NS	✓	NS	✓✓	NS
50 cm	NS	✓	✓✓	✓✓	✓✓	NS	NS	NS	✓	NS	NS	✓✓	NS	✓	NS	NS	✓✓	NS
60 cm	NS	✓	✓	✓	NS	NS	NS	NS	NS	NS	NS	✓	✓	NS	✓	NS	✓✓	NS
70 cm	NS	NS	✓	✓	NS	NS	NS	NS	✓	NS	NS	✓	✓	NS	NS	NS	✓✓	NS
80 cm	NS	✓	NS	✓✓	✓✓	NS	✓	NS	✓✓	NS	NS	NS	NS	NS	✓	NS	✓✓	NS
90 cm	NS	✓	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	✓	NS	✓✓	NS
100 cm	✓	NS	✓	NS	NS	NS	NS	NS	NS	✓	NS	NS	NS	NS	✓	NS	✓✓	NS
110 cm	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	✓	NS	NS	✓	NS	✓✓	NS
120 cm	✓	NS	✓	NS	✓	NS	NS	NS	✓	NS	NS	✓✓	✓	NS	NS	NS	✓✓	NS
130 cm	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	✓	NS	✓✓	NS
140 cm	NS	NS	✓	NS					NS	NS	NS	NS	NS	NS	NS	NS	✓✓	NS
150 cm	✓	✓	✓	NS														

Plantation species and fertilizer application had no significant effect on the maximum volume of soil water extracted from the soil profile to a depth of 130 cm (Table 42). The maximum depth of soil water extraction was not able to be determined from the soil moisture monitoring data due to groundwater fluctuations within the tree root zone, and soil water extraction below 160 cm depth.

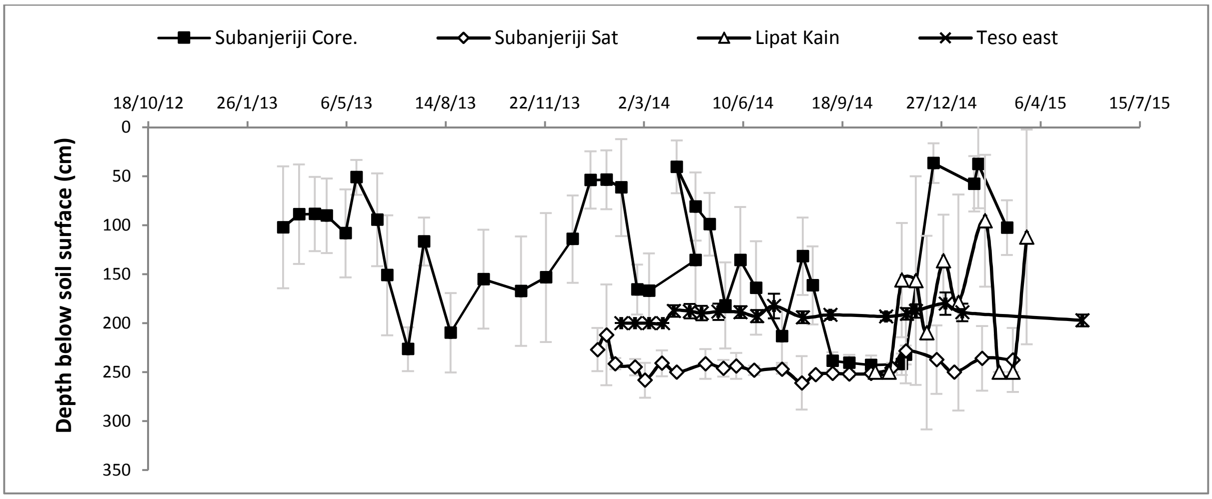
Table 42: Effect of plantation species and fertilizer on the maximum soil water extraction (mm, 0-130 cm depth). No significant differences existed between treatments. Values in brackets represent ±1 standard deviation.

Plantation species	N Fertilizer	Lipat Kain	Subanjeriji-Core	Subanjeriji - satellite	Teso
Eucalypt	0	123.28 (24.64)	328.75 (44.84)	110.32 (31.45)	64.53 (12.29)
	120	113.21 (40.71)	281.39 (82.89)	105.03 (14.65)	82.70 (20.86)
Acacia	0	151.37 (82.36)	272.59 (18.28)	106.10 (38.59)	90.83 (20.20)

Influence of groundwater on soil moisture and soil water extraction

Groundwater response to rainfall differed markedly between sites. At the Subanjeriji Core and Lipat Kain sites the average depth to groundwater underwent considerable fluctuation over the monitoring period ranging from 241 to 37 cm depth at the Subanjeriji Core site, and from 250 to 95 cm depth at Lipat Kain. In comparison, depth to ground water at Teso East and Subanjeriji satellite sites were relatively consistent, varying by only 20 cm and 38 cm respectively over the monitoring period, despite the two Subanjeriji sites being located less than 400 meters apart (Figure 35).

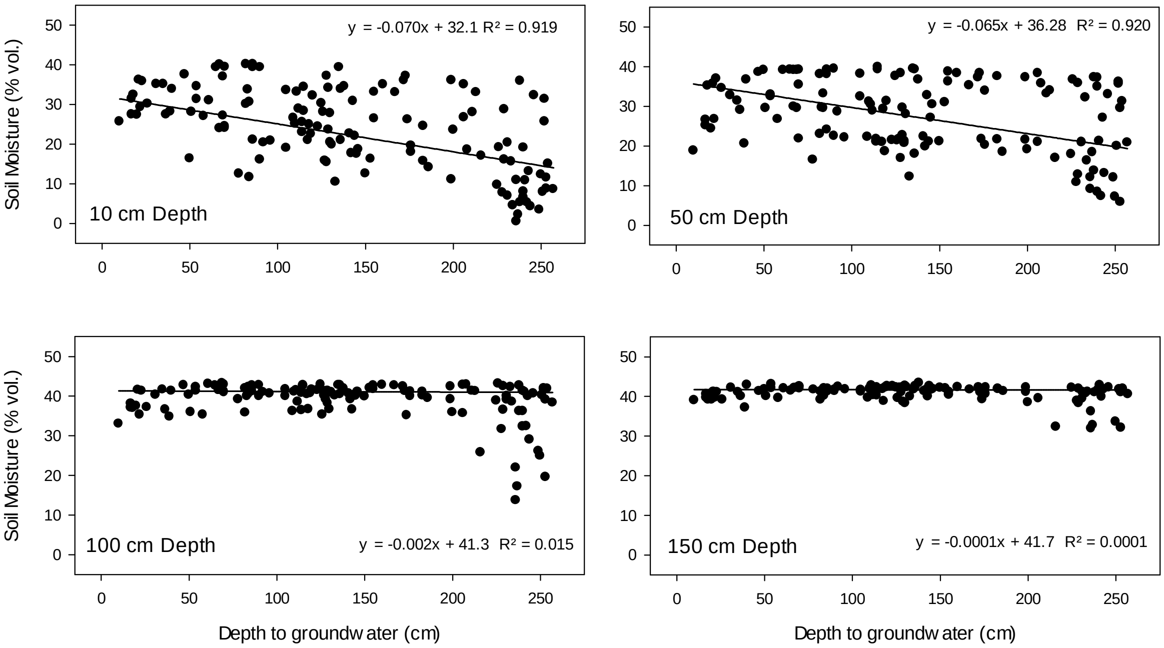
Figure 35: Depth to groundwater over the monitoring period (includes maximum values near pizometer base).



Repeated measures analysis demonstrated that plantation species had no significant effect on the depth to groundwater at any site, despite the fact that depth to groundwater in the eucalypt treatments (E0 122.67 cm ±sd 74.04) was on average double that of the *Acacia* treatments (A0 60.35 cm ±sd 42.66) at Lipat Kain. Curiously fertilizer treatment significantly influenced depth to groundwater at Teso east, however there was no interaction with time.

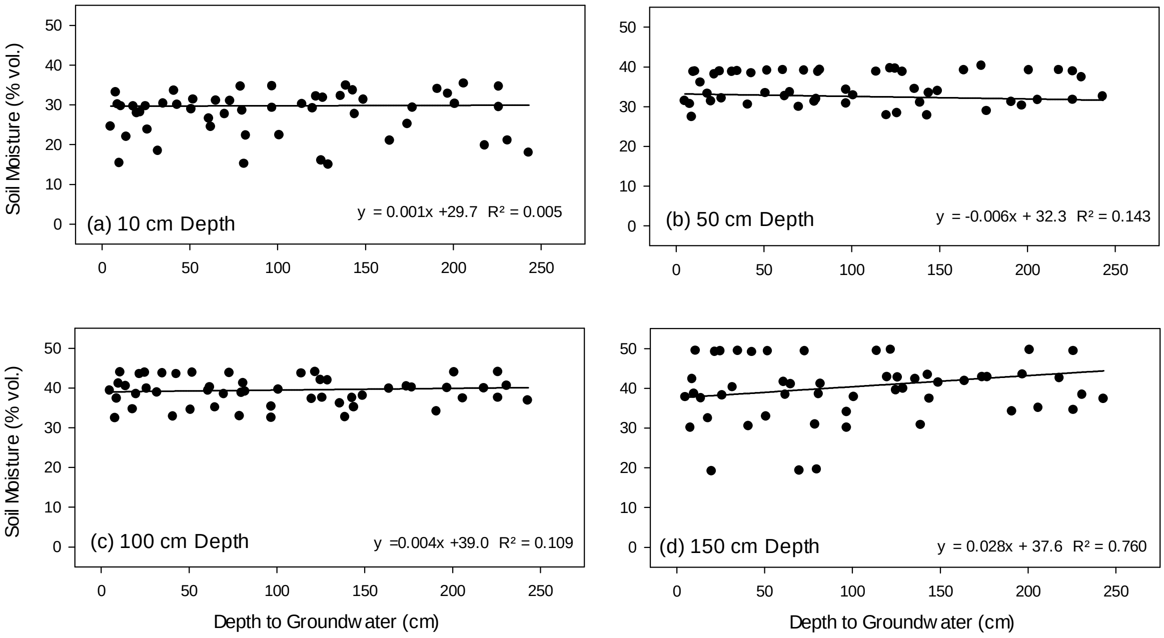
The depth to groundwater had a profound influence on soil moisture at the Subanjeriji core site. The depth to groundwater showed a significant relationship ($P<0.001$, R^2 0.919) to soil moisture at the 10 and 50 cm ($P<0.001$, R^2 0.920) depths (Figure 36a &b), such that topsoil moisture content was strongly correlated with the depth to the groundwater. Soil moisture at 100 cm and 150 cm depth remained constant between 35 and 42% despite the depth to groundwater ranging from 17 to 253 cm from the soil surface (Figure 36). However, a lower rainfall around October-November 2014 resulted in soil moisture falling below 30 %, and groundwater falling below 230 cm (Figure 36).

Figure 36 – Subanjeriji Core: Effect of depth to groundwater on soil moisture at (a) 10 cm depth , (b) 50 cm depth, (c) 100 cm depth, and (d) 140 cm depth



In comparison to the Subanjeriji core site, at Lipat Kain the relationship between soil moisture and depth to groundwater was poor at all depths other than 150 cm (Figure 37). At 150 cm depth, soil moisture was significantly ($p<0.0001$, $R^2=0.760$), and positively related to the depth to groundwater. Slope of the regression between soil moisture and depth to ground water was close to zero (-0.006 to 0.004) which indicated that soil moisture was other than at 150 cm depth, the depth to groundwater appeared to have little effect on soil moisture at the Lipat Kain site.

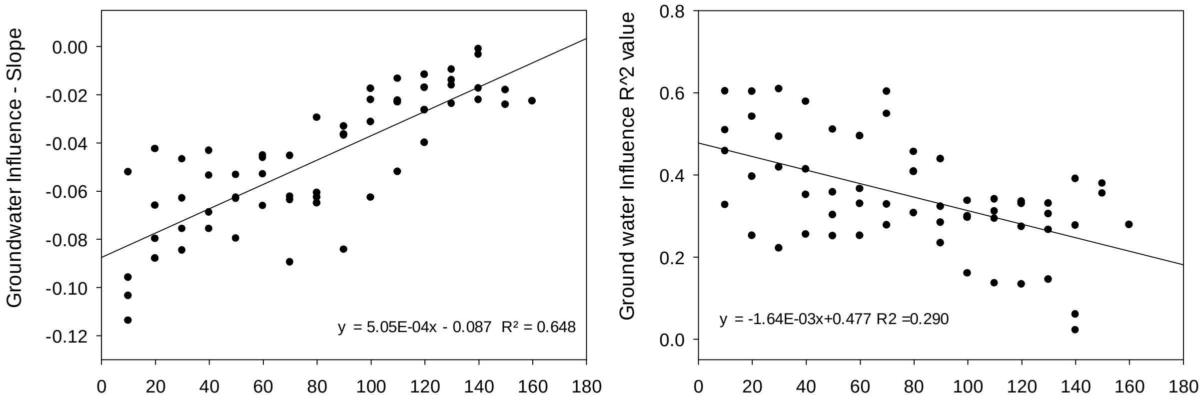
Figure 37 - Lipat Kain: Relationship between depth to groundwater and soil moisture at (a) 10 cm depth , (b) 50 cm depth, (c) 100 cm depth, and (d) 150 cm depth



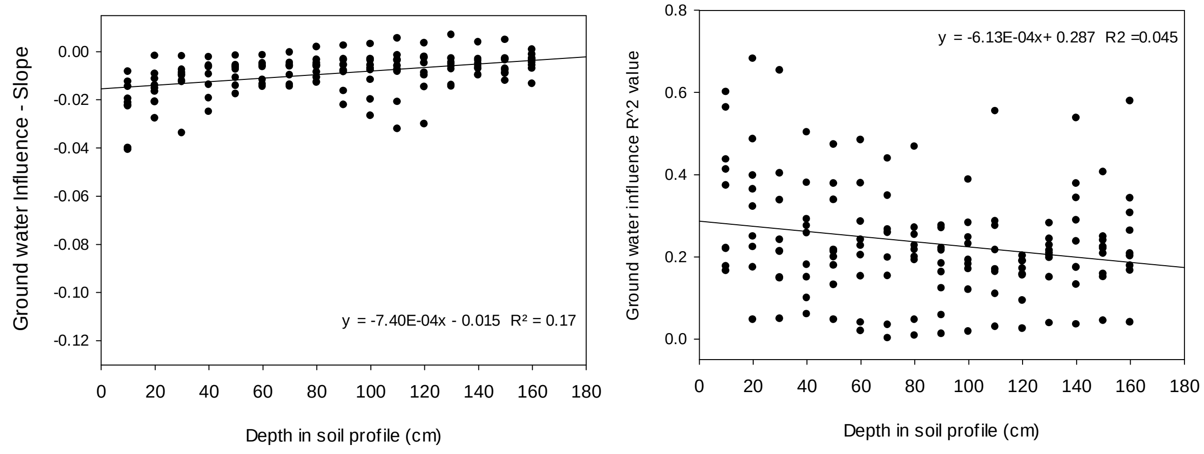
The interaction between the depth to groundwater and soil moisture was further explored between the Subanjeriji core and Lipat Kain sites by plotting the relationship between the slope and regression of the relationship between soil moisture and depth to groundwater vs soil depth (Figure 38). At the Subanjeriji Core site, the slope of the regression between soil moisture and depth to the groundwater was strongly related to soil depth. This indicated that groundwater had a profound influence on soil moisture throughout the soil profile. The value of R^2 also declined with depth indicating that depth to groundwater had the strongest influence near the soil surface (Figure 38). By comparison at Lipat Kain, the slope of the regression between soil moisture and depth to the groundwater and soil depth were much closer to zero (no relationship) in which soil depth appeared to have little influence on either slope or R^2 values, such that depth to ground water appeared to have minimal influence on soil moisture., probably due to the greater drainage potential of the Lipat Kain soils.

Figure 38: Depth to groundwater relationship with soil moisture presented as the slope and R^2 of the linear relationship between depth to ground water and soil moisture vs depth for the Subanjeriji core and Lipat Kain sites.

Subanjeriji - Core



Lipat Kain



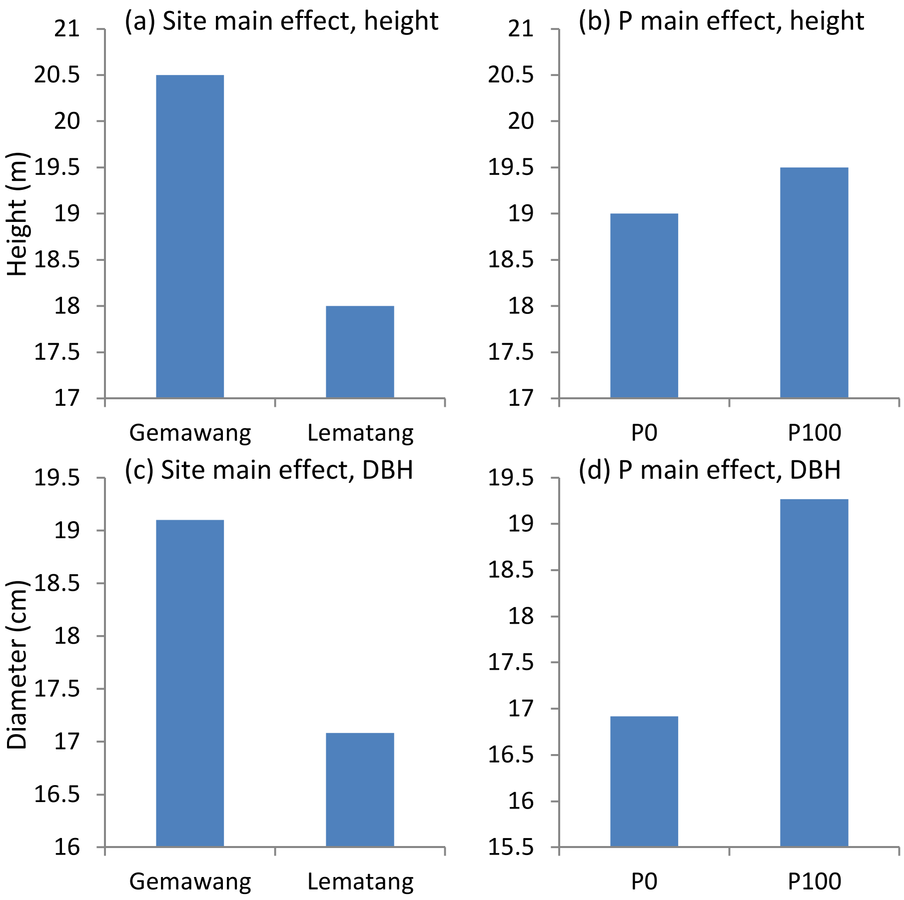
7.2.3 Silviscan study

This study was led by Craig Armstrong, as part of his Masters thesis at the University of Melbourne. It was conducted on older experiments in South Sumatra.

Tree size

Trees from the higher productivity Gemawang site had greater diameter and height than those from the lower productivity site at Lematang (Fig. 39, significant for height only). Note that these assessments were only on the sample trees, not the whole plot, so differences are not necessarily indicative of overall treatment effects.

Figure 39 – Height and diameters of the trees sampled for this study. Main differences between sites and treatments only are shown. There were no significant site or treatment differences in DBH, but the tree heights were both significantly different between treatments.



Impact of site and P fertilizer on pith-to-bark average wood properties

SilviScan analysis from CSIRO included pith to cambium measurements of basic density, modulus of elasticity (MOE), and microfibril angle (MFA). Pith to cambium averages were used in this part of the data analysis, to understand the overall influence of site and treatment on wood properties. The tropical climate and continuous growth characteristics of *A. mangium* in this environment meant that growth rings were not readily identifiable in the cores. Thus, we firstly looked to understand the treatment and site effects on the average wood properties of the full cores.

