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Maximising productivity and profitability of Eucalypts and Acacias in Indonesia and Vietnam

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2 Executive summary

Acacia and eucalypt plantations are an important source of sustainably produced wood for the pulp mills of Sumatra, as well as income for smallholder farmers in Indonesia and Vietnam. Smallholders can grow acacias for pulpwood in both countries, but there is interest in the potential for growing acacias to produce sawlogs. Disease pressures in Sumatra on the industrial acacia resource have resulted in a rapid transition from *Acacia mangium* to *Eucalyptus pellita* in most of the core growing areas, and the need to understand the changes in site and resource requirements of the eucalypts that are being established after several rotations of *A. mangium*. This project aimed to develop the new knowledge and to build capacity that would support improved and increased supply of plantation wood from industrial plantations. It also sought to improve the lives and livelihoods of communities and smallholder farmers in Indonesia and Vietnam through the development, and adoption, of best practice management of fast growing eucalypt and acacia plantations. This was achieved through an integrated approach comprising the following activities:

Improving the site selection and management of E. pellita plantations, responded to reports that *E. pellita* plantations were performing poorly compared to acacias at many sites, and that site selection was more critical for eucalypts than acacias. We found in fact that *E. pellita* is reasonably plastic in its site requirements, but that it is more sensitive to management, particularly weed control, during the 1-2 years after establishment. As genetic selection was still at an early stage of development, and high performing genotypes were still being identified and deployed, a number of genotype x site interaction experiments were established to better understand if there is any specificity to site for different genetics. These experiments have demonstrated that there are no significant genotype x environment interactions, so productive genotypes are productive across the site range.

Development of an appropriate soil management strategy for eucalypts was established with the intention of understanding the effects of changing from an N-fixing (acacia) to non-N-fixing (eucalypt) species. We explored the changes in N cycling and the requirement for additional fertilizer inputs of *E. pellita* compared to acacias. A key outcome was that eucalypt plantations to date do not appear to have any requirement for additional nitrogen, with the previous rotations of acacias having built up the soil N supplies such that they are adequate for the eucalypts now. However, as soil N mineralization is declining over time, the responsiveness of *E. pellita* to exogenous N needs to be monitored into the future. A second outcome is that *E. pellita* is highly responsive to P applied at establishment, and that its demand for P appears to be slightly higher than that of *A. mangium*. In addition, export of cations, particularly K, in the products is high, and this also needs to be monitored into the future.

Improving the management options for eucalypt and acacia plantations was focussed on understanding options for farmers to receive higher returns from their plantations in both Vietnam and Indonesia. We maintained several experiments in both Vietnam and Indonesia through to end of rotation age to explore wood quality (under a range of thinning and fertilizer treatments) and economic value of the management options. Key findings from the wood quality study were that *Acacia auriculiformis* tends to have higher quality wood (it is stiffer, stronger, and more durable) than *Acacia* hybrid, but *A.* hybrid timber is still relatively high quality for its age. Thinning marginally improved the timber quality for *A. auriculiformis*, but not noticeably for *A*. hybrid. Interestingly, a thinning operation at age 3 years was found to strongly improve economic outcomes, irrespective of whether the trees were harvested at any age between 4 and 8 years. Of the *A*. hybrid rotation options, the highest internal rate of return (18%) was achieved with a thinned rotation harvested at age 6 years. Retaining *A. auriculiformis* until age 10 years was found to have internal rates of return of 23% for *A*. hybrid and 24% for *A. auriculiformis*.

Improving pathways to adoption and diffusion through a better understanding of conditions that influence effective farmer investment in forestry explored the uptake and adoption of project outcomes with key stakeholders, including farmers in both Vietnam and Indonesia. The mental models of smallholder acacia growers were compared with those of scientists and experts, to help the project team to better fit our project outputs and outcomes with the existing farmer expectations. A fully controlled study in Vietnam explored the intention of farmers to adopt best practices when they were trained using different styles: a more traditional scientist to farmer lecture-style approach, and a training style that brought scientists and farmers together to actively share each other's understanding of the system, and learn about the ways that farmers could improve their plantation productivity in a manner that extends their current mental model, rather than replaces it. We found that farmers were keen to learn and so either training method appeared to positively increase their application of best practice compared to an untrained control group. In Indonesia, farmers were divided into 3 groups: those given both formal training and seedlings, those given seedlings (with informal training) only, and those who were given neither training nor seedlings. Both the formal training and the supply of seedlings with informal training significantly increased the farmer intention to use best practice in their acacia growing compared to the control group.

Many stakeholders were engaged throughout the project to raise awareness of the outcomes and increase the adoption of project outcomes. These included through the following mechanisms:

- Training and field days with over 160 farmers in Vietnam and 100 farmers in Gunungkidul, Indonesia
- Training of around 20 extension officers in each of Vietnam and Indonesia
- Workshops with over 100 company leaders and managers in Sumatra
- Training of at least 4 PhD students
- Engagement with policy makers in Vietnam and Indonesia

In summary, the project substantially increased the knowledge-base of eucalypt and acacia systems in Indonesia and Vietnam, including both the biophysical management and also the adoption by growers. Awareness of acacias and their best practice management options has been raised directly in many groups of farmers in both countries, and we are already seeing diffusion of the project outcomes leading to adoption amongst other groups of farmers who were not directly involved in the work.

3 Background

After a long period of deforestation in Indonesia and Vietnam, plantation areas in both countries have been expanding (FAO, 2010), supported by government policies and programs. As of project inception there were around 1.1M ha of *Acacia* and *Eucalyptus* plantations in Indonesia and 1.3M ha in Vietnam (Harwood and Nambiar, 2014). Some 70-80% of this area was currently under acacias. Around 50-70% of the acacia plantations in Vietnam are grown by smallholders and provide substantial incomes to families and regional economies (Byron, 2014). In contrast, most of the acacia and eucalypt plantations in Indonesia are grown by companies, or their smallholder outgrowers. There is an additional 1.5 M ha of smallholder farm forestry in Indonesia, mostly in Java, with a number of species, including around 20 000 ha of acacias grown for sawn timber production, mainly in Yogyakarta and East Java (including Madura island). Acacias are the most important plantation species in regions such as the Pacitan District of East Java and in some areas in Gunungkidul of Yogyakarta (e.g. Jepitu Village in Girisubo Sub-district, Gunungkidul), mainly because other species (such as teak) do not perform as well in the local soil types.