Treatment effects on pith to cambium means for density, MOE and MFA were tested using two-way analysis of variance, with two different sites (high and low productivity) and two different phosphorus levels (P0 and P100). Neither of the main effects was statistically significant at a 0.05 confidence level. Figures 40, 41 and 42 below respectively show the variation in density, MOE and MFA across the different sites and treatments.

Figure 40. Average air-dry density of A. mangium across two different sites (a) and two different treatments (b) in Sumatra, Indonesia. Note that the main effects were not significant. Error bars show +/- 1 standard deviation.

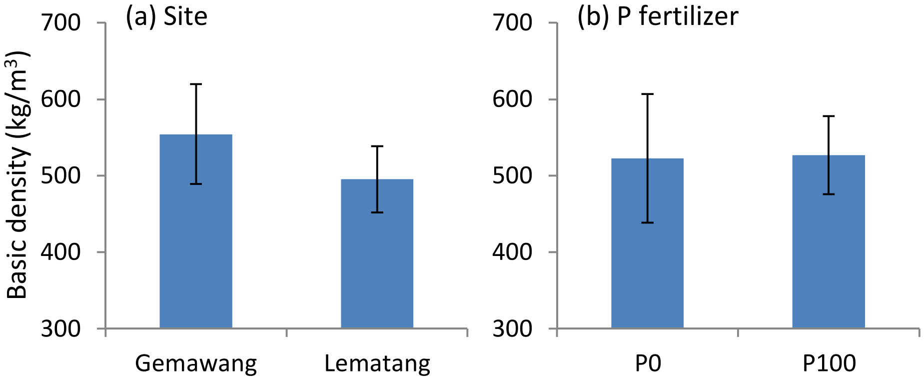


Figure 41. Microfibril angle of *A. mangium* across two different sites (a) and two different treatments (b) in Sumatra, Indonesia. Note that main effects were not significant. Error bars show +/- 1 standard deviation.

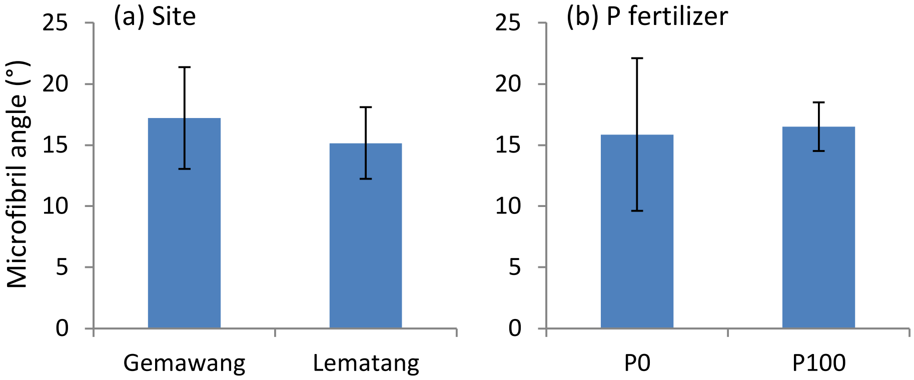


Figure 42 – Modulus of Elasticity of *A. mangium* across two different sites (a) and two different treatments (b) in Sumatra, Indonesia. Note main effects were not significant. Error bars show +/- 1 standard deviation.

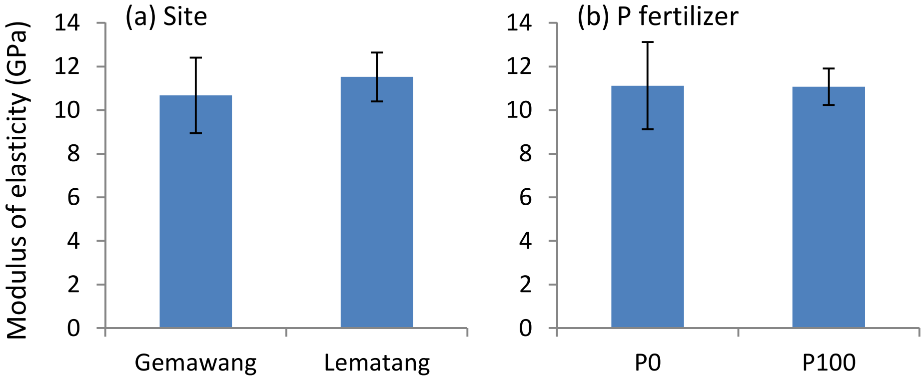


Table 43 below provides averages values for Air-dry density, MFA and MOE calculated from all 12 samples taken in this study. Density figures for the samples ranged from approximately 450 kg/m^3 to 650 kg/m^3 with an average of 525 kg/m^3 across all samples and all treatments. Similarly, MFA and to a lesser extent MOE, had considerable ranges with MFA ranging from approximately 11.0 to 18.9 degrees and MOE from 8.2 to 13.4 Gpa.

Table 43. Wood properties of 5-year-old *A. mangium* across all sites and treatments in Sumatra, Indonesia.

	Air Dry Density (kg/m^3)	MFA (degrees)	MOE (Gpa)
High Productivity	554.3	17.2	10.7
Low Productivity	495.1	15.2	11.5
P0	522.7	15.9	11.1
P100	526.7	16.5	11.1
All sites/treatments	524.7	16.2	11.1

Based on the lack of significant differences between treatments on the whole-core average wood properties, we conducted a follow-up investigation into appropriate sample sizes that would be required to ascertain if there were significant differences in wood properties of the whole-cores. As proposed in Snedecor and Cochran (1989) and recommended by Downes et al (1997) the following equation was used:

$$n = t^2 \frac{s^2}{L^2}$$

Where:

n = required number of samples
t = t value
s = standard deviation
L = relative error (mean x precision level)

Variation in the wood properties across the cores in our study suggested that 7 core samples would be required to test for significant differences in density, 24 samples for MFA, and 9 samples for MOE (Table 44). These sample numbers would provide for 0.05 confidence level if there is a 10% difference in the three different wood properties.

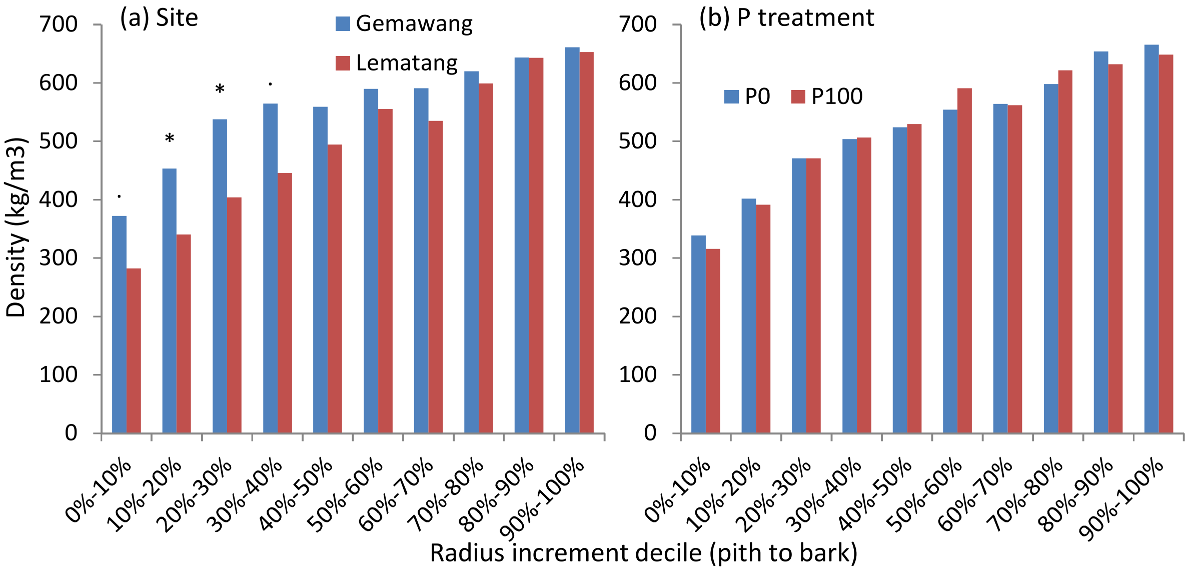
Table 44. Calculated sample numbers required for sampling different wood properties of A. mangium.

Wood Property	Samples required
Density	7
MFA	24
MOE	9

Within-radius changes

It must be noted that most wood properties are not evenly distributed from pith to bark and in general, radial means will be heavily biased towards the pith. In this section we explored treatment differences within the radial cores. It needs to be recognised that the trees each had different diameters, and without a more accurate mechanism to segregate the cores into seasonal or annual growth rings, we used a proportional distance approach, dividing the cores into 10 equal length segments, with the pith representing 0% and the cambium representing 100% of the distance along the radial core. The growth of the trees in this environment has been shown to be relatively constant over the year (few seasonal effects), so the proportional approach to dividing the core into 10 equal length segments is likely to provide a comparison of material within each segment that was deposited at approximately similar times.

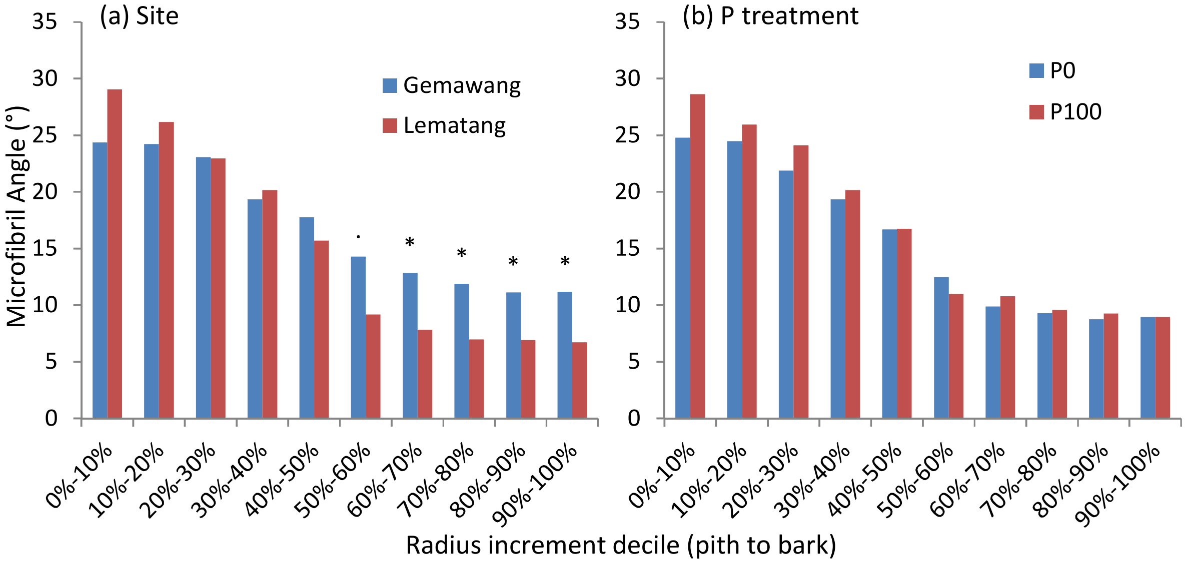
Figure 43 – Main effects of site (a) and P treatment (b) on wood density at each radial distance decile. Significance of the site effects within each decile are denoted as P<0.1 (.) and P<0.05 (*). There were no significant effects of P treatment on density.



The density of the stem increased markedly with distance from the pith, such that it was 300-400 kg/m^3 at the pith, and 600-700 kg/m^3 under the cambial layer (Fig. 43). The cores from the Gemawang site followed this trend, but they had significantly higher density in the samples closer to the pith compared to the Lematang site. From 40% to 60% of the core distance, there were no significant differences between sites in wood density.

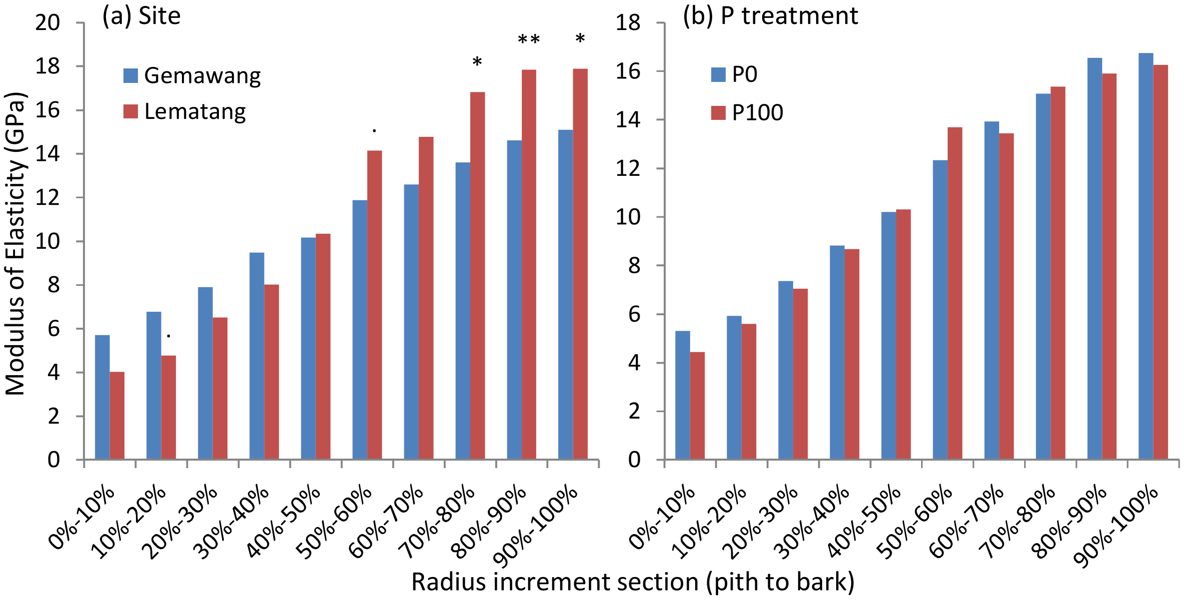
The microfibril angle also changed markedly with distance from the pith, starting at around 25-30° at the pith, and declining to 5-15° from around 60% of the length of the cores (Fig. 44). As with wood density, there was no significant effect of P treatment on microfibril angle, but there was a significant site effect from around 50% to 100% of the core radius (ie. The outer section of the wood), with the higher productivity Gemawang site also having a higher microfibril angle (Fig. 44).

Figure 44 – Main effects of site (a) and P treatment (b) on microfibril angle at each radial distance decile. Significance of the site effects within each decile are denoted as P<0.1 (.) and P<0.05 (*). There were no significant effects of P treatment on density.



As with microfibril angle, the modulus of elasticity also changed markedly with distance along the radial cores, at around 4-6 Gpa in the pith, up to around 16-18 Gpa under the cambium (Fig. 45). Again, there were no P treatment impacts on microfibril angle, but there were significant site effects with the older wood, with cores from the Lematang site showing significantly higher MOE for the last 30% of the core.

Figure 45 – Main effects of site (a) and P treatment (b) on modulus of elasticity at each radial distance decile. Significance of the site effects within each decile are denoted as P<0.1 (.) and P<0.05 (*). There were no significant effects of P treatment on density.



Average air-dry density, MFA and MOE across all samples and treatments were generally similar to those found in the literature (Table 43), however the significant variation between samples for density (from 450 to 650 kg/m^3) suggested that there was a substantial amount of intra-specific variation. There was no relationship between tree size and wood density, suggesting that there may be scope to improve wood density through breeding without sacrificing tree volume.

Whilst not statistically significant for the whole core, the results from this study suggested that higher productivity sites may produce higher wood density as well as a greater volume, with around 10% higher density in the trees from Gemawang compared to Lematang (Fig. 40). However, it is clear from the radial profile (Fig. 43) that the density increase is conveyed early in the rotation, with the later-formed wood (closer to the cambium) having a similar density between the 2 sites, suggesting that the overall density is likely to converge between the sites as the trees gets older. In contrast to density, the more productive Gemawang site tended to produce wood with a lower stiffness (higher MFA and lower MOE) than that from the Lematang site, with these differences mostly apparent in the later wood (Figs 44 and 45). Mohd Sahri *et al* (1998) also found that the faster growing trees in Indonesia had higher wood density than those from a lower productivity site in Malaysia, however, in contrast to our study, they did not find any influence of site on the mechanical properties (e.g. MOE), which is also supported by Mohd Zin *et al* (1991).

Based on the radial profile trends of density and mechanical properties that were found between different productivity sites in this study, older trees are likely to have lower density variation whilst the variation in mechanical properties should be further highlighted with increasing age. These observations are important to consider when designing sampling protocols for wood properties particularly where they relate to breeding programs and early age screening. Supporting this, Mohd Qumruzzaman *et al* (2005) found that variation of physical properties (moisture content, shrinkage and density) were much greater in 10 year old *A. mangium* trees compared to 15 and 20 year old trees.

Phosphorus application across the two sites did not seem to substantially influence wood properties, either as a main effect, or through interaction with site. This does not support the findings of Ani *et al* (1991), who did observe that addition of P to *A. mangium* increased the strength properties of the wood, while addition of nitrogen fertilizer increased wood strength even further. The apparent and consistent lack of P fertilizer effect on wood density suggests that there may be no trade-off between standing volume and wood density through P application, as has been found in some other studies. For example, Cown and McConchie (1981) reported that Fertilizer application in *Pinus radiata* improve standing volume by around 20%, but the fertilized trees also had around 5% lower wood density, so while the net benefit was still positive, it was less than if the volume only had been accounted for.

7.2.4 Soil N mineralization study

This study was led by Gunawan Wibisono and Rustam in plantations in South Sumatra.

Soil organic matter, organic C and total N were all higher in soil under *A. mangium* (8.3-11.4%, 4.9-6.6%, 0.2-0.3%, respectively), compared to soil under *E. pellita* (7.1-8.1%, 4.1-4.7%, and 0.15-0.17%, respectively). The C:N ratio of the soil under the *A. mangium* plantation was also lower than that of the *E. pellita* plantation. N mineralization was close to double that under *A. mangium* compared to that under *E. pellita* at all sites (Table 45). Across the sites, the effect of species change on soil N mineralization was significant, suggesting that *Eucalyptus* induces a significant decline in available soil N, compared to *Acacia*.

Table 45 – N mineralization (mg N/kg soil) under the 2 species at 3 sites in South Sumatra. Standard deviation around each mean is shown in parentheses

Location (age)	*A. mangium* (mg N/kg)	*E. pellita* (mg N/kg)
Subanjeriji (5 years)	10.43 (6.41)	6.27 (2.27)
Gemawang (11 years)	10.36 (4.95)	6.37 (2.09)
Banding Anyar (17 years)	2.39 (7.15_	-2.71 (4.95)

7.3 Objective 3

Objective: To provide management options for enhancing profitability through smallholder plantation systems producing wood for both pulp and timber

7.3.1 Demonstration Trials

Arara: The trial was established in February 2012 on land previous planted to three rotations of *A. mangium* and one rotation of *E. pellita*. A split plot design, weed-free (7 interventions to age 2 yr) and weeds retained (2 interventions to age 4 months) was used. *A. mangium* (seed lot 1013700, origin Claudie River) and *E. pellita* (Clone EP5147 raised in tissue culture, origin PNG N of Kirowo) were examined in adjacent experiments. Three plots each of EP5147 and EP 497 were established at the same time in the adjacent commercial plantation. *Cerrena* (a BCA antagonist to combat root-rot pathogens) blocks was applied to half the trees (green area) in each *A. mangium* weed treatment in Nov. 2012.

At age 3 years, the *A. mangium* plots were no longer viable; survival was <11%. Survival of *E. pellita* (EP5147) in the experiment (<67%) was also affected by J-rooting. EP497 had the highest MAI (27.6 m^3/ha). Diameter growth was inversely related to survival. *Ceratocystis* attack related to monkey damage, poor singling; stem breakage and beetle attack (Nitidulid/Ambrosia) (Figure 46) were the main cause of tree death (64% of the *A. mangium* stand*).* Any beneficial effects of *Cerrena* could not be assessed.

Figure 46: Beetle attack (left) and bark and branch damage by monkeys (centre) associated with *Ceratocystis* attack, and the effect on the *A. mangium* trial at Arara (right).

Key results from this experiment were:

- There was a similar growth response to two applications of weed control to age 4 months in *E. pellita* compared with 7 applications to age two years; therefore, fewer applications are recommended;
- *Ceratocystis* has replaced *Ganoderma* as main cause of tree death of *A. mangium* on this site; management of both diseases needs to remain a research focus;
- J-rooting in *E. pellita* EP 5147 led to an unacceptable reduction in survival; Sinarmas are working to improve the consistency of rooting in their clones.

MHP1: This trial was established in February 2012 on community land. Subanjeriji is now a very high risk area for planting *A. mangium* because of the high populations of monkeys, which are the main vector for *Ceratocystis* in South Sumatra. Because of this, a guard was employed for two years to keep the monkeys away from the experiment. In addition, pruning wounds were painted with an oil-based paint which may have been effective in curtailing disease entry. This allowed the development and tending (pruning and thinning) of stems that had good form and survival remained high; however, after the guard was removed, monkey damage started to occur in the crowns and trees started dying (Figure 47). Thus survival at age 3 yr in the unthinned pulpwood regimes, with and without weed control, were 55% (DBH 14.3 cm; MAI 24 m^3 ha^{-1}) and 70% (DBH 14.7 cm; MAI 33 m^3 ha^{-1}), respectively. There have been responses (relative to unthinned with weed control) to thinning to 600 stems ha^{-1} 17 months after thinning (DBH 15.8 cm) and from 600 to 400 stems ha^{-1} 5 months after thinning (DBH 17.4 cm).

Key results included:

- Trees of good form have developed and thinning has allowed the more rapid development of trees towards a size suitable for harvesting for large sawlogs (DBH 20 cm);
- Although the trial remains viable, survival is now being compromised by *Ceratocystis* and monkey damage. It remains unclear whether this will ultimately affect the commercial viability of the stands, particularly those managed for saw-logs.

Figure 47: Selecting trees to be retained in the saw-log plots (left) and tell-tale signs of *Ceratocystis* damage (right).

MHP2: This demonstration was established in January 2013 on community land. A weed problem that had become severe by June 2013 (see Fig. 48) led to a program of weed control and a recommendation that some replanting be done to bring the site back to an acceptable level of stocking. It was decided that it was too late for replanting, hence the low survival (76%) in the unthinned pulpwood treatment. The first thinning to 600 stems/ha in treatments being managed for sawlogs was undertaken in September 2014. In February 2015 (the latest measure that could be included in this report) the mean DBH five months after first thinning to 600 stems/ha in the Saw-log 200, 400 and 600 stems ha^{-1} treatments was 11.6, 11.6 and 10.7 cm, respectively; DBH in the pulpwood regime was 10.6 cm. The apparent lack of response to thinning was most likely to be attributable to the short time interval between thinning and measurement, and this stand will continue to be monitored into the future.

Figure 48: Severe weed infestation in June 2013 (left) and in August 2013 after weed control (right).

Gunung Kidul: The land at Gunung Kidul is government–owned and administered by the Yogyakarta Provincial Forestry Office. As Gunung Kidul is historically a poor area with an extended dry season, an arrangement has been in place for several decades that allows access to this land for cropping in areas that are not currently being used for research, and for inter-cropping within experiments in the period between tree establishment and canopy closure. This *A. auriculiformis* trial was established in February 2012 and there was an arrangement with 173 community farmers that allowed them to use inter-row areas for cropping until age 2 yr. Soil pH was 7.3-8.1, organic carbon 3.2-3.9%, total N 0.18-0.24% and extractable P 4.4-8.7 ppm. Four seedlots were used, two of improved seed (MHP seed orchard [Subanjeriji] and FSIV clonal seed orchard [Vietnam]) and two of wild seed (Mibini [PNG] and mixture of the three Queensland seedlots [FNQ]). Singling and form pruning have been undertaken. First thinning is scheduled for September 2015. At age 2 yr, survival varied between 77% [PNG] - 83% [Vietnam], and DBH between 5.7 [PNG] and 6.8 cm [Vietnam].

Key results included:

- Survival, height and diameter growth were greater in the improved than wild seedlots;
- The seedlots from the clonal seed orchard in Vietnam currently have the best mean survival, height and diameter growth;
- As the farmers used different cropping systems and weeded their crops with varying diligence (Figure 49), farmer differences may have a differential effect on the performance of the trees across the plots, other than that related to seedlot. It is not possible to quantify this effect in retrospect.

Figure 49: Cultivation by farmer prior to cropping; Plate 6: Maize inter-cropping with *A. auriculiformis*.

Finnantara: The focus of this Sinarmas company is community forestry (tanah kampung), though planting and tending is done by Finnantara. As in Riau, declining yields of *A. mangium* are associated with pest and disease issues. The planting blocks are small and two separate blocks (planted in June and October 2013) were necessary to establish this *E. pellita* trial in March 2014. There are three pulpwood treatments (Standard Operating Procedure; F1: 150 kg N/ha + 30 kgP/ha at age 15/18 months; F2: F1 with repeat at age 2+ yr) and one unreplicated saw-log treatment (to date, pruning to 1 m at age 9 months and 150 kg N/ha + 30 kg P/ha at age 18 months). To date (age 15/18 months), there have been acceptable rates of growth (DBH 6.3-7.1 cm) and survival (80-91%) across treatments.

Sawing trials

Green boards: The boards appeared to be in reasonable condition, with good colour and no rot. The most prevalent defect was dead knots. Distortion was dominated by bow though some also had spring. End splits and wane were present but not severe. Only three boards in total were rejected because of wane on both sides. The saw-mill, which sells their products as green timber, advised that the boards were suitable for the domestic market. However, because of the knots, they would not be suitable for international markets.

After air-drying: There had been shrinkage of width but not thickness. There was no twist. Spring and bow (mm per m length) were measured as the greatest deviation (mm) from a straight line between the corner edges of the two ends of each board; the largest values recorded were 2.7 cm and 7.1 cm, respectively. In addition, surface checking was assessed by measuring the length and width (to nearest mm) of every check on each side of the board. Boards generally fell into two categories, those with a substantial number of checks and those free of checks. The majority were the latter. Those with checks were boards originating from the centre of the tree.

Surface moisture content ranged from 12.0 to 14.7% and values at 15 mm depth from 13.9 to 16.9%, indicating an approximately 2% difference.

Key results included:

- *E pellita* grown in a wet tropical environment can yield acceptable sawn boards at age 10 years;
- Even though *E. pellita* branches tend to be self-pruning, the presence of dead knots showed that pruning will be required for knot-free high quality appearance-grade timber. Thinning will be required to promote diameter growth;
- Although not systematically investigated, a crucial observation was that the application of wax to the cut ends after harvesting was essential if severe end splitting was to be avoided (Figure 50).

Figure 50: A comparison of end-splitting between a log that had been wax-sealed and one that had not.

Sawmill Capacity Survey

The capacity of two sawmills in South Sumatra was around 2,500 m^3 per year. Their wood supply was associated with land clearing and dominated by mixed tropical hardwoods with some *A. mangium*. Log lengths were 4 m and minimum diameter under bark 15 cm. The prices paid by the mill owner for standing timber were around US$40/m^3, including costs of harvesting and transport to mill. The largest logs handled (@ 40 cm diameter) have volumes of around 0.5 m^3. The logs are processed with vertical band-saws to create a range of products (beams, boards, rafters and battens). These products are packaged and sold green into local markets and into Jakarta. The current benchmark price for green Mixed Tropical Hardwood in Jakarta is Rp1,600,000 to 1,700,000 ($US180-190/m^3); the benchmark price for green sawn acacia wood is Rp1,200,000 ($US135).

Key outcomes:

- There are currently no markets for plantation-grown acacias or eucalypts managed for sawn-timber products in Sumatra;
- As a consequence, returns to growers from pulpwood are likely to exceed those realised from managing plantations for sawn timber over longer rotations;
- While markets for plantation-grown saw-logs in Sumatra are expected to develop in the future, the timeline for this remains unclear.

7.4 Objective 4

Objective: To investigate the site factors and/or host properties which reduce the risk of root-rot incidence and/or severity.

7.4.1 GIS study

Tree survival and cause of mortality were significantly influenced by inferred soil type. Sites with fine-loamy Typic Kandiudult soils (KDT-FL) had the highest standing live trees (THA), merchandisable wood volume (Mvol) and also the highest level of infection by *Ganoderma* and *Ceratocystis*, but the lowest incidence of damage and death caused by wind (Table 46).

Table 46 Effect of soil type on tree mortality and wood production of *A. mangium* trees assessed at age 3.2 – 4.0 years in Sumatra, Indonesia.

Soil Family	No. PHI sites	THA - Alive & standing (trees ha $^{-1}$)	SHA –Alive & dead standing (stems ha^{-1})	THT – height of 5 tallest trees (m)	Mortality (%)	Mvol - Merchandisable Volume (m^{3}ha^{-1})
KDT-FI	79	732 (249)^{ab}	765 (263)^{ab}	19.8 (1.2)^{a}	45.1 (18.7)^{ab}	96.0 (37.9)^{a}
KDT-FL	581	751 (229)^{a}	791 (249)^{a}	20.0 (1.5)^{a}	43.7 (17.2)^{a}	97.5 (29.0)^{a}
KHT-FL	220	692 (247)^{b}	732 (263)^{b}	20.1 (1.5)^{a}	48.1 (18.5)^{b}	92.5 (35.7)^{a}

Values in brackets represent ±1 standard deviation. Differences in superscripts between soil types are significant at $p < 0.05$. Original stocking density 1333 trees ha^{-1}.

Correlation or degree of association between soil and topographic variables with THA, Mvol and cause of mortality were typically low and inconsistent between statistical analyses and procedures. Inconsistency between statistical procedures resulted in part from; significance levels for model entry/exit, mix of normally and non-normally distributed soil and topographic variables, the presence of co-related variables such as sand, silt and clay, and size of validation data sets used (or not used) during partition analysis. Confidence with the interpretation and identification of relationships associated with soil attributes (other than soil family type) was low presumably due to use of GIS interpolated soil information, rather than site specific soil analysis. Uncertainty also resulted from potential misclassification of mortality by *Ceratocystis* and *Ganoderma* as having resulted from wind. Diseases such as *Ceratocystis* and especially *Ganoderma* may make a tree more prone to wind throw and are difficult to identify several months after windthrow or tree mortality.

Given the issues with data quality, normality, co-relation, and potential misclassification of the causes of mortality, drawing conclusions from any one form of analysis is likely to lead to erroneous conclusions. As such, our conclusions are based on a ‘multiple lines of evidence’ approach in which conclusions can be supported when multiple sources of evidence are in agreement, even if none of the individual sources of evidence are very strong on their own (Wilson, 1998). The top five most influential or highly correlated soil and topographic variables for each form of analysis are summarised in Table 47.

Table 47 Summary of the five most correlated / influential soil and topographic variables on THA, Mvol and the three causes of mortality

Analysis Type	Analysis Confidence	Cause of Mortality				
		THA	Mvol	Wind	*Ganoderma*	*Ceratocystis*
Spearman correlation	Low (correlation <0.15)	pH$_a$ pH$_b$ P04$_b$ TPI Clay$_b$	TPI VD NH Sand$_b$ PO4$_a$	C:N Ratio$_b$ PO4$_b$ pH$_a$ Clay$_a$ Sand$_b$	PO4$_b$ pH$_a$ PO4$_a$ Carbon$_b$ C:N ratio$_a$	VD Slope pH$_a$ PO4$_a$ Nitrogen$_a$
Stepwise Linear regression	Low (R^2 <0.055)	Abs.TPI pH$_a$	TPI Clay$_a$ CEC$_a$ PO4$_a$ Depth$_b$	Slope MSP Depth$_a$ Carbon$_a$ Silt$_b$	Clay$_a$ Silt$_a$ Nitrogen$_a$ Base Sat.$_a$ Carbon$_b$	Clay$_a$
Partition – Bootstrap Forest	Moderate (R^2 <0.3)	TPI VD TWI Slope NH	VD TPI TWI NH Slope	TPI VD TWI Slope NH	VD TPI Sand$_a$ TWI MSP	Base Sat.$_b$ VD TPI MSP Slope
Partition – Boosted Tree	Low - Moderate (R^2 <0.25)	TPI TWI Soil type Slope NH	VD TWI Nitrogen$_a$ Depth$_a$ NH	TPI Nitrogen$_a$ TWI VD Clay$_a$	Sand$_a$ Base Sat.$_b$ Carbon$_b$ Slope VD	Silt$_a$ Nitrogen$_a$ MSP VD TWI
Quantile regression 90th percentile	Low (R^1 <0.05)	TPI pH$_a$	TPI Clay$_a$ Carbon$_a$ Base Sat.$_a$	CEC$_b$ Clay$_a$	Clay$_b$ Base Sat.$_b$	NH

Subscript represents soil horizon $_a$ = topsoil or A1 horizon $_b$ = subsoil or B21 horizon. TPI is topographic position index, VD valley depth, NH normalised height, TPI topographic position index, MSP mean slope position, TWI Topographic wetness index, Abs.TPI absolute topographic position index, CEC cation exchange capacity,

Multiple forms of analysis including correlation, linear regression, bootstrap forest, boosted tree, and quantile regression indicate that THA was slightly favoured in upslope away from valley floors, and dryer mid-slopes, ridges and hilltops, and soils with very low pH (<3.3) soils. Mvol did not appear to be consistently related to any one particular soil or topographic variable, although there is a suggestion that Mvol was also higher in in elevated topographic positions away from the valley floor. Mvol was also somewhat inconsistently negatively related to a host of soil variables including; clay content, horizon depth, phosphorus content and cation exchange capacity (CEC).

Wind was the greatest cause of tree mortality, resulting in an average loss of an average of 159 trees/ha or 70 % of all tree deaths. *Ganoderma* resulted in loss of an average of 39 trees/ha, or 17% of all tree deaths, while *Ceratocystis* was only identified in 39 of the 880 plots resulting in damage and death to only 1.4 trees/ha or 0.59 % mortality.

Mortality from wind was slightly higher in moist, poorly drained, low lying valley bottoms and topographically flat areas, and there also was a suggestion that infection by *Ganoderma* preferred sandier, better drained soils. Relationships were found between infection by *Ceratocystis* and soil and topographic attributes, but these were considered to be mostly coincidental, rather than causal.

This study found that tree survival, wood production, and cause of mortality were not able to be reliably or consistently related to any one, or combination of, soil and topographic variables using archived PHI, 1:10000 soil mapping and 5 metre digital elevation models. The ability to determine the influence of topography and soil attributes on wood production and cause of mortality was greatly compromised by; lack of site specific soil data, collinear variables, and potential misclassification of the cause of mortality. Future studies should focus on exploring higher resolution spatial approaches such as LIDAR or hyper spectral sensors based on unmanned aerial vehicles, combined with site specific soil sampling and analysis.

7.4.2 Examination of the biology, reproduction, population genetics and dispersal of *Ganoderma philippii*

Basidiospore germination

Basidiospore germination in all three *Ganoderma* species, *G. philippii, G. mastoporum* and *G. australe,* was strongly influenced by basidiospore concentration, and all had the highest viability on media with added sawdust, but there were some interesting differences in responses among the three species. A low concentration of basidiospores resulted in delayed onset of germination and lower overall germination, compared to the optimal concentration, indicating that basidiospores of all three species may exude compounds that promote germination. A high concentration of basidiospores reduced the overall germination rate in all three species, but also delayed the onset of germination in *G. philippii*. In contrast, *G. australe* had a higher germination rate at 24 h but lower germination rates at subsequent assessments. These results indicate that *G. philippii* basidiospores may exude self-inhibitors, while *G. australe* self-inhibitors are not produced until after germination has begun. Basidiospores of *G. mastoporum* germinated much earlier than the other two species, often reaching maximum germination, or close to it, by 24 h, whereas the other two species had no or very little germination by this time.

The temperature ranges for germination of *G. philippii* and *G. mastoporum* were very similar; 22-31 °C, with an optimum temperature of 27 °C. *Ganoderma australe* basidiospores germinated over a wider range of temperatures, 10-35 °C, with an optimum at 22 °C. This reflects the broader geographic range of *G. australe,* which extends from temperate to tropical regions (Moncalvo & Buchanan, 2008).

Basidiospores of *G. philippii* only germinated on media containing 2% ethanol, whereas the other two species germinated on all media tested. This is the first report of successful axenic germination of *G. philippii* basidiospores without prior ingestion by insect larvae (Lim 1977). It is possible that the ethanol renders the spore walls more permeable, as has been suggested for insect ingestion. The role of insects, ethanol or other chemicals in modifying the permeability of basidiospore walls, or otherwise promoting germination, in nature is unknown, though it is possible that similar chemicals occur in the woody substrates colonised by *G. philippii.*

Overall, results indicate that *G. philippii* has more particular requirements for basidiospore germination than *G. australe* or *G. mastoporum*. The low permeability of its basidiospores may enhance long-term viability and the requirement for specific germination triggers may act to prevent germination in the absence of suitable host material.

This understanding of Ganoderma spore germination will enable us to carry out experimental stump inoculations with the pathogen and BCA to assess competiveness of BCA in the field.

Mating systems of G. philippii, G. mastoporum and G. australe.

In all three species, the ratios of compatible to incompatible pairings were consistent with a heterothallic, tetrapolar mating system. In addition, the occurrence of semi-compatible reactions was characteristic of reactions between isolates with different MATa but identical MATb alleles, as seen in other tetrapolar species. The presence of more than two alleles at each MAT locus was confirmed by non-sibling pairings in *G. philippii,* and *G. australe.*

This mating system, particularly where multiple alleles occur, strongly promotes outcrossing and the development of genetic diversity, increasing adaptability to changing environmental conditions and host species.

The designation of tester strains is a significant step as it will allow detection of additional alleles within and among populations. The *G. philippii* monokaryon offspring are also useful to validate the independence (lack of co-segregation) of microsatellite loci being used for population genetic studies.

Population genetics of Ganoderma philippii in Indonesian hardwood plantations

Microsatellite development: Shotgun sequences were screened for simple sequence repeat motifs of 2-6 bp, with at least four repeats, producing a file of 856 potential microsatellite sequences. A subset of 54 sequences that had sufficient sequence on both sides of the microsatellite locus to allow primer design and that did not contain additional microsatellite or mononucleotide repeats was selected for primer design. Primers were designed with a universal tail to allow labelling with fluorescent marker. Primers were screened against three isolates of *G. philippii* from geographically separate locations. All but two of the primer pairs successfully amplified *G. philippii* DNA, but the majority amplified a single product that did not vary among the test isolates. Eight of the primer sets were polymorphic and heterozygous in at least one of the test isolates. Another two primer pairs require additional testing to confirm suitability.

The development of microsatellite markers underpins any study of population analyses that will allow us to determine the mode of spread of the pathogen.

Ganoderma philippii populations.