ACIAR has supported research on domestication and management of *Eucalyptus* and *Acacia* in both Indonesia (Lindner, 2011) and Vietnam (Fisher and Gordon, 2007) for over 20 years and the technologies developed through this program have been widely adopted by smallholders, government and private sector growers. Acacias are widely adopted because of their rapid growth rates, high quality for pulping and sawing, and adaptability to many site types. Harwood and Nambiar (2014) identified two main disease threats to the sustainability of these plantations in southeast Asia, with root rot (*Ganoderma*) a major problem earlier, and then from around 2010 the *Ceratocystis* fungal wilt started to deeply impact on *Acacia* plantation viability. *Ceratocystis* poses a greater immediate threat because it is spread by a range of vectors, including monkeys and insects, while *Ganoderma* spreads relatively slowly from root contact or movement of contaminated soil. In Sumatra these two diseases have forced major growers to mostly replace *Acacia mangium* with *Eucalyptus pellita*. There is a significant concern that disease could threaten the productivity of acacia plantations in other parts of Indonesia and in Vietnam.

Eucalypts have demonstrated a potential for high growth rates and good wood properties. However, they are less productive than acacia at many sites: In the absence of disease, acacia growth rates in Sumatra were reported (Harwood and Nambiar, 2014) to average 22-35 m^3/ha/y, while *E. pellita* averaged only 16-18 m^3/ha/y. In addition, little was known about the site-management requirements of eucalypts (which are not N fixers like acacias) under humid and semi humid environments in Sumatra and Vietnam (Nambiar et al, 2015). Harwood and Nambiar (2014) found that 30% of *E. pellita* inventory plots in Sumatra had MAI below 10 m^3/ha/y, while only 10% were above 30 m^3/ha/y. If the reasons for the gap between actual and potential productivity are quantified it may be possible to improve productivity at many sites. Harwood and Nambiar also identified several key areas for research to ensure sustained production of tropical eucalypts, including managing the nitrogen cycle efficiently, conserving site organic matter and nutrients and judicious fertilizer use, weed control, and breeding for improved disease resistance.

Demand for wood from these plantations is increasing, driven by the large installed pulp production capacity in Sumatra, Japan and China and the smaller but more numerous sawmills and furniture production factories in Vietnam and Java. Both Indonesia and Vietnam also enjoy strong export markets for wood products, and both countries have severe constraints in accessing new land for forestry. Therefore, maintaining and increasing productivity and profitability of the existing plantations is an imperative for ensuring wood supply to the downstream processing and for promoting regional development. Additionally, shortfalls in wood supply from plantations poses a risk of returning to over-exploitation of natural forest resources.

Variations in the pattern of adoption and diffusion of acacia in different regions of Indonesia had been found in a previous project, ACIAR FST/2009/051, with farmers in some regions benefiting more from acacias than farmers in other regions. For example, acacias are an important source of family income for many farmers in Gunungkidul, and some parts of East Java especially for meeting large expenses due to sickness, a family wedding, or education. Although acacia was introduced to the region in the 1960s, farmers' knowledge of acacias and management are still limited. There is minimal management and often poor quality planting stock is used, and hence benefits are lower than they could be. Income from acacias and eucalypts and other social benefits were equally important to farmers who have entered into partnership with timber companies. However, there is generally a low proportion of farmers in these areas who grow acacias and eucalypts independently, even though economic returns from independently grown plantations can be higher.

As part of the socio-economic analysis of the impacts of acacia and eucalypt forestry, it was therefore important for the present study to identify and analyse social enablers and barriers to their adoption by small landholders. The contrasts in the legal, economic, social and cultural institutions between Indonesia and Vietnam are crucial to understanding the adoption and diffusion of acacia/eucalypts and their management practices. Integral to the study was the understanding of existing social networks in both countries. The importance of social networks as a type of farmers' social capital has been well highlighted in past research. Social pressure, or fear of being left out, was one of the drivers for the initial plantings of acacias through partnerships (Kallio, 2013). Existing social relationships were also reported to influence people's economic opportunities to engage in work in acacia plantations (Tyynela et al., 2003). In Gunungkidul and East Java, there are informal social arrangements between growers, brokers and processors to sell trees. Previous research had noted significant informal network relationships in the region. Growers could sell trees to anyone (e.g. a family member or next-door neighbour) who could act as a broker to the local processor. This network works efficiently in Gunungkidul allowing individuals to sell trees easily and thereby increasing the adoption of acacia trees in the region. The extent to which these types of networks can facilitate in the adoption of acacia management practices was not yet known.

Thus there was a need for research to ensure that growers who choose to adopt short rotation plantations have access to suitable information to maximise the productivity of eucalypt plantations, and that smallholders are able to receive and adopt this information. ACIAR[1] had identified country priorities of enhancing livelihoods from forestry products and services for Indonesia, and for advancement towards higher value plantation forestry products in Vietnam. This research addressed both of these priorities by focusing on enhancing regional wealth and livelihoods from forestry products and services, and through generating knowledge on how to enhance value from plantation resources.

[1] *ACIAR Annual Operational Plan 2014/15*

4 Objectives

The aim of this project was to improve productivity and profitability of short rotation *Eucalyptus* and *Acacia* plantations in Indonesia and Vietnam, and to ensure that growers are aware of the comparative benefits and limitations of these two genera. The profitability of higher value products (such as saw- and veneer logs) was also explored as an option to benefit growers. The project consisted of four linked objectives as follows:

Objective 1. Improving the site selection for new Eucalyptus plantations.