Two studies were planned for the population analyses and the data collection for these is ongoing. The first study is based on isolates collected from *A. mangium* plantations in the previous ACIAR root-rot project, FST 2003/048 and will test the hypothesis that genetic diversity of *G. philippii* increases as the rotation number increases. This will help in determining the contribution of sexual vs. asexual reproduction in the spread of *G. philippii.* The isolates have been revived, DNA extracted and sent to Australia and microsatellite analysis of these samples will commence shortly.

The second study is based on two trial sites established by RAPP. The Baserah and Logas trials were originally established to examine the effects of destumping on root-rot incidence and the susceptibility of four different host species. These plots were offered to the ACIAR project at the conclusion of RAPP’s study and were considered excellent sites to be included in the study of *Ganoderma philippii* population genetics. Each site contained 100-tree plots of *A. mangium, A. auriculiformis, E. pellita* and *E.* hybrid, with 6 replicates of each treatment (species x destumping = 8 treatments). This provided the opportunity to examine gene flow among the different host species and to consider the potential for host adaptation, as well as looking at genetic diversity in subsequent rotations at the same site.

We surveyed and sampled the plots to obtain *G. philippii* isolates before the sites were harvested, and again after replanting. Baserah was replanted to *Eucalyptus* and Logas was to be replanted to *Acacia* but delays in paperwork prevented this occurring in time for a post-harvest resampling within this project. A second pre-harvest sampling at Logas was conducted in April 2015, just prior to the harvest, with the expectation that it may be possible to conclude this study in a future project. The Baserah site was surveyed and sampled twice after replanting; in March 2013, at 6 months of age, when little disease was detected and only eight isolates obtained and again in March-April 2015. In this latter sampling, a much higher disease incidence was observed, with many more samples taken. In addition to isolations, DNA was extracted directly from root samples from four of the plots and microsatellite analysis will be attempted directly from this DNA.

Unforeseen personal circumstances have prevented the completion of this study within the time-frame of the project but microsatellite analysis is half completed and two manuscripts will be prepared for journal submission before the end of 2015. Analysis of microsatellite data from the pre-harvest Baserah population shows a high level of genetic diversity, indicating that sexual recombination is a major contributor to population structure. Tree to tree vegetative spread was also detected, but is not the predominant mode of dispersal as was previously postulated.

This research has great significance for implementing disease management methods, particularly biocontrol as knowing about the mode of dispersal will enable the BCA to be appropriately targeted to reduce pathogen inoculum.

Pot trials assessing relative host susceptibility to various pathogens under different conditions (e.g. nutrient status, pH)

The two mineral soils used in the pot experiment varied widely in clay and sand content (Table 48), but were similar in other respects. The peat soil had a lower pH and much higher nitrogen and carbon content than the two mineral soils.

Table 48: Soil test results

	R41	R51	Peat
Sand (%)	72.25	87.93	-
Silt (%)	6.58	8.33	-
Clay (%)	21.16	3.73	-
Total N (%)	0.19	0.19	0.95
Total C (%)	2.49	2.87	38.74
CEC	15.45	11.79	88.22
pH	4.15	4.23	3.87
Organic C (%)	2.75*	2.77	*
Bulk density	1.14	1.11	0.25

**Possible errors in measurement system.*

Tree mortality:

A total of 23 out of 120 trees inoculated with *G. philippii* died (Table 49), mostly *A. mangium* with inoculum placed adjacent to the roots. The first tree deaths were recorded at week 10 and most occurred between weeks 10 and 15, though mortalities still occurred from 28 to 38 weeks after planting and inoculation. Above-ground visual symptoms prior to tree death were observed in only four cases, up to 13 weeks before tree death was recorded. In two cases, above-ground visual symptoms were observed but the tree subsequently recovered and one tree was symptomatic from week 38 but remained alive until the end of the experiment.

At the end of the experiment, roots were dug up and examined for latent infections. In all cases, the inoculum blocks had been penetrated by roots but most roots remained healthy (Figure 51). Only small, localized lesions were observed in a minority of trees.

Figure 51: *Ganoderma philippii* inoculum block with roots surrounding and penetrating the block.

No tree deaths were recorded in either *A. mangium* or *E. pellita* in the pots with *Phellinus noxius* inoculum. Mortality in *E. pellita* inoculated with *G. philippii w*as too low to be amenable to analysis.

Table 49: Tree deaths in *A. mangium* and *E. pellita* inoculated with *G. philippii* (pooling data from both isolates).

	Acacia mangium		*Eucalyptus pellita* EP0077AA	
Soil type	Model 1 (out of 8 trees)	Model 2 (out of 12 trees)	Model 1 (out of 8 trees)	Model 2 (out of 12 trees)
R41	3 (37.5%)	0	0	1 (12.5%)
R51	5 (62.5%)	6 (41.7%)	2 (25%)	0
Peat	4 (50%)	0	3	0

Inoculum survival:

Based on morphological identification of fungal isolates obtained from woody inoculum incubated under soil, inoculum blocks remained viable for at least 9 months. Only two of the 48 inoculum blocks harvested were unviable after 9 months in soil, and these were both from R51 soil. Some inoculum blocks were also colonised by opportunistic soil fungi, mostly species of *Gliocladium* or *Trichoderma*.

These trials support indications given by the GIS study that soil texture affects the interaction between the host and pathogen. A coarser, sandy soil favours the development of disease although inoculum survives well in all soil types tested. As the inoculum survives in all soil types this indicates that the soil type may affect host vigour and/or infection processes rather than any direct influence on inoculum. The knowledge will assist in further studies of disease risk and impact and in targeting specific disease prone areas for BCA experiments.

7.4.3 Histological investigations of differences between less and more susceptible hosts

Macro-descriptions of Ganoderma *root disease*

The outer surface of infected woody roots of both *A. mangium* and *E. pellita* exhibited the characteristic reddish-brown mycelial sheath, as previously described for *Ganoderma* root disease (Eyles et al. 2008, Agustini et al. 2014, Hidayati et al. 2014). However, we also noted that some parts of the mycelial sheath of both young and old *A. mangium* roots were comprised of crystal-encrusted hyphae (Fig 52). It is interesting to note that the outermost layer of many mycelial cords have similarly been shown to contain crystal-encrusted hyphae—the crystals were identified as calcium oxalate (Thompson and Rayner 1983).

Fig. 52 – Roots of (A) *Eucalyptus pellita* and (B) *Acacia mangium* infected with *Ganoderma philippii* and displaying typical symptoms of *Ganoderma* root disease such as a reddish mycelial sheath and small pebbles (arrow) embedded in the mycelia sheath.

A **B**

Microscopic descriptions of Ganoderma *root disease for A. mangium*

The morphology of infected roots of young *A. mangium* was clearly different to that of ‘healthy’ tissue (Fig. 53). Infected roots were characterized by three main features—the presence of a continuous multilayered mycelial sheath (100-200 µm thick), fungal outgrowths and the production of a wound periderm. The mycelial sheath comprised of two different types of tissues: an outer melanised layer of roughly round cells (< 40 µm thick) and an inner amorphous layer (> 100 µm thick). The fungal outgrowths appeared to originate from the mycelial sheath and comprised of hyphae of varying shapes and sizes with a melanised outer layer.

Fig. 53. Light micrograph (transverse) of ‘healthy’ (A) vs infected (B) tissue of *Acacia mangium*. Stained with toluidine blue.

A B

Infection by *G. philippii* induced the production of a continuous wound periderm (> 300 µm thick) of multiple layers of new parenchyma cells of differing shape in the roots of young

A. mangium. The cells walls of wound periderm stained strongly for the presence of lignin with phloroglucinol-HCl (figure not presented).

Microscopic descriptions of Ganoderma *root disease for E. pellita*

The infected roots of *E. pellita* were characterised by two features only—a discontinuous mycelial sheath and fungal outgrowths. Unlike *A. mangium*, fungal outgrowths formed in the absence of the mycelial sheath and appeared to be less complex in morphology. The mycelial sheath when present, had a similar morphology to that observed for *A. mangium*, however, the mycelial sheath in some areas of the infected root was noticeably thinner. We found no evidence that infection by *G. philippii* induced the production of a wound periderm in *E. pelllita.*

This research is significant as a knowledge of host defence responses can be exploited to help explain the comparative susceptibility of *A. mangium* (in relation to other acacia and eucalypt species) to a range of biotic agents e.g. heart rot and *Ceratocystis*.

7.5 Objective 5

Objective: To test the effectiveness of potential biological control agents discovered by project FST2003/048.

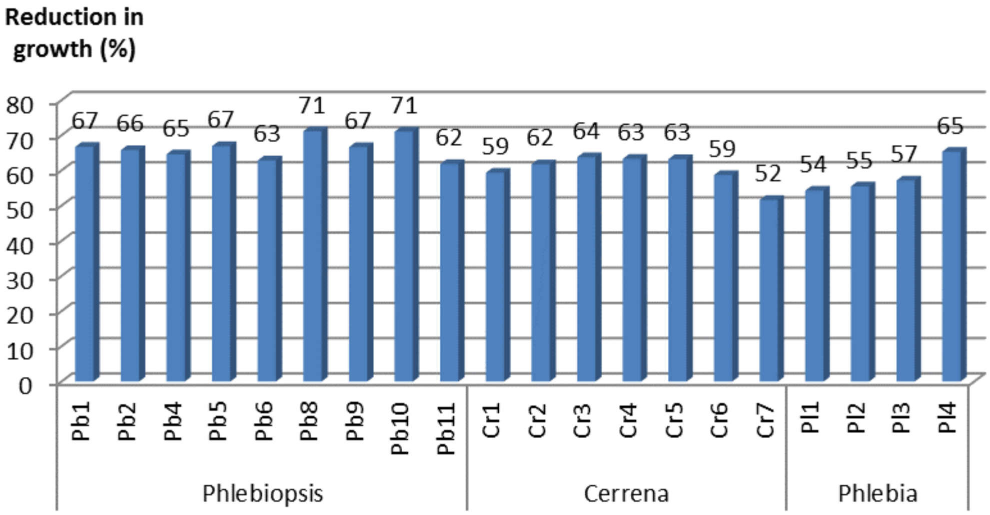
7.5.1 *In vitro* assessment of biocontrol (BCA) antagonism.

Dual cultures on agar media and wood blocks

The ranking of 20 candidate BCA isolates according to their biocontrol activity.

The 20 BCA isolates were ranked according to the level at which the width of a pathogen colony was reduced in comparison to its control. The rankings for *G. philippii* and the 20 BCA isolates are in Fig. 54. The reductions in growth vary between approximately 52 and 71%. Different isolates of *Cerrena* show the most variation in BCA activity on agar medium. *Ganoderma philippi* in dual cultures with the 20 BCA isolates

Fig. 54 – The percentage reduction in *G. philippi* growth in dual cultures with 20 BCAs



The dual cultures were scored (presence or absence) for signs of hyphal interference, mycoparasitism or antagonism at a distance (e.g. the presence of a sparse zone between cultures or pigmentation lines). These indications were rarely seen except for a sparse zone with *Phlebia* isolates and it was most common for the BCA to grow over or swamp the pathogen (i.e. gross mycelial contact). Isolations taken from different positions in the dual culture after 5-6 months never gave rise to a pathogen culture in dual cultures with the pathogen *Phelbiopsis* but occasionally a pathogen was re-isolated in confrontations with *Cerrena* and *Phlebia*.

Validation of BCA activity in dual cultures on agar medium

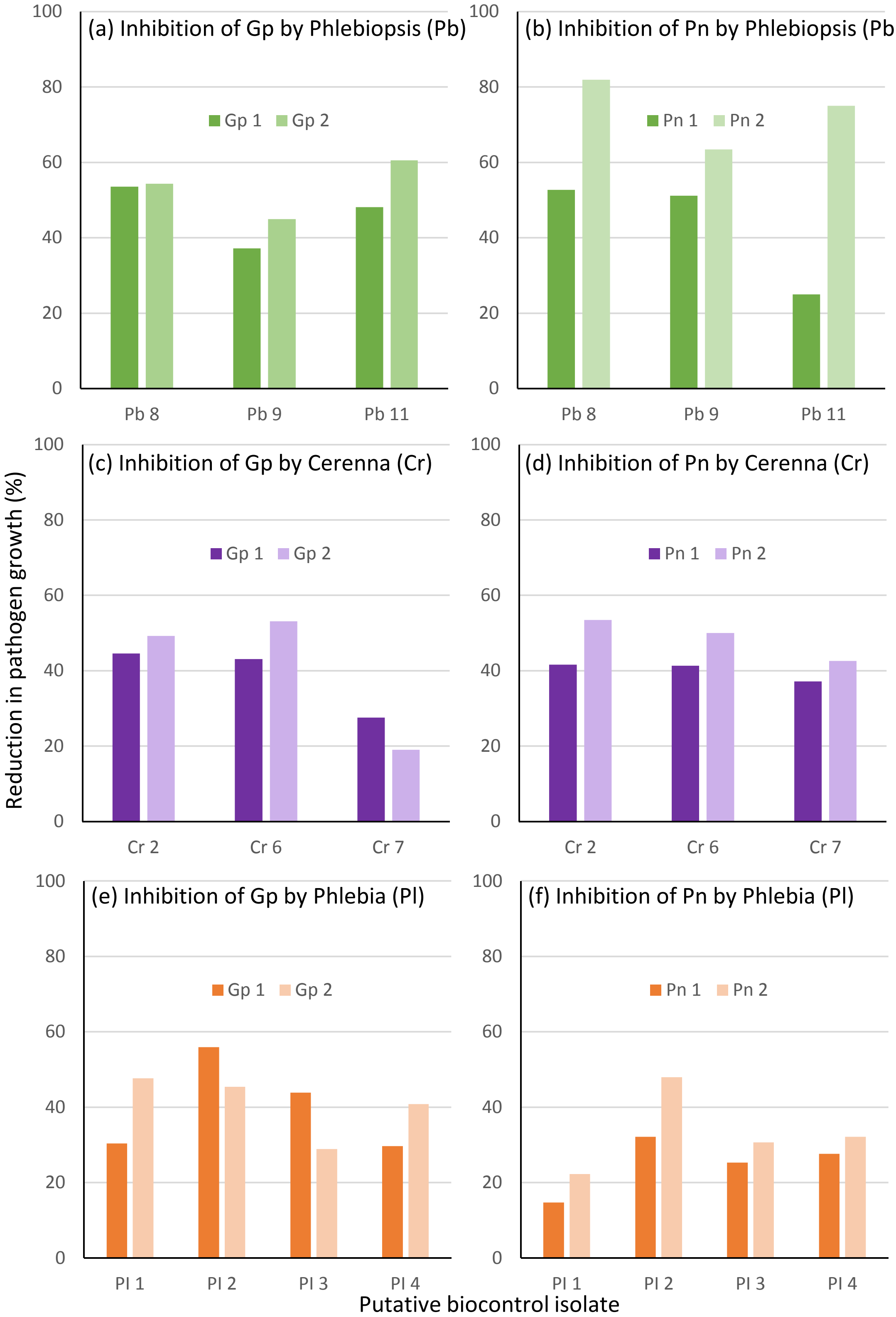
Isolates were selected for this trial from the 20 BCAs based on their performance in the trial above. Two BCAs associated with the highest reduction in pathogen growth and one isolate associated with the lowest reduction in pathogen growth were selected for each of *Phlebiopsis* and *Cerrena*. For *Phlebia* all four isolates (each a different species) tested in the first screening were also used for the validation screening.

Reductions in pathogen growth (*G. philippii* and *P. noxius*) were similar to those in the first screening trial (Fig. 55). The two isolates of *P. noxius,* however, grew at different rates. Pathogen growth was clearly inhibited by the BCAs but the faster growing isolate (Pn1) was less inhibited by BCAs than the slower growing isolate of this species (Pn2) (Figure 55).

There was little variation between replicates of the same dual cultures[1] and in all dual cultures the growth of the pathogen slowed at day 4 of the confrontations and then ceased between days 4 and 6 (data not shown).

[1] statistical analyses to be completed

Fig. 55 – Validation of BCA activity in dual cultures on agar medium. Ganoderma philippi (Gp) is shown on the left, Phellinus noxious (Pn) is shown on the right.



Dual cultures or confrontations on sterile rubber wood blocks

In confrontations established on sterile rubber-wood blocks, the BCA quickly (in one week) over-ran the pathogen (Fig. 56). If either the pathogen or BCA was incubated for 1 week before introducing the partner in the dual culture the wood block was completely colonised so trials are being repeated with a 2-3 day interval rather than one week.

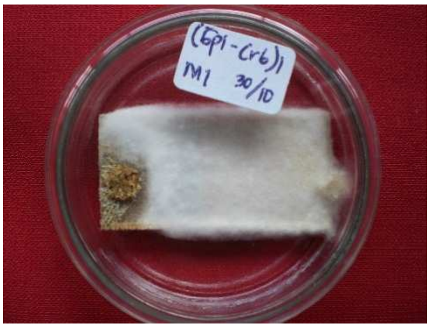


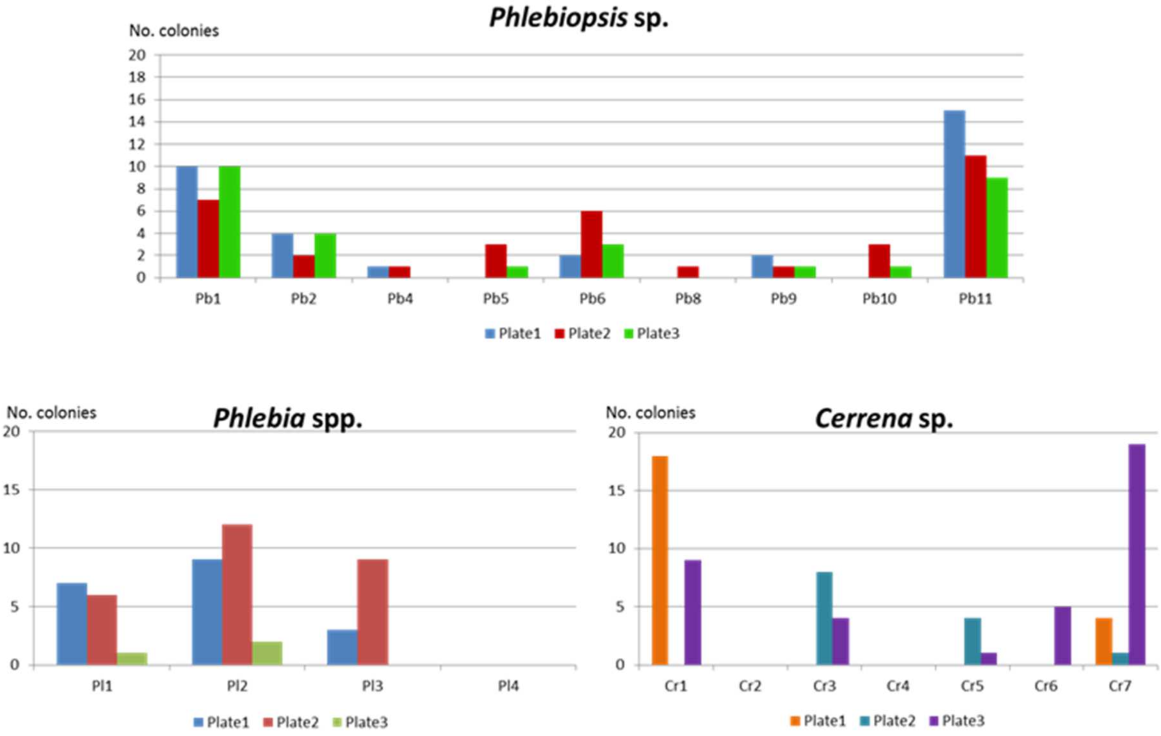
Figure 56: Dual culture between *G. philippi* and *Cerrena*. The BCA has overgrown the pathogen in a period of one week after inoculum of each isolate was placed at opposite ends of the wood block.