Activities in this objective included:

1.1 A review of tropical *Eucalyptus* performance and response to site and soil conditions

1.2 Collection and collation of existing eucalyptus plantation information, from permanent sample plots, inventory, and/or available experimental data

1.3 Development of empirical models to relate site/soil characteristics to *Eucalyptus* productivity, and synthesis into simple guidelines for assisting in site selection.

Objective 2. Developing an appropriate soil management strategy for eucalypts, including managing the nitrogen economy.

Activities in this objective included:

2.1 Establishment and maintenance of up to 4 experiments in Sumatra to explore the response to N and P fertilizer at mid rotation.

2.2 Monitoring of soil nitrogen cycling dynamics at 2 key sites on an annual basis

2.3 Re-treatment and maintenance of up to 2 existing core experiments in Sumatra up to rotation age (age 6)

2.4 Development of site and soil management guidelines for farmers

Objective 3. Improving the management options for eucalypt and acacia plantations.

Activities in this objective included:

3.1 Establishment and maintenance of up to 6 new experiments in Java, South Vietnam and North Vietnam with thinning and fertilizer treatments.

3.2 Maintenance of key high value thinning experiments through to the end of the rotation.

3.3 Modelling and economic analysis of different land use options and plantations for higher value products and/or pulpwood.

Objective 4. Improving pathways to adoption and diffusion through a better understanding of conditions that influence effective farmer investment in forestry.

Activities in this objective included:

4.1 Development of training program and user friendly information sheets about growing acacia/eucalypts to suit local growers;

4.2 Implementation of training and evaluation programs with local extension officers and acacia/eucalypt growers to improve farmer livelihoods;

4.3 Analysing existing social capital, through a network survey to identify points of strong social capital that can be leveraged and network gaps that are impediments to improved return from forestry

4.4 Improving the capacity of women to benefit more from plantations

4.5 Preparation of policy briefs based on social study outcomes

4.6 Collation and synthesis of project outcomes into a full technical report.

5 Methodology

The methods used to deliver on each of the objectives were as follows:

Objective 1: Improving the site selection for new Eucalyptus plantations.

Activity 1.1 – Review of tropical Eucalyptus performance and response to site and soil conditions

Available information, including published articles/reports, grey literature/reports and existing grower experience were reviewed and synthesised to give a better understanding of the site and soil conditions that are related with tropical *Eucalyptus* productivity potential. This included discussions with key growers who have had experience with eucalypts, focused on Indonesia, but also included relevant experience in Vietnam and elsewhere.

Activity 1.2 – Collection and collation of existing eucalyptus plantation information, from permanent sample plots, inventory, and/or available experimental data.

The original plan was to collate existing information on eucalyptus plantations from a range of tropical environments, but company IP sensitivity around data sharing resulted in a change of approach to a more focussed study exploring relationships between plantation productivity and site-based soil information from co-located soil pits and productivity measures, along with relevant soil descriptions and chemical and physical analyses. This approach has the advantage of being able to directly relate the site and soil conditions at known points in the landscape.

Activity 1.3 – Development of empirical models to relate site/soil characteristics to eucalyptus productivity, and synthesis into simple guidelines for assisting in site selection

The information from Activity 1.1 and database developed in Activity 1.2 were synthesised to explore key trends and predictive relationships between site and soil characteristics and productivity information, using both qualitative and quantitative (including regression and multiple regression) approaches. A set of guidelines was produced to assist with site selection. This will be integrated with our existing knowledge of *Acacia* site selection to make best estimates of the suitability and potential productivity of sites for both *Acacia* and *Eucalyptus*.

Objective 2: Developing an appropriate soil management strategy for eucalypts, including managing the nitrogen economy

Activity 2.1 – Establishment and maintenance of up to 4 new experiments in Sumatra to explore the response to N and P fertilizer at mid rotation.

Experiments were established at a range of sites with different productivity potential. The experimental treatments were broadened to include management options other than mid-rotation fertilizer because this was identified as likely being of lower importance to maintaining productivity than earlier thought. Experimental treatments as well as mid-rotation fertilizer included weed control, coppice x seedling x nutrition, and alternative species and mixtures of acacias and eucalypts. Experiments were monitored at annual intervals for productivity and response to treatments.

Activity 2.2 – Monitoring of soil nitrogen cycling dynamics at 2 key sites on an annual basis

Soil nitrogen cycling dynamics were assessed at 4 sites in South Sumatra. Soils were sampled pre-harvest in August 2016, and then sampled annually from 2017-2019 towards the end of the wet season when soil moisture was non-limiting, so that the trends in N mineralization potential could be assessed over time. The upper 0-10 cm of soil was sampled for incubation and analysis.

Activity 2.3 – Re-treatment and maintenance of up to 2 existing core experiments in Sumatra up to rotation age (age 6)

Two existing experiments in South Sumatra and one in Riau were maintained through to end of harvest. These experiments were established in 2011 (South Sumatra) and 2012 (Riau), so around 3-4 years old at the beginning of the project. The N fertilizer treatments were reimposed at one treatment within the core and satellite sites in South Sumatra, and growth responses monitored to harvest age. These experiments were used as demonstration sites for company managers and extension officers.

Activity 2.4 – Development of site and soil management guidelines for farmers

Information from Activities 1-3 were integrated into a set of guidelines for site and soil management, for application by farmers.

Objective 3: Improving the management options for eucalypt and acacia plantations.

Activity 3.1 – Establishment and maintenance of up to 6 new experiments in Java, South Vietnam and North Vietnam with thinning and fertilizer treatments.