Production of oidia

Ranking of the 20 different candidate BCA isolates of Phlebiopsis, Cerrena and Phlebia according to their level of oidia production.

There is a high level of intra and inter-specific variation in the production of oidia (Fig. 57). There can also be variation between replications (plates) of the same isolate. Isolates of *Cerrena* (Cr1 and 7) appeared to produce the highest number of oidia if the colonies that grow from the oidia reflect oidial production. Isolates Pb1 and Pb11 of *Phlebiopsis* produced the highest number of oidia. Table 50 ranks the 20 candidate BCAs according to the production of oidia.

Figure 57: The production of oidia by 20 candidate BCAs



The isolates that ranked highest in terms of ability to reduce the growth of the pathogen did not appear to be those that produce the highest number of oidia i.e. isolate Pb11 is the highest producer of oidia but ranks 15th for its ability to reduce the growth of *P. noxius* (Table 50).

Table 50: Ranking of the 20 candidate BCAs according to their biocontrol activity and the production of oidia

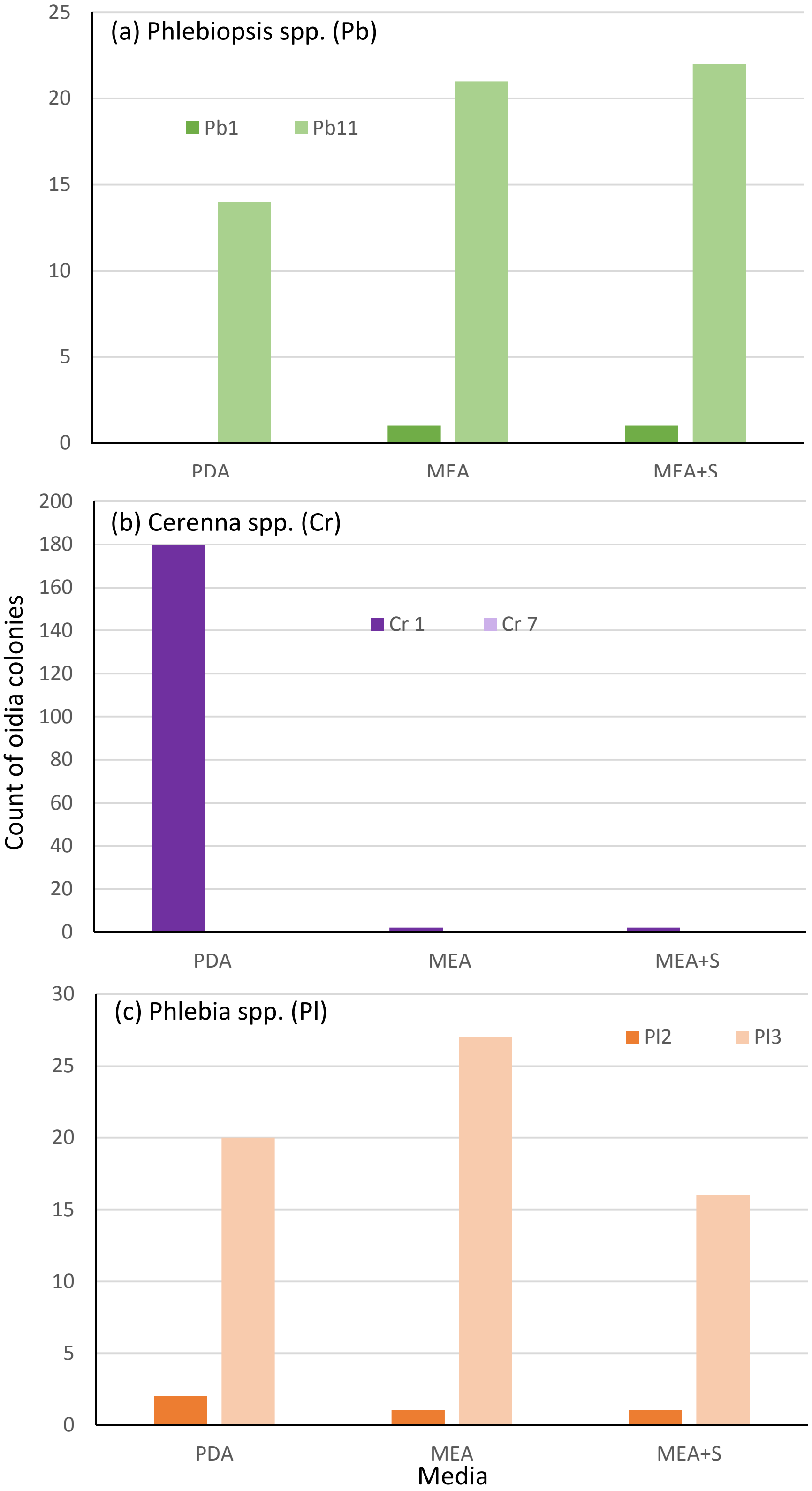
Species	Isolate	Code	BCA activity	Oidia prod'n
Phlebiopsis sp. 1	LC-RK-11A-4	Pb1	11	2
Phlebiopsis sp. 1	LC-RK-11A-6	Pb2	7	10
Phlebiopsis sp. 1	LC-RK-11A-32	Pb4	12	16
Phlebiopsis sp. 1	LC-RK-11A-37	Pb5	9	13
Phlebiopsis sp. 1	LC-RK-11B-3	Pb6	8	9
Phlebiopsis sp. 1	LC-RK-11B-16	Pb8	1	17
Phlebiopsis sp. 1	LC-RK-11C-18	Pb9	3	14
Phlebiopsis sp. 1	LC-RK-11C-34	Pb10	10	15
Phlebiopsis sp. 1	LC-RK-11C-35	Pb11	15	1
Cerrena sp.	7-L-4-B-20(M)-A.1	Cr1	19	3
Cerrena sp.	7-L-4-B-15(W)-A	Cr2	13	18
Cerrena sp.	6-SU-2-B-55(W)-B.2	Cr3	18	7
Cerrena sp.	7-SU-3-B-55(W).1	Cr4	16	19
Cerrena sp.	7-SU-3-B-77(M)-B.2	Cr5	14	11
Cerrena sp.	7-S-4-A-25(M)-A.1	Cr6	4	12
Cerrena sp.	LC-RK-11B-4	Cr7	20	4
Phlebia brevispora	7-SU-3-E-3(FB)-B	Pl1	17	6
Phlebia sp. 1	T175B1 (L-T17-B.1)	Pl2	6	5
Phlebia sp. 2	E8898-A	Pl3	2	8
Phlebia sp. 3	FB1A2 (BS-FB1-A.2.3)	Pl4	5	20

Testing the influence of different agar media on oidial production.

The influence of media on the production of oidia as reflected by the number of colonies from oidial suspensions appears negligible in this trial (Fig. 58).

For the two highest producing *Phlebiopsis* isolates of oidia, one isolate seems not to have produced oidia in this trial and the other isolate does not appear to be influenced by the type of agar media. One isolate of *Cerrena* produced nearly 10-fold the colonies than the other isolates tested but only on MEA and not on other media.

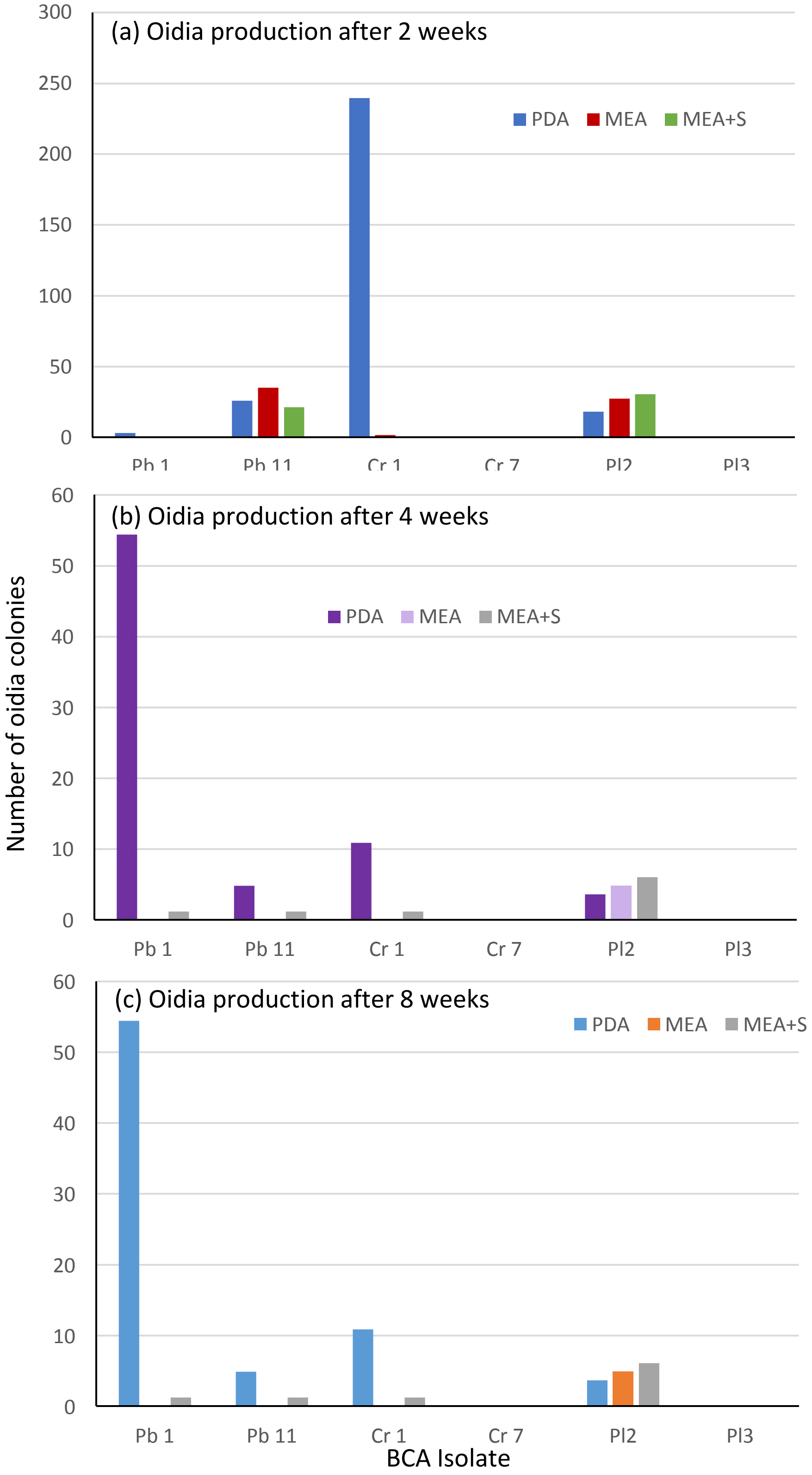
Figure 58: The influence of media on the production of oidia



Comparing the oidial production of BCA isolates as a function of culture age.

There appears to be a general decline in viable oidia with the age of a culture although this influence (as for media) appears to be isolate specific (Fig. 59).

Figure 59: The oidial production of BCA isolates on different media as a function of culture age.

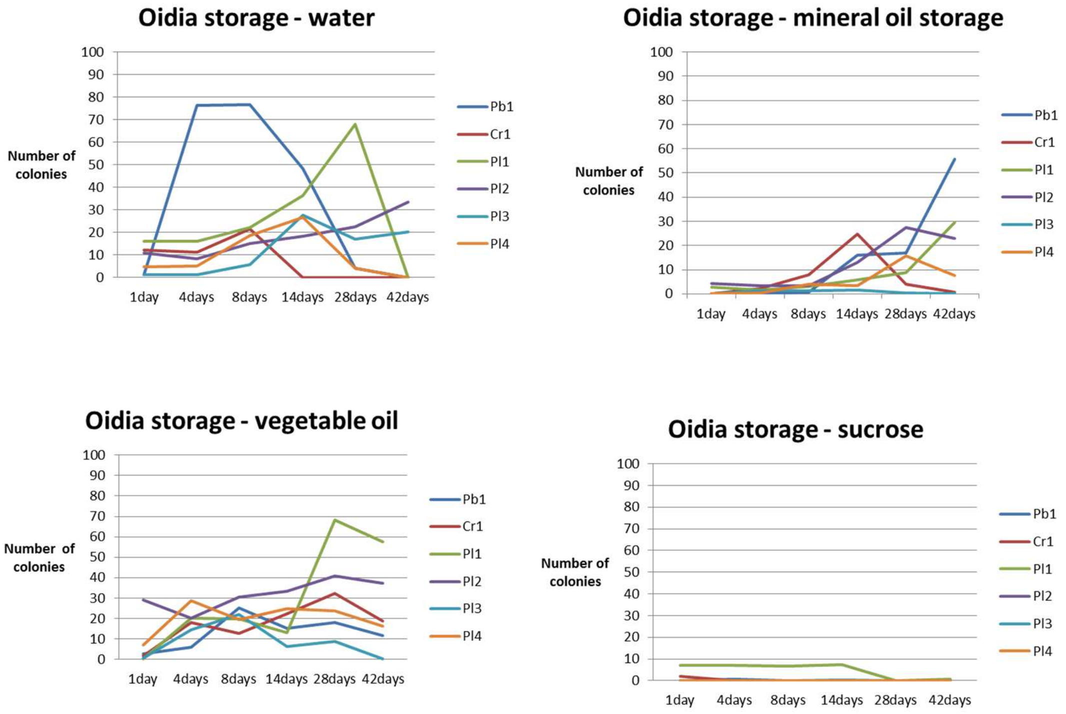


The longevity of oidia in water, sucrose solution, vegetable oil and mineral oil.

The longevity of oidia was extremely poor in sucrose solution (Fig. 60). Storage of oidia was best in mineral oil with only one of the 6 isolates reaching a colony count of zero when the oidia were plated out onto agar medium after 42 days in storage (Fig. 60). The

Cerrena isolate had shorter viability in water and mineral oil than the *Phlebiopsis* isolates (Fig. 60).

Figure 60: The longevity of oidia in different storage solutions



Colonisation of wood blocks with oidial preparations in oil, sucrose and water.

The wood blocks were colonised from all oidia preparations in oil, sucrose and water (Fig. 61).

Figure 61: Colonisation of sterile rubber wood (left) and acacia wood (right) by BCA agents stored in oil.

These are the first studies to be reported in the literature investigating basidiomycete BCA agents in Indonesia against *G. philippi* and *P. noxius*. It is the first time that isolates of *Cerrena* have been induced to form oidia. This promising BCA (currently deployed by industry as blocks in the planting hole) has not been previously found to form these propagules.

It is clear from the screening of BCA agents *in vitro* that variation exists in their biological control ability and it is recommended that a larger number of isolates be obtained from the environment and continually screened. These isolates must be formally identified either by a more intensive search for sporocarps or fruiting in the laboratory. However, some of the candidate isolates show promise and are currently undergoing field testing. Further refinements in the viability testing may be necessary as it appears that the number of oidia actually increase in some of the storage solutions. This may be due to oidia gradually sloughing off the mycelial plug in the storage liquid and in future tests it may be preferable to filter the oidia suspension to remove this source of variability.

Commonly occurring basidiomycete root-rot pathogens can act as biocontrol agents of basidiomycete pathogens through competition for space and nutrients in wood substrates via interspecific combative interactions; these include antagonism at a distance, hyphal interference, mycoparasitism and gross mycelial contact. We only saw evidence of gross mycelial contact with *Cerrena* and *Phlebiopsis* isolates although in previous studies with the same *Phlebiopsis* isolates evidence of mycelial coiling has been seen. In future studies we will use a low nutrient agar media to see if we can observe hyphal interference mechanisms. There are indications that isolates of *Phlebia* had some antagonism at distance to pathogens as indicated by the formation of a sparse zone.

It must be noted that the more prolific producers of oidia are not necessarily the most combative during *in vitro* tests. Therefore no isolate should be discarded especially as we are still field testing the range of BCA activities in pots and field trials. Methods of inducing oidia should be developed for the more combative BCA isolates that appear to produce oidia less readily in culture.

The storage of oidia is best in mineral oil and this is an important finding enabling further stump inoculation trials as the oidia may have to be transported long distances. We will also investigate applying oidia to seedling roots in the nursery and a variety of ways are under discussion.

We now have an overall vision of a production chain for BCAs from laboratory to field.

7.5.2 Pot-trial to verify BCAs are non-pathogenic and assess effectiveness of reducing plant mortality in soil

Pathogenicity of BCA isolates

None of the candidate BCA isolates appeared to be pathogenic to *A. mangium* or *E. pellita.* Several deaths were recorded from the BCA control pots at Sinarmas but these were attributed to *Ceratocystis* or wood borer and all root systems were healthy upon inspection (Tables 51 and 52).

Table 51: Tree deaths in plants inoculated only with BCA isolates at Sinarmas (all attributed to agents other than root rot).

Host	BCA	Inoculum type	No. and Cause of Death (/15)
E. pellita	Pb1	Sawdust	1 (*Ceratocystis* or borer)
A. mangium	Cr4	Sawdust	1 (*Ceratocystis* or borer)
Acacia mangium	Pb9	Sawdust	1 (*Ceratocystis* or borer)
Acacia mangium	Cr4	Woodblock	2 (*Ceratocystis* or borer)
Acacia mangium	Pl1	Woodblock	2 (*Ceratocystis* or borer)

Table 52: Symptoms in trees inoculated only with BCA isolates at RAPP (cause of death not verified)

Host	BCA	Inoculum type	No of symptomatic trees
Eucalyptus pellita	Cr5	Woodblock	1 dead (not root-rot)
Acacia mangium	Cr5	Sawdust	1 dead (not root-rot)
Acacia mangium	Pl3	Sawdust	1 dead (not root-rot)
Acacia mangium	Pb2	Woodblock	1 root infection

Effectiveness of candidate BCAs in reducing infection by G. philippii and/or P. noxius.

Few deaths were recorded in the trial overall. At Sinarmas, deaths were caused mainly by *P. noxius* (Table 53), in contrast to RAPP, where deaths were even rarer and root infections were mainly caused by *G. philippii* (Table 54), so data are presented separately for each company.

At Sinarmas, only four deaths were attributed to other disease agents (data not shown). *Phellinus noxius* isolate PHA-007 (Pn1) was more virulent than LC-RK-11C-36.1 (Pn2) and killed more *E. pellita* controls than *A. mangium* controls. The low mortality level makes statistical analysis based on mortality difficult, but results suggest that sawdust inoculum is less effective than wood-block inoculum. It was also more difficult to prepare, being more prone to contamination with other fungi.

Table 53: Mortality attributed to root-rot in *A. mangium* inoculated with *Phellinus noxius* and candidate BCA isolates at Sinarmas.

Pathogen	BCA or control	BCA Inoculum type	% dead trees (n = 15)
Gp1	Cr4	Wood-block	7
Gp1	Pb9	Wood-block	7
Gp1	EP control	No BCA	7
Gp2	Pb1	Wood-block	7
Pn1	Pl1	Sawdust	33
Pn1	Pl1	Wood-block	13
Pn1	Pl2	Sawdust	27
Pn1	Pl2	Wood-block	20
Pn1	Cr4	Sawdust	13
Pn1	Cr4	Wood-block	13
Pn1	Cr6	Sawdust	27
Pn1	Cr6	Wood-block	20
Pn1	Pb1	Wood-block	13
Pn1	Pb9	Sawdust	27
Pn1	Pb9	Wood-block	27
Pn1	AM control	No BCA	27 (+7% infected)
Pn1	EP control	No BCA	54 (+7% infected)
Pn2	Pb1	Sawdust	20
Pn2	Cr4	Wood-block	7
Pn2	Cr6	Sawdust	7
Pn2	AM control	Wood-block	13

Deaths in control pots at RAPP were much lower, with a maximum of 1 tree per treatment infected or killed (Table 54). There was a higher infection rate in some of the pots with sawdust BCA inoculum (Table 55) or with Cr5 or Pl2 as BCA. Statistical analyses will be carried out to assess the significance of the variation among the BCA isolates.