Experiments were established to explore the gaps in knowledge around optimising thinning and nutrition for maximising stand value. Experiments included:

- One site in Northern Vietnam (Hoa Binh, research station land), demonstrating pulpwood vs sawlog regime options for farmers
- One site in Central Vietnam (Hue, farmer land), demonstrating thinning options and the growth/productivity of *A. auriculiformis* vs *A*. hybrid. This was the first introduction of *A. auriculiformis* to Central Vietnam.
- Two sites in South Vietnam (research station land), exploring thinning at age 3 in *A. auriculiformis* and *A*. hybrid.
- Two sites in Gunungkidul regency (farmer land), demonstrating a sawlog regime

The sites were generally laid out in a demonstration format, with the exception of the South Vietnam sites, which are laid out in more of a designed experiment, to address the known gaps in knowledge around later and less intensive thinning.

Activity 3.2 – Maintenance of key high value thinning experiments through to the end of the rotation

Several experiments and demonstration trials that had been established through previous ACIAR projects in Indonesia and Vietnam were retained through to harvest. These included:

Indonesia

- Subanjeriji (*A. mangium* and *E. pellita*, core and satellite experiments)
- Gunungkidul – Experiment at Playen, demonstrating *A. auriculiformis* growth and productivity under a thinned regime

Vietnam

- Tuyen Quang (*A. mangium* and *A*. hybrid). This site was selected originally for retention, but damage because of flooding from an adjacent holding lake led the owner (Anh Hoa) to salvage harvest this plantation in late 2016, before we could properly assess it.
- The Phu Binh site (South Vietnam) was maintained through to harvest age, and was the subject of a wood quality study and economic analysis (see below).

Activity 3.3 – Modelling and economic analysis of different land use options and plantations for higher value products and/or pulpwood

The experimental outcomes from Activities 1 and 2 were synthesised to develop a quantitative understanding of the biophysical relationships between thinning time and intensity on sawlog yield, and the results from the experiment were the subject of an economic analysis where we explored cash flow, labour requirements, and internal rates of return for different management options. The inputs to the analysis will include input costs (site preparation, labour, fertilizer, herbicide), and values for different log sizes and markets collected by project staff within each region.

Objective 4: Improving pathways to adoption and diffusion through a better understanding of conditions that influence effective farmer investment in forestry.

Activity 4.1 – Development of training program and user friendly information sheets about growing acacias/eucalypts to suit local growers

The acacia growers manual arising from FST2009/051 contained extensive information to help growers to effectively manage their acacia trees for both short and long-term rotations. To make this information more accessible to farmers, information sheets with illustrations and brief but crucial details about effective silviculture management were developed, in partnership with a training program to firstly educate extension officers and then enable extension officers to educate small holders. The program and information sheets were piloted with extension officers and local growers in Indonesia.

Activity 4.2 – Implementation of training and evaluation programs with local extension officers and acacia/eucalypt growers to improve farmer livelihoods.

This activity aimed to find effective ways to diffuse best practice acacia/eucalypt management practices in different regions. The study tested two adoption methods (hereafter referred to as ‘interventions’) in Indonesia and one in Vietnam. The first intervention involved the extension of best practices through a traditional one-directional mechanism (researchers to farmers). The second intervention explored the use of an active learning approach where we looked at understanding the current practices and how we can integrate best practices into current practices, through engaging researchers and farmers together to solve a common problem.

For both interventions, the adoption intentions of farmers were explored through evaluation surveys pre-training, post-training, and at 6 months after training.

Activity 4.3 – Analysing existing social capital, through a network survey to identify points of strong social capital that can be leveraged and network gaps that are impediments to improved return from forestry

The focus of this activity was changed (as agreed at the mid-term review) to better explore the mental models of farmers. Mental model workshops were carried out in January 2017 to understand farmer existing livelihood strategies, and how they manage their *Acacia* plantations.

Activity 4.4 – Improving the capacity of women to benefit more from plantations;

We explored the different roles of men and women in acacia and eucalypt farming, assessing the importance of acacia or eucalypt income to household and village livelihoods, and assessing the differential distribution of costs and benefits from farming on men and women. We explored the possibility of establishing small businesses for women around nursery culture and seedling distribution, and we worked with a women famer group in Namberan, Gunungkidul, to establish demonstration plots of genetically improved ‘straight acacias.’

Activity 4.5 – Preparation of policy briefs based on social study outcomes

As there are many components to the project, key findings were synthesised into policy briefs to convey important messages to stakeholders in Vietnam and Indonesia, including relevant government departments.

Activity 4.6 – Collation and synthesis of project outcomes into a full technical report

The project experiments, activities and outcomes have been written into a range of technical reports, manuscripts and journal articles.

6 Achievements against activities and outputs/milestones

6.1.1 Objective 1: Improving the site selection for new Eucalyptus plantations

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
1.1	Review of tropical *Eucalyptus* performance and response to site and soil conditions	Literature and data collected and collated	May 2016	Achieved on time. All relevant literature was collated and collected.
		Review of eucalypt productivity in relation to site, soil and climate completed and uploaded to project website	June 2016	An ACIAR special edition paper was published, but the manuscript was extensively modified in light of associate editor comments, and the focus was drawn back to being on acacias. Instead the key learnings from the review for eucalypts are presented as an appendix to this report (Appendix 1).
1.2	Collection and collation of existing eucalyptus plantation information, from permanent sample plots, inventory, and/or available experimental data	Database of: • available industry data • DEM • Available soil information	May 2017	The design of this activity was adjusted slightly to focus on a smaller number of sites that are characterised in more detail. This was to overcome the IP issues that became problematic when discussing sharing of broad scale industry information.
		Estate stratified and soil and/or stand assessment conducted at selected subset of sites	Feb 2018	May 2018: Preliminary results from this study suggested that factors other than site variability were driving *E. pellita* productivity across the landscape. These factors include management and genotype, and have resulted in the establishment of the clone x site series of experiments noted as an additional set of experiments in Activity 2.1.
1.3	Development of empirical models to relate site/soil characteristics to eucalyptus productivity, and synthesis into simple guidelines for assisting in site selection	Report on geospatial analysis outcomes and relationships between productivity and site/management variables	September 2018 Revised May 2019	A study into the relationships between soil characteristics and *E. pellita* productivity at age 3 was completed and the report written as presented at the final review.