Table 54: Deaths in *A. mangium* and *E. pellita* control pots at RAPP (cause of death still to be verified). There were no deaths in the control treatments not listed here.

Host	Isolate	Inoculum type	% dead trees (n = 15)	% infected trees (n = 15)
Eucalyptus pellita	Gp1 (pathogen)	Wood-block	7	0
Acacia mangium	Gp2 (pathogen)	Wood-block	0	7
Eucalyptus pellita	Cr5 (BCA)	Wood-block	7	0
Acacia mangium	Cr5 (BCA)	Sawdust	7	0
Acacia mangium	Pb2 (BCA)	Wood-block	0	7

Table 55: Death and infection in *A. mangium* trees with both pathogen and BCA inoculum at RAPP. There were no deaths in treatment combinations not listed here, i.e. most of the pots with *Phellinus noxius.*

Pathogen	BCA	Sawdust Inoculum		Woodblock inoculum	
		% dead	% infected	% dead	% infected
Pn2	Pl3	7	0	0	0
Pn1	Pl2	7	0	0	0
Gp1	Pb2	0	67	0	0
Gp1	Pb9	0	67	0	0
Gp1	Cr5	0	40	0	60
Gp1	Pl2	0	80	7	13
Gp1	Pl3	0	80	7	0
Gp2	Pb2	0	54	0	0
Gp2	Pb9	0	33	0	0
Gp2	Cr5	0	13	0	27
Gp2	Pl2	0	60	0	47
Gp2	Pl3	0	40	0	0

Harvesting of block inoculum and root observations

One complete replicate (21 polybags) was harvested in June 2014 and the remaining polybags in March 2015. Root infections were not observed in the BCA-only or in the pathogen-only control bags, despite roots penetrating the inoculum blocks (Figure 62). Harvesting of roots at the end of the trial showed that some trees had small root infections that were apparently contained by the host (Fig. 63).

Figure 62: *A. mangium* roots penetrating pathogen inoculum blocks.

Figure 63: Small infection that was contained by otherwise healthy host.

Isolates were obtained from BCA and pathogen inoculum blocks. Species identity was based on morphology and will be confirmed by molecular analyses. BCA activity based on tree deaths was difficult to measure because of the low level of mortality in pathogen-only controls, but observations at harvest and re-isolation indicated that *Phlebiopsis* isolates can maintain biocontrol activity in soil for up to a year. More detailed data will be derived from molecular identification of the fungi isolated from the inoculum blocks.

At harvest, *Phlebiopsis* mycelium was observed growing over the pathogen wood-blocks (Fig. 64). After harvest the woodblocks were stored in plastic bags until isolations were made and the *Phlebiopsis* mycelium continued to grow from both BCA and pathogen woodblocks, indicating that it was still viable a year after planting. In contrast, *Cerrena* inoculum blocks were overgrown by *Phellinus noxius* (Fig. 65).

Figure 64: *Phlebiopsis* mycelium growing over the pathogen wood-blocks at harvest (left, Pb9 x Pn1) and after storage (top right, Pb1 x Gp2; bottom right, Pb9 x Pn2), indicating that it was still viable a year after planting.

Figure 65: *Cerrena* inoculum blocks overgrown by *Phellinus noxius* (Pn1 x Cr6).

7.5.3 Field test of successful BCAs

Stump trials: Half of the *Eucalyptus* stumps were harvested at 10 weeks after inoculation, by which time vigorous coppice regrowth had occurred. Re-isolation from these 36 samples resulted in 194 fungal isolates, most of which were not BCA isolates (results not shown). All but one of the BCA isolates, Cr7, was re-isolated from at least one stump (Table 56). The remaining stumps were harvested after 12 months, and re-isolations are complete but identification of the isolates is not yet available.

Table 56: The number of *Eucalyptus* stumps each candidate BCA was re-isolated from, and the depths from which it was isolated.

Isolate	Stumps colonised	1 cm Depth	5 cm Depth	10 cm Depth
Pb1	4/4	2	3	3
Pb11	1/4	1	1	1
Cr1	2/4	1	1	1
Cr7	0/4	0	0	0
AACr	1/4	1	1	1
Pl2	1/4	0	0	1
Pl3	3/4	2	1	2

All of the *A. mangium* stumps were harvested at 10 weeks after inoculation and 284 isolates obtained. Again, most were not BCA isolates. All the *Phlebiopsis* and *Cerrena* isolates were re-isolated from *Acacia,* but the *Phlebia* spp. were not (Table 57).

Table 57: The number of *A. mangium* stumps from which each candidate BCA was re-isolated, and the depths from which it was isolated.

Isolate	Stumps colonised	1 cm Depth	5 cm Depth	10 cm Depth
Pb1	5/8	3	2	2
Pb11	2/8	2	0	1
Cr1	3/8	2	0	1
Cr7	4/8	1	3	2
Pl2	0	0	0	0
Pl3	0	0	0	0

BCA field trial: The first assessment of the BCA field trial took place at 6 months of age. The level of deaths caused by root rot was low in all treatments and the standard deviation was greater than the mean in most treatments (data not shown). Tree heights and missing trees were also recorded (data not shown). A second assessment at age two years will be conducted.

Overview of biocontrol research

At the end of the previous root rot project we had identified several candidate BCAs and carried out some preliminary testing – isolates of *Phlebiopsis* were of special interest. Sinarmas was already applying *Cerrena* as block inoculum in planting holes by the end of the last project and we had been instrumental in giving advice and identifying the isolates for this operational activity. We were asked by industry partners during the final review of the previous project to carry out some basic science and publish this - and in so doing make both information and isolates publicly available (Sinarmas could not officially share its information or isolate).

Therefore the biocontrol research included

- Laboratory trials to investigate the combative behaviour of BCA isolates, observe the mechanisms of biocontrol,
- Polybag trials to assess any inhibitory effect of BCAs on disease expression and develop standard operating protocols for such polybag trials,
- Field trials to inoculate stumps
- A field trial to test as many BCA agents as possible delivered as wood block inoculants in the planting hole.

While not all experiments went according to plan we established the basis for the further development i.e.

- Several candidate BCAs were competitive against *G. philippii* and *P. noxius in vitro* and in wood blocks
- All candidate BCAs produced oidia although production is inconsistent and difficult to predict
- The BCAs are not pathogenic towards *A. mangium* or *E. pellita*
- The BCAs can survive in wood in soil for 12 months and overgrow pathogen inoculum under these conditions.
- Oidia remain viable in mineral oil or vegetable oil for at least 6 weeks.
- *Phlebiopsis* and *Cerrena* both colonise *A. mangium* and *E. pellita* stumps.
- BCAs applied as oidia colonise stumps and after 3 months have grown at least 10 cm into the stump.

The research clearly indicates the potential for these BCAs to reduce pathogen inoculum provided the following knowledge gaps are addressed.

- Can we develop consistent, reliable and large scale production methods for oidia and methods of boosting oidia production of competitive strains?
- Does stump colonisation depend on environmental variables? Will application in an oily substrate provide better adhesion, particularly in wet weather?
- Do BCAs inoculated onto stumps penetrate into the root system and if so, are they capable of destroying any pathogen inoculum already present?
- Is stump colonisation a more effective method of applying BCA compared to addition of woody inoculum colonised by BCA?
- Cost-effective and efficient application method? Can oidia be applied evenly in chain-saw oil?

Objective 6

Objective: To better understand the knowledge, social experiences and conditions of the small landholders in order to enhance their capacity to manage their short-rotation plantations.

Activity One. West Kalimantan: Impacts of company-community partnership on local livelihood

- The most common reasons for joining a partnership were the attractiveness of the scheme to potentially increase income and provide other incentives that open better access to gain information and markets (e.g. road construction).
- The contributions Finnantara Intiga (FI) made to road construction, healthcare and social funds were widely acknowledged by smallholders.
- About two-thirds of *partnered* participants were dissatisfied with their partnership, most commonly because of lack of profit, but also because original promises were not delivered and because of a lack of communication.
- About half of the participants in Sintang were unwilling to continue their contract until the end, and most were unwilling to renew the partnership after the contract had concluded. In contrast, almost three-quarters of participants in Sanggau were willing to continue with their current contract, but about half of the participants were not sure whether they would renew their contract or not. Lack of financial return was the most common reason for participants being unwilling to continue with the current contract or for not wanting to renew their contract.
- Participants mostly rated low levels of trust in both the timber company and NGOs, but did trust village leaders (formal and informal), head of regency, and scientists.
- A trusted agency needs to be engaged to mediate the partnership between the company and communities since the trust level with the timber company is low
- On the whole, participants were relatively poor, and those in partnerships seemed to be living without essentials (food and clothing) as much as were those not in partnerships.
- Open communication with the local partners was found to be essential to improve the satisfaction rating.
- About half of participants reported being aware of the change in FI's ownership. Most of the participants (82%) thought the change had negatively impacted on FI's partnership with the community. The main change reported by participants was that they were no longer involved in paid employment with FI. They were less involved in the plantation work after the change.

Activity Two. Conditions (or attributes) of partnership most important to smallholder farmers

Results are grouped to compare respondents who were familiar with Company-Community Partnerships (CCP group) and those who were not (non-CCP group).

1. CCP group
    - Attributes of partnerships that increased adoption include higher expected income, better road access both to forests/farms and villages, better access to forests, followed by production insurance
    - Attributes that negatively affected partnerships and discourage their uptake are lengthy contracts, more days spent for additional farmers' participation in forest protection, and attending training about tree management.

- Staying in existing contract results in disutility and about one third of respondents prefer to bail out of any contract that will be offered in the future.
- Based on the value of each attributes, forest managers can shorten the contract length, and reduce farmers' participation for forest monitoring. Providing better road to forests will significantly attract respondents to keep rejoining the schemes.
- The contract needs to compensate at least Rp 6,304,000/ha/year to prevent respondents from disjoining the contract.
- Before offering the hypothetical contract changes, about 90% of respondents intended not to renew contract in the future. After showing them the choice sets indicating revised contract options, about one third of respondents indicated they would re-join the contract.
- Some social-economic characteristics were found to influence CCP farmers' decisions to opt out: younger respondents with little training in agriculture, those owning bigger farms, and those with no debts tended *not* to join partnerships.

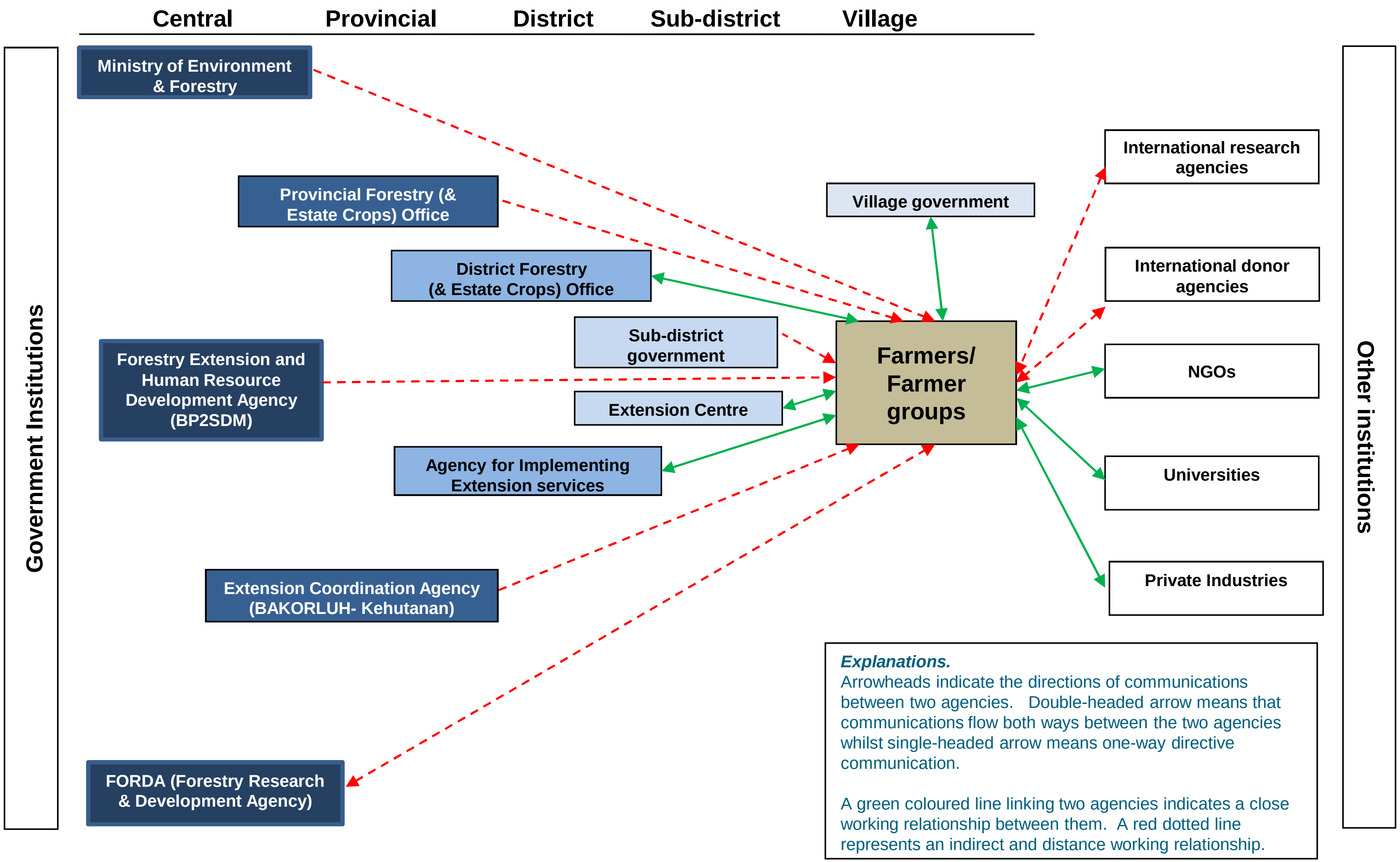
2. Non-CCP group
    - Positive contract attributes that can influence people' decisions to join partnerships include better roads to forests and villages, higher expected income, training about tree management, training about trees and food crops, and production insurance. The only attribute that seems to detract from partnership is the length of contract.
    - With more positive and significant contract attributes, there is more room for forest managers to offer variations to contract.
    - Less than one fifth of respondents always bail out of the contract and their willingness to accept compensation is higher than in CCP regions (that is, Rp 8.674.000/ha/year).
    - Socio-economic factors that can influence non-CCP farmers' unwillingness to join the partnership scheme are: those farmers with smaller land and owing money to institutions.

Activity Three. Gunung Kidul Farmers and short rotation plantations

- Gunung Kidul farmers perceive trees as a significant source of income to cover for large expenses and life emergencies. Whilst teak is the most preferred tree to grow, acacia is considered by farmers to be an excellent substitute to teak on less fertile regions of Gunung Kidul - especially in the southern regions.
- Farmers recognised they were not getting the most economic benefits from their trees because they sold their trees too early.
- Communities are therefore actively seeking fast growing trees that they can sell in the short term to help with their livelihood.
- Farmers preferred Albizia (Sengon Laut) to acacias. Acacias were locally known to be prone to theft - acacia leaves were stolen as stock feed and their bark is used to make rope.
- Across the three hamlets, there are marked differences in the support smallholder farmers received for growing trees. In particular, the hamlet located in sub-district Panggang received the most support from Indonesian government and NGO groups. The other hamlets from Purwosari and Tepus sub-districts received no, or very little support for growing trees.
- The most likely reason for this discrepancy is due to the large national forests in Panggang compared to other sub-districts. The large national forests had attracted

significant investments to protect, conserve and utilise the parks over the years. The established networks helped small landholders to obtain support for their tree growing activities.

- The other two sub-districts have a larger proportion of smallholder forests to national forests.
- The hamlet in Tepus sub-district, with a large proportion of private lands, received little support in tree growing.
- Activity three also looked at the overall institutions which assist tree farmers in Indonesia. The figure below shows the institutions working with farmers according to research scientists in Indonesia
- Seven institutions were thought to work closely with farmers: the district and subdistrict extension centres, district forestry office, village government, university (forestry) staff, NGOs and private industries. Of these, extension staff maintained most consistent contact with local farmers or farmer groups.
- In the current arrangement, assistance to farming is mainly a top-down process.
- The farmer workshops also produced similar findings. Extension staff from the district forestry office were the main people that the community liaised with for forestry support. Therefore, the best way to increase adoption of short-rotation plantation such as acacias, eucalypts requires support from forestry extension staff.
- The forestry extension staff are not well resourced. Indeed, the government has moved the focus of extension services from enhancing capacities of farmers to encouraging greater independence in farming. The extension services are moving towards more of a voluntary position.
- In Gunung Kidul, every subdistrict has one forestry extension staff member – in Panggang subdistrict, one forestry extension staff looks after 5 villages with 32 farmer groups.
- Many of the forestry extension staff are about to retire are there are currently no plans to replace those positions.
- Married women in the region had to perform the role of housewives as well as farmers. Despite this, tree management training is considered as a men-only activity. Women were only included when men in their household were unable to attend.
- Despite the importance of forestry to the livelihood of farmers in the region, forestry was not seen as important as agricultural assistance by Indonesian government.



Explanations.

Arrowheads indicate the directions of communications between two agencies. Double-headed arrow means that communications flow both ways between the two agencies whilst single-headed arrow means one-way directive communication.

A green coloured line linking two agencies indicates a close working relationship between them. A red dotted line represents an indirect and distance working relationship.

Activity Four. Desktop reviews of partnership arrangements

Policy options can be ‘hard’ or ‘soft’. Soft options to promote tree-planting are more effective if they establish equity and trust between partners, in which risks and benefits are shared fairly. This can be difficult when partners differ in power, resources, and dependence on the partnership.

Our review reiterates Vermuilen et al.’s (2008, p. 15) conclusions about effective partnerships. For partnerships to work well there should be the following characteristics.

1) Mutual respect of each partner’s legitimate aims
2) Fair negotiation process, where partners can engage and make informed, transparent, and free decisions
3) Learning approach, allowing room for disagreement and change
4) Realistic prospects of mutual profits
5) Long-term commitment to optimise the returns from deals (i.e., overcoming short-term risk aversion)
6) Equitably shared risks (short, medium, and long-term)
7) Sound business development principles; not exploitative relationships, not PR
8) Sound livelihoods – partnerships focused on increasing capital assets of the poor
9) Contribution to broader development strategies
10) Independent scrutiny and evaluation of partnership proposals and monitoring of progress

From the relevant literature, we conclude that policy to promote tree-planting is most likely to be effective if it highlights and promotes advancing equitable partnerships. Improved relationships of trust need to be facilitated among partners, especially between smallholders and forestry companies, and this should be addressed mindful of the socio-ecological, historical, and economic contexts in particular regions where uptake of tree-planting among smallholders is seen as desirable.