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
		Site selection methodology fact sheet available and published on project website. Workshop with industry managers and/or extension staff	December 2018	The site selection methodology fact sheet was written and uploaded to the project website.

6.1.2 Objective 2: Developing an appropriate soil management strategy for eucalypts, including managing the nitrogen economy

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
2.1	Establishment and maintenance of up to 4 experiments in Sumatra to explore the response to N and P fertilizer at mid rotation	Suitable sites selected and set up. Initial pre-treatment site measure.	September 2015	Site selection occurred in stages, depending on the partner. Progress was as follows: • In South Sumatra, with MHP, we selected and established 2 mid-rotation management experiments Other experimental priorities emerged from the conclusion of the previous project, and were decided on during the inception workshop as having a higher priority and likelihood of impact than establishment of more mid-rotation fertilizer experiments. These included • Also in South Sumatra, another experiment was established to explore establishment method (coppice or seedling) x nutrients. • A series of experiments were established in Riau and South Sumatra (all companies) to explore the genotype x environment effects to better understand the plasticity of clone to site • RAPP established two experiments to better understand whether the apparent rapid loss in leaf area and reduced growth rate at canopy closure is related to water and/or nutrient constraints. • RAPP explored the opportunity for *A. crassicarpa* as a dryland species as part of the succession strategy either after eucalypts or after *Acacia mangium*. • RAPP established an experiment to understand the benefits of eucalypts and acacias in a mixture. Originally this was designed to study the benefits of wildling recruitment, but the wildlings are also susceptible to *Ceratocystis*, so the focus has

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
				changed to explore mixtures of *A. crassicarpa* and eucalpyts
		N and P rate treatments applied	January 2016	Completed
		Sites maintained to high standard	ongoing	Completed
		Annual productivity assessment	April 2016, April 2017, April 2018, April 2019	Measurements occurred on an annual basis, depending on establishment time of each experiment.
		Report on mid-rotation responses to fertilizer	June 2019	Responses in experiments in South Sumatra were written into a report, and summarised in Section 7 below.
2.2	Monitoring of soil nitrogen cycling dynamics at 2 key sites on an annual basis	Suitable sites selected	September 2015	4 sites were selected in South Sumatra.
		Soils sampled and analysed for N mineralization annually	Jan 2016, Jan 2017, Jan 2018, Jan 2019	Soils were sampled in August 2016 (pre harvest) and annually through to 2019.
		Progress report on N cycling studies	March 2017	Progress report was delivered at the mid-term review
		Manuscript/ report on N cycling dynamics	May 2019	The field work on the N cycling study was completed by Gunawan Wibisono and was reported on at the final review, and summarised in Section 7 below.
2.3	Re-treatment and maintenance of up to 2 existing core experiments in Sumatra up to rotation age (age 6)	Audit of experimental resources available, experiments chosen for focus. Treatments finalised.	August 2015	• In South Sumatra, an additional 80 kg of N was applied to the N40 treatment in January 2016. This was done in both the Core and Satellite experiments, to bring the total application up to 120 kg/ha. This is equivalent to the highest N rate that was applied at establishment of 120 kg N/ha. • The same approach is being adopted at the Lipat Kain experiment in Riau with Sinarmas. • The Teso East site (RAPP) was established prior to the others, and so was due for harvest imminently, thus was not selected for re-treatment • The ex-CIFOR site management experiment of RAPP was chosen as a test site to explore the response of E. hybrid to additional nutrition at 18 and 30 months.
		Stand assessment annually to harvest date	Annual measureme nt, on	Assessments are completed for the project, but continuing on retained experiments

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
			original schedule	
		Pre-harvest measure	Timing dependent on experiment age	Completed
		Report on productivity to end of rotation	June 2018	Update May 2018: The end of rotation productivity has been reported on for MHP (May 2018), and a manuscript on the Teso E experiment has been drafted. November 2019: End of rotation productivity has been written into a report and manuscripts, as presented to the final review.
2.4	Development of site and soil management guidelines for farmers	Manuscript/Report on optimal site management strategies for *Eucalyptus pellita* in Sumatra. Site and soil management guidelines/fact sheet released and uploaded onto project website	May 2019	June 2019: Site and soil management guidelines have been written into a manuscript has been published in Southern Forests. Manuscripts by Bich et al. also report on optimal management strategies. The site and soil management guidelines for *E. pellita* fact sheet is complete and available on the project website.
		Workshop with industry managers and/or extension staff	June 2019	November 2019: A workshop was held in Subanjeriji with around 50 PT MHP operational managers in February 2019.

6.1.3 Objective 3: Improving the value of eucalypt and acacia plantations

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
3.1	Establishment and maintenance of up to 6 new experiments in Java, South Vietnam and North Vietnam with thinning and fertilizer treatments.	Suitable sites selected. Treatments finalised. Experiments laid out and pre-treatment measures taken. The focus will be on acacias in Indonesia and Vietnam.	September 2015	Sites have been selected in the following locations: • 1 site in Northern Vietnam (Hoa Binh, research station land) • 1 site in central Vietnam (Hue, farmer land) • 2 sites in South Vietnam (research station land) • 2 sites in Gunungkidul regency (farmer land) The sites were generally laid out in a demonstration format, with the exception of the South Vietnam sites, which were laid out in more of a designed experiment, to address the known gaps in knowledge around later and less intensive thinning.

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
		Thinning and fertilizer treatments established: thinning to 1000, 800, 600 stems/ha at around age 3, with 3 x P and 2 x N fertilizer rates.	March 2016, revised to June 2016	The thinning and fertilizer treatments were modified depending on priorities within each region.
		Experiments maintained to high standard	Ongoing	Completed
		Annual measurement of stand	April 2017, April 2018, April 2019	Measured as per schedule. Note that month of measurement varied, depending on location
		Report on thinning and fertilizer effects on tree diameter, height and standing volume	May 2019	Reports were written for Vietnam, and the Karangmojo demonstration plot (Gunungkidul) as part of the Hardiyanto and Inail report (as presented at final review). The Playen experiment was also written into a report (Fauzi et al.), which was also presented at the final review.
3.2	Maintenance of key high value thinning experiments through to the end of the rotation	Audit of experimental resources available, experiments chosen to retain. Treatments finalised.	August 2015	Completed. The following sites established in the previous project were retained through to harvest: *Indonesia* • Subanjeriji (*A. mangium* and *E. pellita*) • Gunungkidul – Experiment at Playen, demonstrating A. auriculiformis growth and productivity under a thinned regime *Vietnam* • The Phu Binh site (South Vietnam) has been selected to replace Tuyen Quang (*A.* hybrid and *A. auriculiformis*). This site is a good choice, as the site has been intensively studied through the CIFOR site management experiments, as well as more recently supporting experimentation for Mr Vu Dinh Huong's PhD project.
		Experiments maintained to high standard	ongoing	Site maintenance completed as per plan.
		Annual measurement of stand through to harvest.	Annual measureme nt, on original schedule	Completed. The latest round of measurements at Phu Binh suggest that although responses to thinning are initially greater in *A.* hybrid than *A. auriculiformis*, this may reverse with stand age.
		Pre-harvest measure	When experiments	Completed at all sites

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
			reach suitable age	
		Report on Wood quality assessment of selected trees/treatments	May 2018 Revised to November 2018	David Blackburn (formerly from UTas, and latterly engaged with CSIRO) was engaged on this study. The key questions that we asked were (1) How does wood quality change as plantations age, from age 4/5 (the current harvest age for many plantations) through to age 8-10?, (2) Is wood quality impacted by thinning treatment? And (3) How does *A. hybrid* differ in its wood quality to *A. auriculiformis*. The resources to answer these questions were sourced from experiments in South Vietnam, and the trees were harvested in March 2018. 15 logs were sliced for veneer in South Vietnam, and 105 boards were sent to the Research Institute of Forest Industries (a VAFS sub-centre) in Hanoi. The samples were air dried and assessed for visual grading, oven dry density, Modulus of Elasticity (MOE), Bending strength (Modulus of Rupture - MOR), Tensile strength, Compression strength, Hardness, and Machinability. Reports were written for the study in Vietnam and South Sumatra and presented at the final review, and a manuscript was submitted to Southern Forests Journal.
3.3	Modelling and economic analysis of different land use options and plantations for higher value products and/or pulpwood	Collection of data on input costs and value of products of differing size/quality in each region	Dec 2016 Revised in May 2017 to: December 2017	Relevant data was collected on a trip to Vietnam in November 2017.
		Excel-based tool developed to predict productivity response to thinning at each location	Dec 2018	November 2019: Excel spreadsheet was completed and presented at the final review.
		Report on profitability of different management options for farmers to produce timber and in *Acacia* and *Eucalyptus* plantations. Fact sheet uploaded to web site. Workshop held with extension	May 2019	November 2019: Report on the economics of acacias in Vietnam was completed and presented at the final review. A manuscript was also written and submitted to Southern Forests Journal (review pending). A workshop with extension staff was held in Vietnam on May 29th, 2019, in Hoa Binh and on April 9th, 2019 in Yogyakarta. The economics fact sheet and workshops were completed and delivered in the latter half of 2019.

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
		staff in Java and Vietnam		

6.1.4 Objective 4: Improving pathways to adoption and diffusion through a better understanding of conditions that influence effective farmer investment in forestry.

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
4.1	Development of training program and user friendly information sheets about growing acacia/ eucalypts to suit local growers	Potential participants selected in two Indonesian districts (hereby called Districts 1 & 2), and one district in Vietnam (District 3) following discussions with local partners.	June 2015	The study locations were finalised in both Indonesia and Vietnam. May 2017: This milestone was achieved. Desktop reviews led Obj 4 researchers to conduct preliminary studies to understand the role of forestry in people's livelihood and the current practices adopted by farmers. In particular, a gender analysis was undertaken along with mental model workshops were carried out. These tasks were completed in January 2017. Subsequently, a training program was devised. November 2019 -The *A. auriculiformis* manual for Indonesia was completed and presented at the final review. The Technical information sheets in English and Vietnam were also presented
		Pilot study in Indonesia	August 2015	This activity was completed. A pilot training program was conducted with farmers in April 2017.
4.2	Implementation of training and evaluation programs with local extension officers and acacia/eucalypt growers to improve farmer livelihoods	Baseline questionnaire with social network questions and end-workshop questionnaire developed in English	September 2015 Revised: September/ October 2016	The questionnaire and evaluation program were designed as per the milestone. November 2019: In summary, training and evaluation programs that were developed and delivered by the project were: 1. In Indonesia, formal training #1 in April 2017 with 27 farmers, and training #2 in August 2018 with 59 farmers. We have also distributed over 9000 seedlings to over 100 farmers, each of whom have received either formal or informal training in growing 'straight acacias.' This training was focussed on encouraging adoption of 'straight acacias' and associated enhanced silviculture. This was followed up with a survey of adoption intention in January 2019 to examine the impacts of training program and seedling distribution on adoption of acacia silviculture management practices. 2. In Vietnam, the training programs were focussed on 2