8 Impacts

8.1 Scientific impacts – now and in 5 years

This project has advanced our understanding in several key areas, and there is a strong pipeline of publications arising from the project to attest to this. Key scientific impacts include a greater understanding of the productivity, sustainability and resilience of plantation systems, including the following:

A body of knowledge has been derived from the studies in Objective 1, helping us to understand the nutrient requirements of new *Eucalyptus* plantations that are established in this environment on ex-acacia sites. Specifically, we have demonstrated across a range of sites that nitrogen is not a significant limiting factor to *Eucalyptus pellita* plantation productivity in these environments, for at least 2 rotations. This is in contrast to many environments where eucalypts are grown, where nitrogen can be a key limitation. However, we have also found that nitrogen dynamics are subject to change under *Eucalyptus* plantations, at least in comparison with acacia plantations, with lower soil N availability under *Eucalyptus*, and that this may induce N deficiency in later rotations. This situation requires future monitoring to ensure that the plantations do not become N limited once demand exceeds the natural supply capacity of the soil. For other nutrients, we have demonstrated that phosphorus nutrition is again the most important aspect, as has been found for acacias. We also anticipate that while P nutrition is important, it will probably be easy to manage, as has been found in acacias, through only small applications during the plantation establishment phase. At this stage, there is little evidence of responses to cations or to lime amendment of these soils. We have also demonstrated that *Eucalyptus* plantations can support levels of pulp production per hectare similar to those from *Acacia*, especially if the higher pulp productivity (tonnes pulp per m^3 of log volume, over bark) of *Eucalyptus* is taken into account, but that there is some improvement required to optimise the matching of genotypes to different environments. We anticipate that these questions will occupy the minds of scientists over the next few years.

Our understanding of the biophysical drivers of plantation productivity have also been improved, through the activities in Objective 2. The model for site characterisation that was developed in South Sumatra was found to have some application in Riau, with soil drainage a key factor influencing productivity. However, the soil attributes influencing this were less easy to define, perhaps because the soils are generally better drained in Riau, and the range in productivity is not as great as was found in South Sumatra. The implications of soil drainage in South Sumatra became clear in the core experiment, where the water table fluctuated greatly from season to season, influencing the rooting depth and productivity at that site.

The *E. pellita* sawing study demonstrated that trees of 21-27 cm DBH harvested from a 10-year-old stand can be back sawn and dried to provide boards which have the potential (if knot-free) to be sold into international markets. However, in spite of fine branches which are naturally shed, the presence of dead knots indicated that pruning is still necessary and this is being used as a silvicultural input in the demonstration trials. Waxing of the cut log ends after harvesting was undertaken as a precaution in the trial, and fortuitously, it became clear failure to apply quickly resulted in severe end-splitting.

The GIS study in Objective 4, while not giving definitive results in relationships between tree mortality and site factors, has shown the level of detailed data that is needed to properly accomplish these goals. The potential link between soil texture and root rot that was identified in this study was supported by results of the pathogenicity pot trials. Studies of *Ganoderma philippii* biology have provided new insights into the modes of reproduction and spread in this pathogen, which affects a broad range of woody hosts.

The in-vitro tests have demonstrated that the potential biological control agents first identified in ACIAR FST 2003/048 are competitive against *G. philippii* and *P. noxius*, In addition, all have been shown to produce oidia, a spore form that is more amenable to commercial deployment than current practices of producing woody inoculum. Oidia of all candidate BCA species were able to colonise freshly cut stumps of *A. mangium* and *E. pellita*. Pot trials have demonstrated that the candidate BCAs are non-pathogenic and maintain their competitivity against *G. philippii* and *P. noxius* in soil. Oidia can also be stored for at least 6 weeks in oil, so that commercial production and utilisation of these BCAs is much closer.

Objective 6 has produced insights into the relationship between company-community forestry partnerships on farmers' livelihoods, quantified community preferences for different partnership contract attributes, shown the importance of social networks and institutions for supporting farmers and disseminating information to them, and shown the important role played by forestry extension officers at a time when their positions are being reduced.

The results from Activity One provide a picture of livelihoods of remote communities after participating in a company-community partnership scheme for nearly two decades. Activity One was the first research to provide a comprehensive view on how a partnership can change over time resulting in different livelihood impacts to the local communities. With Indonesian government pushes to open more commercial plantations, the study gave the scientific community an understanding of the local experiences and recommends a way to promote partnerships to become more equitable to all parties.

The choice experiment was the first research conducted to value community preferences for partnership (or contract) attributes. Community preferences have been either excluded or under-represented in the initial partnership negotiations. The study outcome can be used to inform forestry company managers of community preferences for the partnership arrangements. This is especially crucial for the long-term success of company-community partnerships. The choice experiment outcome was well received by Finnantara Intiga, the forest company involved in the West Kalimantan scheme. They had not been able to gauge community preferences for the scheme, and having the results allowed them to feedback to their parent company SinarMas to start initiating necessary changes to ensure long-term viability of the partnership scheme.

Institutions assisting farmers in Indonesia have been undergoing significant changes in recent years. Despite farmers relying on tree income for significant household expenses, some hamlets were not getting assistance necessary to effectively manage their trees. The study brought awareness to the growing worries amongst forestry research stakeholders as Indonesian government moved to reduce extension support for farmers.

8.2 Capacity impacts – now and in 5 years

The large project team from several different organizations and backgrounds has been a strength of this project, engaging with scientists from FORDA, 2 universities in Indonesia, and 3 private companies. The project has had a number of formal capacity building opportunities (see below), but also, the informal opportunities for scientists from different companies, and other organizations in Indonesia to get together and share experience, and participate in action learning through project design and implementation has helped to strengthen the capacity of forest plantation researchers. These skills extend beyond the life of the project. Desy Puspitasari has completed a postgraduate studies at UGM while supported by this project (salary and tuition fees).

John Allwright Fellowships (JAF)

The John Allwright Fellowship scheme is an excellent capacity building opportunity, allowing scientists from Indonesia to work very closely with scientists from Australia. This is a great personal development opportunity for the candidates, and leaves a strong legacy in-country when the candidates return. This project has been successful in sponsoring 3 JAF candidates during the project. The project has also continued to support 1 JAF candidate carried over from an earlier project.

- Dwiko Budi Permadi commenced studies at University of Western Australia in February 2013. His topic of research was on "Increasing productivity and profitability of Indonesian smallholder plantations". He will complete his PhD by the end of 2016, and will then return to a lecturing position at UGM.
- Arom Figyantika commenced studies at the University of Tasmania in mid-2014. The topic of her research is on understanding the competitive and beneficial interactions between trees and agriculture in Australia and Indonesia.
- Aswardi Nasution commenced studies at the University of Tasmania in October 2014. His research is focussed on managing *Ceratocystis* disease in *Acacia mangium,* (i) by developing rapid and simplified screening protocols for resistant germplasm and (ii) screening bacterial endophytes of *A. mangium* for biocontrol activity against *Ceratocystis.*

Scientific writing workshop

The project held a scientific writing workshop in Yogyakarta in October 2014 to improve the capacity of Indonesian scientists working across this projects, as well as the project led by Dr Digby Race around community-based commercial forestry.

Ethical consideration in conducting social research

The current project also attempted to bring about awareness in the forestry research communities about research ethics. Indonesian researchers are not required to apply any ethical considerations when conducting research with local farmers. Publishing social research without ethical approval can be problematic for international journals. This can impede the potential impacts of the work of Indonesian researchers. Our discussion with Indonesian social researchers about ethics marks the first step into changing the conduct of social research to one that meets international publishing needs.

Sawmilling study

Dr Chris Beadle worked closely with Pak Alen Maydra Inail (MHP), Pak Heru Indrayadi (Sinarmas) and Pak Mohamad Anis Fauzi (FORDA) to enhance their presentation skills for the mid-term and final reviews. He also worked with Pak Alen and Pak Anis on strategies and application of pruning and thinning in plantations, and with Pak Alen on how to undertake sawing trials.

Capacity building through paper writing

Indonesian and Australian social scientists who worked either in FST/2009/051 or FST/2008/030 collaborated to produce a technical report looking at various institutions working to improve on the livelihood of tree farmers in Indonesia. This collaboration used synergies and expertise from scientists in both countries to investigate a research area that is not commonly known. The collaboration also fostered good working relationships between two groups of scientists from separate ACIAR projects, who share common experiences working with farmers in Indonesia but who have not previously worked together.

Several other jointly-authored papers have arisen from the project, with Indonesian authors taking the lead in many cases.

8.3 Community impacts – now and in 5 years

We have helped to highlight the challenges and difficulties encountered by smallholder farmers and the forest company during their partnership. The outcomes from the project provide an opportunity for both parties to come to an understanding so the partnership remains a viable option for both parties in the long-term. The company can used this information to improve their interactions with their community partners and non-partners.

8.3.1 Economic impacts

The project has several outcomes that are likely to be implemented, both by industrial partners, and by smallholder farmers. For example, we have demonstrated that *E. pellita* is a better option than *A. mangium* in many circumstances. Nutrient management of *E. pellita* is less demanding than we originally expected, which will assist in the cash-flow of growers. Similarly, the demonstration trials show strong promise for improving grower returns, either through value adding to the crop, or though best-practice management to achieve high yields.

Greater understanding of the potential to predict risk of mortality will improve decision-making and hence profitability of plantations. The development of BCAs that can be applied as oidia rather than colonised wood-blocks will result in substantial savings in the application of BCAs.

Smallholder growers that were engaged in Java were keen to explore the options for growing acacias, and asked whether seedlings could be provided for initial testing on-farm. We anticipate that this will lead to greater grower incomes in 5-10 years.

The social science outcomes around partnership arrangements, which were fed back to the company in West Kalimantan, will be able to help the company to improve their interactions with farmers, and improve the value proposition such that farmers are getting a more equitable share of the benefits. Once the project outcomes are implemented, even if only partially, then more partnerships should be established and should persist for longer, resulting in better financial returns for the company and in improvements in farmers' livelihoods.

8.3.2 Social impacts

The main social impacts from the project are yet to be realised, but there are several prospects for impact as follows:

- There are enhanced prospects to increase household income through (1) improved management of acacias and eucalypts to maximise productivity and reduce risk due to disease, (2) adoption of technologies that improve returns to farmers, including sawlog production, and, possibly in the future, agroforestry-type regimes.
- We have started to understand, and account for, the gender impacts of growing trees. This is particularly in Java, where tree growing is more of a family enterprise than in Sumatra and West Kalimantan. We anticipate that this will lead to greater social equity in our approaches to helping farming families to manage their trees.
- This study has demonstrated that both *A. mangium* and *E. pellita* can be managed for saw-log production. This provides a potential pathway for smallholder growers to realise enhanced incomes from investment in acacia and eucalypt plantations. However, until reliable means for managing *Ganoderma* and *Ceratocystis* diseases have been developed, this is not an option for acacia plantings. Illegal logging and lack of markets for sawn plantation timber in Sumatra also mean that *E. pellita* is also not a viable commercial option in domestic markets. Developing this species for international markets might be possible and such an option was considered 10 years ago by MHP for *A. mangium*. However it would first be necessary to develop a sustainable resource.

8.3.3 Environmental impacts

The project outcomes help growers to improve the productivity and sustainability of wood production from plantations in Sumatra. Sumatra already has a very large installed pulp production capacity, and more pulp mills are under construction. A sustainable source of wood to supply this large pulp capacity in Indonesia is essential to minimise further harvesting of the natural forest. This project contributes to the knowledge and understanding to allow (1) the best productivity from the existing plantation area, and (2) the opportunity to increase wood supply from farmer plantations, through an understanding of more equitable partnership arrangements.

In addition to the potential for protection of natural forest, the project outcomes around nutrient management will help growers to optimise N and P fertilizer use by the trees, so that the risk of nutrient leaching and subsequent waterway eutrophication is minimised.

8.4 Communication and dissemination activities

Key communication and dissemination activities supported by the project included the following:

- A farmer field day in South Sumatra, in June 2015, with 60 farmers + 15 others.
- A farmer field day in Gunung Kidul, February 2015, with attendance from 10 farmer-group leaders (representing around 100 farmers)
- Ongoing engagement with communities in South Sumatra and Gunung Kidul
- A workshop and field visit for company managers, in Riau, in May 2015, with participation from around 35 managers
- A workshop and field visit for company managers in South Sumatra, in April 2015, with participation from around 40 managers.
- Discussions with company staff in West Kalimantan around the outcomes from the choice experiments, and mechanisms for them to improve relationships with communities.
- Publication of growers manuals (in Bahasa Indonesia) for *E. pellita*, and an update of the *A. mangium* growers manual (available from the project website).
- Publication of a Handbook of Pests and Diseases in *Acacia* and *Eucalyptus* plantations (in Bahasa Indonesia)
- Publication of a number of scientific manuscripts (see Section 10), and preparation of several more drafts that had not been published as of project completion.
- Several presentations at workshops and conferences, including IUFRO Acacia in May 2014, and abstracts submitted to IUFRO *Eucalyptus* in October 2015
- Formal and informal engagement with staff from FST/2008/030 (Community Based Commercial Forestry Project)
- A project website has been developed for information dissemination: www.pohoncepatumbuh.com.

9 Conclusions and recommendations

9.1 Conclusions

- *Eucalyptus pellita* can be as productive as *A. mangium*, on a volume per hectare basis, which is at the top end of productivity that can be achieved in plantations anywhere in the world. However, site × clone matching seems critical to get right. The current pool of high performing genetic material seems small, but the available material does demonstrate that there is potential to expand the number of high performing clones.
- *E. pellita* has a reported higher pulp conversion factor than *A. mangium*, so under the right conditions, its pulp productivity can be higher than that of *A. mangium*.
- Sites should be managed with care around harvest time, to ensure that losses of organic matter, nutrients and soil are kept to a bare minimum. All our experiments were pre-treated in this way.
- Nutrient management of *E. pellita* is essential, with 10-30 kg/ha P required at establishment, but there is little nitrogen requirement. Results to date suggest that nitrogen carried over from acacia plantations is sufficient to support growth of at least 2 rotations of *E. pellita*. There is no evidence yet that suggests that addition of cations will give a growth response.
- Soil nitrogen availability declines under *Eucalyptus* plantations, relative to that under *Acacia*, suggesting that N deficiency may become an issue in the future.
- Soil drainage is a key factor influencing productivity, and site characteristics that help diagnose drainage capacity are likely to be important for growers to account for when assessing potential site productivity.
- Although *Acacia mangium* plantations have the potential to be managed for sawn timber in Sumatra and Kalimantan, the effects of *Ceratocystis* diseases are seriously compromising any possibility of maximising and sustaining commercial yields. A sawing trial showed that *E. pellita* also had potential and that boards could be sawn and dried with satisfactory results; however pruning will be required to stop the development of dead knots. Domestic markets are not currently an option for either species, in part because of illegal logging providing an alternative log source for millers, but also the lack of a proper market.
- Fundamental scientific research has been conducted that underpins the development of potential biocontrol agents for *Ganoderma phillipi*, including understanding the risks and potential impacts.
- Several potential biocontrol agents that showed substantive promise in laboratory and pot tests are currently undergoing field testing.
- Current soil mapping and pre-harvest inventory data are insufficient for robust prediction of tree mortality risk.
- The current partnership arrangements by Finnantara Intiga are not making any significant contributions to the livelihoods of their community partners in West Kalimantan, although their earlier contributions to roads and health are recognised. Given the lack of other industries operating in the region, Finnantara Intiga remains crucial for encouraging economic activities in the region. Changes must be made to the partnership conditions to allow the partnerships to continue in the future. The current study recommends three ways Finnantara can change to directly improve the livelihoods of their partners:
    - increasing royalties for acacias & eucalypts;
    - including a provision of job opportunities for community partners in the partnership; and
    - re-introducing a community development fund.
- The choice experiment technique was found to be useful to understand community preferences for partnership attributes. The technique allows forest managers to

use the study findings to improve forest policy. The current study found no single model can be used to explain community preferences across regions, indicating regional diversity of the respondents. Therefore, heterogeneous social economic factors are important to be taken into account in proposing policy changes.

- To improve the partnership policy for farmers, forest managers can modify the partnership contracts specifically to increase expected income, shorten contract length, provide insurance, and include community development programs that allow greater access to roads. Attracting community partners in non-partnership regions will be more acceptable by simply adding training for tree and food crop management to partnership contracts.
- Gunung Kidul has long been known for its tree growing culture. Despite this, certain hamlets in the region still received little or no support in their efforts to grow trees for livelihoods. Tree income constitutes a very important income source for farmers. Tree income is used to cover large expenses and life emergencies.
- With greater community preference for shorter rotation trees, acacias and/eucalypts will be readily accepted by smallholder farmers living in Gunung Kidul. However, community concerns about potential theft need to be alleviated before the communities can fully embrace them. The best method to engage farmers was for them to have close working relationships with the forestry extension staff. Forestry extension staff are the primary unit within the district forestry office who maintains close relationship with farmers. Despite their importance, the role played by the forestry extension staff has not been widely recognised. Now the change in government focus on extension services may further undermine their role. The potential adverse effects on farmers and their livelihoods are not fully understood.
- Similar to other regions in Indonesia, forestry in Gunung Kidul tends to be considered as a male job and all forestry training opportunities are for men only. This was despite the fact that women had to work on the farms as much as the men in the region. Women too make decisions about trees to plant and sell. Women are only allowed to be on the forestry training workshops if their male partners are absent. In the hamlet within Panggang sub-district, high support for tree farming and interactions with external agencies seemed to have alleviated some of the forestry gender role disparities that we observed in other hamlets.

9.2 Recommendations

- *E. pellita* can be planted by smallholders for a range of potential products, but to maximise productivity, further work needs to be conducted to ensure that the best material is matched to the available sites.
- Nutrient management of *E. pellita* plantations that follow acacia plantations does not seem to require much further investment at this stage, but this conclusion may need to be re-visited after multiple rotations of *Eucalyptus*, or in situations where environments and land use histories differ.
- Several of the experiments that have been established in this project will accrue much more value if monitored for the rotation length. For example, nutrient response experiments, and the thinning studies in *E. pellita* (MHP2 and Finnatara) and *A. auriculiformis* (Gunung Kidul). Incorporation of this activity into FST/2014/064 is sought, particularly if it can be done in a way to help realise the goals of this new project.
- Further development of site risk analyses for predicting tree mortality should focus on higher resolution spatial approaches such as UAV-based LIDAR or hyper-spectral sensors and site-specific soil sampling and analysis.
- Further development of potential biocontrol agents should focus on using oidia to colonise woody waste left after harvesting, thus avoiding the time-consuming and

labour-intensive production of woody inoculum that also involves high transport and application costs.
- Ongoing development and testing of additional BCA strains is recommended, along with studies into stump colonisation under different weather conditions.
- Further monitoring of the BCA field trial is necessary to determine the effectiveness of a range of candidate BCA isolates applied as woody inoculum in the planting hole.
- Forestry companies actively need to seek to repair damaged relationships with communities, with a focus on restoring community trust in the company and ensuring that partnership agreements produce livelihood benefits for farmers. Key components of trust in company-community relationships are that agreements are seen to be fair and effective.
- Specifically focussing on the company-community partnership that we studied in detail, a trusted agency needs to be engaged to mediate the partnership between the company and communities since the trust level with the timber company is low. Both parties need to be consulted about the current partnership arrangement and any changes to the partnerships in the future. The study suggested that an intervention to mediate the relationships between the company and the community partners must be done soon before it deteriorates further.
- The value of forestry extension staff needs to be emphasised, as they are the key agents that have the greatest impact on farmer decision making about their tree plantations in Gunung Kidul, where trees form an important part of the household livelihood strategy.
- In consideration of local culture, separate tree management workshops should be organised in future to allow women the opportunity to be involved and to improve their capacity to work on farms. Increasing the availability of support to farmers across various hamlets will hopefully raise the capacities of women in those hamlets and reduce the stereotypical gender role currently attached to forestry.