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
				groups, with training conducted in partnership with Chris Beadle and the Crawford Fund. A matrix of training was developed that compared two training methods: a 'traditional' training and 'active learning' training styles. This was implemented at 2 villages in each of Hue and Hoa Binh provinces. Workshops were delivered separately to male and female participants, with 20 participants per training session. The total number of people trained was 2 training styles x 2 provinces x 2 villages x 2 genders x 20 participants = 160 participants (actually 166 due to redundancy in participant selection). Again, these were followed up with a survey of adoption intention to explore differences in the training styles on internalisation of training points. An additional 80 participants were included in the adoption survey as a control (untrained) group.
		Intervention 1: Training of extension officers and growers with baseline and end-workshop surveys in Districts 1 & 3	February 2016 Revised: January 2017 Revised to May/June 2018 in Vietnam, and September 2018 in Indonesia	Pilot training was completed in 3 villages in Gunungkidul in April 2017. The main training interventions were delayed to 2018 to accommodate changes in our thinking about the value of training in management of existing acacias. Thus there was a change in the focus of the initial training from more broad silvicultural training to training in the growing and distribution of high quality seedlings (for 'straight acacias') based on good quality genetic material. Farmers are impressed with the 'straight acacias' produced by the project and are willing to learn how to produce them. To this end, more focus early in the project has been placed on training in seedling raising and distribution, and using the seedlings as demonstration material for farmers. The project team has had a strong push on training in seedling production in the last 12 months, and as a result has produced over 6000 seedlings, and distributed them to around 100 farmers in Gunungkidul. The farmers are being closely monitored and they are being trained by local staff in appropriate management as the seedlings develop. In line with the original thinking regarding silvicultural training, training of extension officers in Vietnam and 160 farmers was conducted in May/June 2018. November 2019: As noted above, 151 farmers in Gunungkidul had seedlings distributed to them, and one of 3 levels of training applied (formal training #1,

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
				and/or formal training #2, or informal training)
		Intervention 2: Training of extension officers and growers with baseline and end-workshop surveys in District 2 plus close monitoring	February 2016 Revised: January 2017	Completed as per revised time schedule
		Report on qualitative and quantitative workshop data including discussion about women's roles Evaluation of Interventions Step 1	June 2016 Revised: June 2017	November 2019: The report on gender roles in Vietnam was combined with the Indonesia data and written into a combined report, which will soon be available on the CSIRO publications repository.
		Evaluation of Interventions Step 2: Follow-up Survey 1 in all Districts	November 2016 Revised: Nov. 2017 Revised: January 2019	Delivered as per revised time schedule Update May 2018: As noted above, this activity had been revised to account for the mental-models-adjusted training. The planned post-training surveys were delayed to January 2019 in Vietnam and March 2019 in Indonesia.
		Evaluation of Interventions Step 3: Follow-up survey 2 in all Districts	July 2017 Revised: July 2018 Revised: March 2019	Delivered as per revised time schedule This was conducted at 6 months post training intervention in January 2019 in Vietnam and March 2019 in Indonesia.
		Evaluation report comparing interventions	November 2017 Revised: Nov 2018 Revised: November 2019	On track for delivery on revised time schedule November 2019: The preliminary report was drafted and presented at the final review. The final report will soon be publicly available on the CSIRO publications repository.
4.3	Analysing existing social capital, through a network survey to identify points of strong social capital that can be leveraged and network gaps that are impediments to improved return from forestry	Social network surveys in Districts 1, 2, & 3 as in Activity 4.2	February 2016 Revised: Jan 2017	Mental model workshops were carried out in January 2017 with surveys with farmers looking at their existing livelihood strategies. Further social network surveys will be carried out after the training to examine how knowledge has been transferred. Social network analysis was included in the survey and write-up of Activity 4.2

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
		Report on social network survey including Analysis of women's position and policy brief	June2016 Revised: June 2017 Revised: December 2018	The social network survey has been focussed on understanding the seedling distribution network for the seedlings that were produced and distributed in the revised Activity 4.2. As agreed at the mid-term review, the social capital analysis was replaced by the mental models study, as this better helped us to explore the critical issues for adoption of acacia technology. The mental model report for Indonesia was completed in 2017, and for Vietnam in April 2018.
4.4	Improving the capacity of women to benefit more from plantations	A participatory workshop with women on farms with input from findings of activity 4.2 & 4.3 plus training program if appropriate	November 2016 Revised: Nov 2017	This task was completed in October 2016 when gender analysis were conducted.
		Plantation training program developed for women	November 2016 Revised: Nov 2018	November 2019 update: We have worked with a group of around 20 women to train them in seedling production and acacia silviculture, with Ibu Sarmi from Namberan village showing a lot of interest and established a demonstration plot of over 1000 trees. Ibu Sarmi is a local farmer leader and is an ambassador for 'straight acacias'.
		Report on the workshop with policy brief	March 2017 Revised: Jan 2018	Completed.
4.5	Preparation of policy briefs based on social study outcomes	Policy briefs prepared in Indonesia and Vietnam	March 2018 Revised May 2019 Revised: November 2019	Delivered. Policy briefs were released in March 2020
		Briefing policy makers about the study findings	May 2018 Revised November 2019	Delivered. Policy briefs were released in March 2020
4.6	Collation and synthesis of project outcomes into a full technical report	Compiled report on project technical findings	June 2019 Revised November 2019	A number of technical reports and publications have arisen from this project (see Section 10.2), such that most of the outputs are publicly available and compilation of a full report would double up and/or prejudice publication of the work. The unpublished material has been summarised in Section 7 (below), and is at various stages of manuscript preparation in preparation for publication.

7 Key results and discussion

7.1 Objective 1. Improving the site selection for new Eucalyptus plantations.

7.1.1 Review of tropical *Eucalyptus* performance and response to site and soil conditions

This review was completed (see Appendix 1). The review was intended to be included as part of a broader chapter in an ACIAR proceedings arising from a previous project (FST/2009/051), but for various reasons this initiative did not receive enough material to be worthy of a stand-alone proceedings.

The premise that *Eucalyptus pellita* is more site specific than *Acacia mangium* was not supported by the review, as was the premise that *E. pellita* has a lower productivity potential. The experience to date probably reflects the earlier stage of breeding and deployment that *E. pellita* is up to, compared to *A. mangium*. Many *E. pellita* plantings have lower volume productivity than *A. mangium*, but this is at least partially offset by the reportedly higher pulp productivity of *E. pellita*.