10 References

10.1 References cited in report

Agustini L, Francis A, Glen M, Indrayadi H, Mohammed C. 2014. Signs and identification of fungal root-rot pathogens in tropical *Eucalyptus pellita* plantations. *Forest Pathology* 44: 486–495.

Badia D, Valero R, Gracia A, Marti C, Molina F. 2007. Ten-year growth of woody species planted in reclaimed mined banks with different slopes. *Arid Land Research and Management* 21: 67–79.

Baillères H, Hopewell G, McGavin R. 2008. Evaluation of wood characteristics of tropical post-mid rotation plantation *Eucalyptus cloeziana* and *E. pellita*, Part (c) wood quality and structural properties.

Chowdhury Q, Shams I, Alam M. 2005. Effects of age and height variation on physical properties of mangium (*Acacia mangium* Willd.) wood. *Australian Forestry* 68: 17–19.

Cown D, McConchie D. 1981. Effects of thinning and fertilizer application on wood properties of *Pinus radiata*. *NZJ For. Sci* 11: 79–91.

Deleporte P, Laclau J, Nzila J, Kazotti J, Marien J, Bouillet J, Szwarc M, D'Annunzio R, Ranger J, Nambiar E, et al. 2008. Effects of slash and litter management practices on soil chemical properties and growth of second rotation eucalypts in the Congo. *Site Management and Productivity in Tropical Plantation Forests. Edited by EKS Nambiar. Centre for International Forestry Research, Jayakarta, Indonesia*: 5–22.

Downes GM, Hudson I, Raymond CA, Dean GH, Michell AJ, Schimleck LR, Evans R, Muneri A. 1997. *Sampling plantation eucalypts for wood and fibre properties*. CSIRO publishing.

Eyles A, Beadle C, Barry K, Francis A, Glen M, Mohammed C. 2008. Management of fungal root-rot pathogens in tropical *Acacia mangium* plantations. *Forest pathology* 38: 332–355.

FAO. 1990. Food and Agriculture Organization of the United Nations Soil Map of the World. Revised Legend. World Soil Resources Report 60. FAO-UNESCO, Rome.

Francis A, Beadle C, Puspitasari D, Irianto R, Agustini L, Rimbawanto A, Gafur A, Hardiyanto E, Hidyati N, Tjahjono B, et al. 2014. Disease progression in plantations of *Acacia mangium* affected by red root rot (*Ganoderma philippii*). *Forest Pathology* 44: 447–459.

Goncalves, J.L.M., Gava, J.L., and Wichert, M.C.P. 2004a. Sustainability of wood production in Eucalypt plantations of Brazil. In: Nambiar, E.K.S., Rangers, J., Tiarks, A. and Toma, T. (Editors) Site Management and Productivity in Tropical Plantation Forests. Proceedings of Workshop in Congo July 2001 and China February 2003. Bogor, Indonesia: Center for International Forestry Resarch (CIFOR) 2004. pp.3-14.

Goncalves J.L.M. 2008. Soil Fertility and Growth of *Eucalyptus grandis* in Brazil under Different Residue Management Practices. In *Site Management and Productivity in Tropical Plantation Forests*Nambiar E.K.S. (ed).

Hardiyanto EB, Nambiar EKS. 2014. Productivity of successive rotations of *Acacia mangium* plantations in Sumatra, Indonesia: Impacts of harvest and inter-rotation site management. *New Forests* 45: 557–575.

Hardiyanto EB, Wicaksono A. 2007. Inter-rotation site management, stand growth and soil properties in *Acacia mangium* plantations in South Sumatra, Indonesia. In *Site Management and Productivity in Tropical Plantation Forests. Proceedings of Workshops in Piracicaba (Brazil) 22-26 November 2004, and Bogor (Indonesia) 6-9 November 2006.* Nambiar, E. K. S. (ed). Bogor: CIFOR; 107–122.

Harwood CE, Nambiar EKS. 2014. Productivity of acacia and eucalypt plantations in Southeast Asia. 2. Trends and variations. *International Forestry Review* 16: 249–260.

Hidayati N, Glen M, Nurrohmah S, Rimbawanto A, Mohammed C. 2014. *Ganoderma steyaertanum* as a root-rot pathogen of forest trees. *Forest Pathology* 44: 460–471.

Badan Pusat Statistik. 2014. Statistik Indonesia .

Koenker R, Bassett Jr G. 1978. Regression quantiles. *Econometrica: journal of the Econometric Society*: 33–50.

Laffan M, Tuson D, Robertson I. 1998. Soil-observation strategies for assessing plantation potential in Circular Head District, north-western Tasmania. *TASFORESTS-HOBART-* 10: 59–68.

Lagura NY NWPS. 2012. Productivity of RAPP Plantation in three successive rotations. Riau Andalan Pulp and Paper, Kerinci.

Lim T. 1977. Production, germination and dispersal of basidiospores of Ganoderma pseudoferreum on Hevea. *Journal of the Rubber Research Institute of Malaysia*.

Mendham DS, Heagney EC, Corbeels M, O’Connell AM, Grove TS, McMurtrie RE. 2004. Soil particulate organic matter effects on nitrogen availability after afforestation with *Eucalyptus globulus*. *Soil Biology and Biochemistry* 36: 1067–1074.

Mendham DS, Hardiyanto E, Sjarkowi F, Nurudin M, Soeprijadi D, Wicaksono A, Untung S, White D, Drake P, Rimbawanto A. 2011. *Realising Genetic Gains in Indonesia and Australia Through Water and Nutrient Management*. Canberra: Australian Centre for International Agicultural Research.

Ministry of Forestry (2007). A Road Map for the Revitalization of Indonesia’s Foresty Industry. Ministry of Forestry, Indonesia.

Mohd Zin J, Jawen D, S. Mohd H. 1991. Physical and mechanical properties of *Acacia mangium* Wild. of selected ages grown in Malaysia.In *Proceedings of Symposium on Recent Developments in Tree Plantations of Humid/ Subhumid Tropics of Asia, Malaysia*.

Moncalvo J-M, Buchanan PK. 2008. Molecular evidence for long distance dispersal across the Southern Hemisphere in the *Ganoderma applanatum-australe* species complex (Basidiomycota). *Mycological research* 112: 425–436.

Nawir AA, Santoso L, Mudhofar I. 2003. Towards mutually-beneficial company-community partnerships in timber plantation: lessons learnt from Indonesia

Roux J, Wingfield M, Bouillet J-P, Wingfield B, Alfenas A. 2000. A serious new wilt disease of *Eucalyptus* caused by *Ceratocystis fimbriata* in Central Africa. *Forest Pathology* 30: 175–184.

Sahri MH, Ashaari Z, Abdul Kader R, Mohmod AL. 1998. Physical and mechanical properties of *Acacia mangium* and *Acacia auriculiformis* from different provenances. *Pertanika Journal of Tropical Agricultural Science* 21: 73–81.

Salehi A, Maleki M. 2012. Evaluation of soil physical and chemical properties in poplar plantations in North of Iran. *Ecologia Balkanica*: 69–76.

Silva SR da, Barros NF de, Costa LM da, Leite FP. 2008. Soil compaction and *Eucalyptus* growth in response to forwarder traffic intensity and load. *Revista brasileira de ciência do solo* 32: 921–932.

Smethurst P. 2004. Nutritional physiology of trees. *Encyclopedia of forest sciences, Oxford*: 1616–1622.

Snedecor GW, Cochran WG. 1989. Statistical methods 8. ed. *Iowa State Univ*.

Soil Survey Staff. 1992. *Keys to soil taxonomy*. Soil Conservation Service.

Soil Survey Staff. 1998. *Keys to Soil Taxonomy. 8th ed*. Blacksburg, VA: USDA.

Spurr AR. 1969. A low-viscosity epoxy resin embedding medium for electron microscopy. *Journal of ultrastructure research* 26: 31–43.

Siregar, S. 2013. *Acacia mangium* pulpwood plantation management - current knowledge. Riau Andalan Pulp and Paper, Kerinci.

Sulaiman A, Kadir WRA, Midon MS. 1991. Effects of fertiliser on wood properties of plantation grown *Acacia mangium*.

Tarigan M, Van Wyk M, Roux J, Tjahjono B, Wingfield MJ. 2010. Three new Ceratocystis spp. in the Ceratocystis moniliformis complex from wounds on *Acacia mangium* and *A. crassicarpa*. *Mycoscience* 51: 53–67.

Thompson W, Rayner A. 1983. Extent, development and function of mycelial cord systems in soil. *Transactions of the British Mycological Society* 81: 333–345.

Vermeulen S, Nawir AA, Mayers J. 2008. Rural poverty reduction through business partnerships? Examples of experience from the forestry sector. *Environment, Development and Sustainability* 10: 1–18.

Wibisono MG, Veneklaas E, Mendham DS. 2015. Quantifying nitrogen fixation of *Acacia mangium* Willd. plantations grown at different levels of phosphorus in Lematang, South Sumatra, Indonesia. *Southern Forests* in press.

Wilson OE. 1998. *Consilience: The unity of knowledge*. New York: Knopf.

Yuskianti V, Glen M, Puspitasari D, Francis A, Rimbawanto A, Gafur A, Indrayadi H, Mohammed C. 2014. Species-specific PCR for rapid identification of *Ganoderma philippii* and *Ganoderma mastoporum* from *Acacia mangium* and *Eucalyptus pellita* plantations in Indonesia. *Forest Pathology* 44: 477–485.

10.2 List of publications produced by project

10.2.1 Published

Agustini, L., Francis, A., Glen, M., Indrayadi, H. & Mohammed, C. L. 2014. Signs and identification of fungal root-rot pathogens in tropical *Eucalyptus pellita* plantations. *Forest Pathology,* 44**,** 486-495.

Agustini, L., Wahyuno, D., Indrayadi, H. & Glen, M. 2014. *In vitro* interaction between *Phlebiopsis* sp and *Ganoderma philippii* isolates. *Forest Pathology,* 44**,** 472-476.

Beadle, C., Glen, M., Agustini, L., Yuskianti, V., Puspitasari, D., Francis, A., Rimbawanto, A. & Mohammed, C. 2012. Biology, spread and management of root rot in *Acacia mangium* plantations in Indonesia. *In:* MOHAMMED, C., BEADLE, C., ROUX, J. & RAHAYU, S., eds. Proceedings of the International Conference on the Impacts of Climate Change to Forest Pests and Diseases in the Tropics October 8th – 10th, 2012 Yogyakarta, Indonesia 2012, 2012. Faculty of Forestry, Universitas Gadjah Mada, Jln. Agro No. 1, Bulaksumur, Yogyakarta 55281.

Eyles A, Drake P, Thanh QL, Van BV, Dung PT, Mendham D, White D, Beadle C. 2015. Ecophysiology of *Acacia* species in wet-dry tropical plantations. Southern Forests. *In press*.

Francis, A., Beadle, C., Puspitasari, D., Irianto, R., Agustini, L., Rimbawanto, A., Gafur, A., Hardiyanto, E., Junarto, Hidyati, N., Tjahjono, B., Mardai, U., Glen, M. & Mohammed, C. 2014. Disease progression in plantations of *Acacia mangium* affected by red root rot (*Ganoderma philippii*). *Forest Pathology,* 44**,** 447-459.

Inail, M.A., Beadle, C., Hardiyanto, E.B. 2014. An evaluation of sawn timber from a 10 year old stand of *Eucalyptus pellita* in South Sumatra. Proceedings of IUFRO Acacia 2014 Conference, March 18-24, Hue Vietnam.

Glen, M., Yuskianti, V., Puspitasari, D., Francis, A., Agustini, L., Rimbawanto, A., Indrayadi, H., Gafur, A. & Mohammed, C. L. 2014. Identification of basidiomycete fungi in Indonesian hardwood plantations by DNA barcoding. *Forest Pathology,* 44**,** 496-508.

Greenhill, M. P., Wibisono, M. G., Sumirat, B. K., Suka, A. P., Bisjoe, A. R., & Irawanti, S. (2015) Institutions Assisting Forestry Farmers: An Indonesian case study. CSIRO, Australia.

Greenhill, M, Permadi D and Walker I (2014) Acacia Plantations in West Kalimantan: Impacts on Community Livelihood. CSIRO, Australia.

Hardiyanto, E.B. 2015. Panduan pembuatan tanaman *Eucalyptus pellita* (Manual for growing *Eucalyptus pellita* plantation). Fakultas Kehutanan Universitas Gadjah Mada, Yogyakarta

Hidayati, N., Glen, M., Nurrohmah, S. H., Rimbawanto, A. & Mohammed, C. L. 2014. *Ganoderma steyaertanum* as a root-rot pathogen of forest trees. *Forest Pathology,* 44**,** 460-471.

Kumaraswamy, S.; Mendham, Daniel; O'Connell, Anthony; Grove, Tim; Sankaran, K.V.; Rance, Stanley. Harvest residue effects on soil organic matter, nutrients and microbial biomass in eucalypt plantations in India. Forest Ecology and Management. 2014; 328:140-149.

Maharani, P.H. 2014. Penggunaan fungsi pedotransfer untuk memperkirakan permeabilitas si sub grup Typic Plintudults dan dan Typics Hapluduts di Sumatera Selatan dan Riau. Tesis Pasca Sarjana Ilmu Tanah, Universitas Gadjah Mada, Yogyakarta (Pedotransfer function to predict permeability on soils of the Sub group Typic Plintudults dan dan Typics Hapluduts in South Sumatra and Riau. Master Thesis at Graduate Program of Soil Science, Gadjah Mada University, Yogyakarta).

Mohammed, C. 2012. The challenges of modelling forest pests in a changing climate. *In:* Mohammed, C., Beadle, C., Roux, J. & Rahayu, S., eds. Proceedings of the International Conference on the Impacts of Climate Change to Forest Pests and Diseases in the Tropics October 8th – 10th, 2012 Yogyakarta, Indonesia 2012, 2012. Faculty of Forestry, Universitas Gadjah Mada, Jln. Agro No. 1, Bulaksumur, Yogyakarta 55281.

Mohammed, C. L., Rimbawanto, A. & Page, D. E. 2014. Management of basidiomycete root- and stem-rot diseases in oil palm, rubber and tropical hardwood plantation crops. *Forest Pathology,* 44**,** 428-446.

Harwood CE, Nambiar EKS. 2014. Productivity of acacia and eucalypt plantations in Southeast Asia. 2. Trends and variations. *International Forestry Review* 16: 249–260.

Nurudin, Makruf; Ohta S.; Hardiyanto, Eko B.; Mendham, Daniel S.; Wicaksono, Agus; Heriyanto, J. Relationships between soil characteristics and productivity of *Acacia mangium* in South Sumatra. Tropics. 2013; 22(1), 1–12.

Puspitasari, D., Yuskianti, V., Rimbawanto, A., Glen, M. & Mohammed, C. 2012. Identification of several *Ganoderma* species causing root rot in *Acacia mangium* plantations in Indonesia. *In:* Mohammed, C., Beadle, C., Roux, J. & Rahayu, S., eds. Proceedings of the International Conference on the Impacts of Climate Change to Forest Pests and Diseases in the Tropics October 8th – 10th, 2012 Yogyakarta, Indonesia 2012, 2012. Faculty of Forestry, Universitas Gadjah Mada, Jln. Agro No. 1, Bulaksumur, Yogyakarta 55281.

Sjarkowi, F. 2014. Ekosistem Lahan Basah Lestari; Titah Kedaulatan Pangan Nasional & Kesejahteraan Masyarakat Agraris [=*Sustainable Wetland Ecosystem; The Legacy of National Food Sovereignety and The Prosperity of Agrarian Community*].

Sjarkowi, F. 2015. Kedaulatan Pangan: Siasat Agribisnis Pangan Kebangsaan Penguat Keutuhan NKRI [=*Food Sovereignety; National Strategy for Food Agribusiness to Maintain Solidity of The State of NKRI*]. 2015. Badan Kajian & Penerbitan ICMI Sumsel. pp.329. ISBN 978-602-71657-4-8

Wibisono, G. M., Veneklaas, E., Mendham, D. S. & Hardiyanto, E. B. (2015). Nitrogen fixation of *Acacia mangium* Willd. from two seed sources grown at different levels of phosphorus in an Ultisol, South Sumatra, Indonesia. *Southern Forests: A Journal of Forest Science*, *77*, 59-64.

Yuskianti, V., Glen, M., Puspitasari, D., Francis, A., Rimbawanto, A., Gafur, A., Indrayadi, H. & Mohammed, C. L. 2014. Species-specific PCR for rapid identification of *Ganoderma philippii* and *Ganoderma mastoporum* from *Acacia mangium* and *Eucalyptus pellita* plantations in Indonesia. *Forest Pathology,* 44**,** 477-485.

10.2.2 Submitted

Greenhill, M., Walker, I., & Mendham, D.S. (2015) West Kalimantan Industrial Plantation Scheme: Twenty years on.

Greenhill, M. P., Wibisono, M. G., Sumirat, B. K., Suka, A. P., Bisjoe, A. R., & Irawanti, S. (2015) The effectiveness of current institutional support for farmers.

10.2.3 Presentations

Glen, M., Francis, A. & Mohammed, C. 2011. *Ganoderma* (and rust). Invited talk. Innovation in Urban Ecological Management Conference, Arboriculture Australia, 1st-2nd March, 2011 Brisbane

Greenhill, M. & Walker, I. (2015). Institutional support for small tree growers in Gunung Kidul, Indonesia. Abstract submitted to smallscale forestry confrerence.

Inail, M.A., Hardiyanto, E.B., Mendham, D.S. (2015). Nutrient management of *Eucalyptus pellita* plantations after two rotations of *Acacia mangium* in South Sumatra. Abstract submitted to the IUFRO *Eucalyptus* 2015 conference.

Narwari, A., Hardie, M. A., Mohammed, C., Mendham, D., Glen, M., Periasamy, M. P. & Sharma, M. 2014. Contribution of spatial analysis to understanding mortality in *Acacia mangium* in Central Sumatra. 8th Australasian Soilborne Diseases Symposium, Hobart, Tasmania, 10-13 November 2014.

Puspitasari, D., Glen, M. & Mohammed, C. 2014. Screening basidiomycete fungi as potential biocontrol agents against root-rot disease. Proceedings of IUFRO International Conference “Acacia 2014 - Sustaining the Future of *Acacia* Plantation Forestry", 2014 March 18-21, 2014. Hue, Vietnam

Sjarkowi, F. 2013. Ekologika Pembangunan dan Rekayasa Sosio-Antropologis Agro-Ekosistem Lahan Pangan (= Ecological Development & Socio-Anthropological Arrangement for Food Land Agroecosystem). Keynote Paper. Presented in National Conference & 7th National Seminar on Land Conservation; Hosted by Indonesian Community on Land Conservation of South Sumatra; attended by 600 participants from all over Indonesia; 6-8 November 2013.

Sjarkowi, F. 2014. Determinan Kelola Efektif SUPK di Kawasan Taman Nasional Bukit Barisan Tenggamus Lampung (Effective Management Determinant of SFMU (social forestry management unit) at Bukit Barisan National Park in Tenggamus Lampong. Paper presented at National Meeting of Indonesian Community of Forest Management; hosted by University of Hasanuddin, Makassar (South Sulawesi) 4-5 September 2014.

Wibisono, M.G., Rustam, L.O., Mendham, D.S., Hardiyanto, E.B. (2015) Decline in soil net nitrogen mineralization under *Eucalyptus pellita* after *Acacia mangium* in South Sumatra, Indonesia. Abstract submitted to the IUFRO *Eucalyptus* 2015 conference.