The review helped the team to realise that the biggest influence on productivity of existing stands was more likely to be the *E. pellita* genotype than site characteristics, and it highlighted a gap in the knowledge around understanding whether different *E. pellita* genotypes responded to site differently. In response to this, an experiment was established to explore site x genotype influences.

7.1.2 Collection and collation of existing eucalyptus plantation information, from permanent sample plots, inventory, and/or available experimental data

The approach to this objective was modified at the mid-term review to focus more on a smaller number of more intensively characterised sites. This was partly in response to industry resistance to releasing their operational data to the broader project, and the fact that early in the project there were few operational plantings available with 2 of the companies.

7.1.3 Development of empirical models to relate site/soil characteristics to eucalyptus productivity, and synthesis into simple guidelines for assisting in site selection

Permanent Sample Plots (PSP's) of *E. pellita*, established by PT Musi Hutan Persada were used in this analysis. The PSPs represented various site conditions from across the company's planting area in South Sumatra. The size of each PSP is 0.05 ha. The company soil map was used to select sites that represented different soil mapping units. In this study we specifically chose to collect growth data from PSPs which were co-located in the same area, or in close proximity to the soil profiles that had been described for the soil mapping exercise. Soil physical and chemical soil properties were available for every soil profile, namely depth to the root impeding layer, bulk density, texture (sand, silt and sand), pH, organic C, N total, extractable P, CEC, and exchangeable cation (K, Ca and Mg). Only growth data for 3 year measurements was used in the analysis to maintain consistency across the dataset.

Soil properties were analysed using Principal Component Analysis (PCA) to reduce the number of variables for soil properties as many are auto-correlated. Soil properties with a range of values were selected and included in the regression analysis. In total 20 PSPs representing a range of site qualities in three regions of the company (8 plots in Subanjeriji, 7 plots in Pendopo and 5 plots in Lagan) were used for the analysis. While there were more than 20 PSPs aged 3 years that met the overall criteria for matched soil and growth data, several needed to be excluded from the analysis because they had poor growth that was largely attributable to improper silvicultural practices, and not due to soil constraints.

Results

Principal component analysis indicated that eigenvalues (λ) 1 - 6 contributed to more than 88% of variability of the soil property (Table 1). The variables with the highest contributions were sand content, cation exchange capacity (CEC), N content, depth of root impeding layer, pH, P content, bulk density and clay content (Table 2). These variables were then included in a regression analysis. Results of the regression analysis showed that depth of root impeding layer, bulk density, N content and sand content were significant, while pH, CEC, P and clay content did not significantly contribute to the regression equation. Therefore these latter soil properties were dropped from the analysis. The derived regression equation explaining the relationship between *E. pellita* productivity and soil properties was as follows:

$$MAI = 27.948 + 0.111DIL - 18.81BD + 0.204Sand + 32.79N \qquad R^2=0.75$$

where MAI = mean annual increment (m^3/ha/yr), DIL= depth of root impeding layer (cm), BD= bulk density (g/cm^3), Sand= sand content (%), N = total nitrogen content (%).

Productivity increased with a deeper root impeding layer, higher sand and higher nitrogen content while increasing soil bulk density decreased the MAI.

Table 1. Eigenvalues and cumulative percentage of variation associated with eigenvalues from principal component analysis

Eigenvalues		Proportion	Cumulative
1	4.3970	0.3382	0.3382
2	2.3582	0.1814	0.5196
3	1.8501	0.1423	0.6620
4	1.2965	0.0997	0.7617
5	1.0343	0.0796	0.8413
6	0.6306	0.0477	0.8890
7	0.5727	0.0441	0.9330
8	0.3844	0.0296	0.9626
9	0.2848	0.0219	0.9845
10	0.1256	0.0097	0.9942
11	0.0427	0.0033	0.9975
12	0.0327	0.0025	1.0000
13	0.0000	0.0000	1.0000

Table 2. Variables from soil properties and the first six eigenvectors from principal component analysis

Variables	Eigenvectors					
	1	2	3	4	5	6
Depth of root impeding layer (cm)	-0.1033	**0.4474**	0.0151	0.0921	0.4631	-0.4412
Bulk density (g/cm^3)	-0.2808	-0.0509	0.0255	**0.4800**	0.0537	0.3311
Clay (%)	0.2801	0.0381	0.0295	**0.6261**	-0.1700	-0.3783
Silt (%)	0.1919	-0.4136	-0.2906	-0.2044	0.3770	0.2192
Sand (%)	**-0.3437**	0.3196	0.2228	-0.2406	-0.2024	0.0655
pH	-0.1834	-0.2394	**0.5369**	-0.1041	0.0556	-0.2819
CEC (cmol/kg)	**0.4067**	-0.1756	0.1371	0.2855	-0.1067	0.0896
Organic C (%)	0.2937	0.3611	0.1419	-0.1899	-0.2570	0.0840
N total (%)	**0.3817**	0.2999	0.0273	-0.1688	-0.0574	0.2357
P (mg/kg)	0.1273	0.0236	**0.6001**	0.1203	0.0553	0.4177
K (mg/kg)	0.1750	-0.1619	0.0320	-0.2836	-0.2136	-0.3795
Ca (mg/kg)	0.1750	0.4325	-0.2601	0.1089	0.2136	0.1714
Mg (mg/kg)	0.2565	-0.0042	0.3270	-0749	0.6250	-0.0453

7.1.4 Additional work in Objective 1

The early work in Objective 1 led us to the understanding that site selection in *E. pellita* was not currently the main limiting factor influencing production. Instead we found that there was much greater need to understand (1) the comparison in productive potential between *E. pellita* and *A. mangium*, (2) the bigger picture around the transition from acacias to eucalypts, and (3) the optimum management of *E. pellita*, including if there was any site x genotype effects that needed to be accounted for. The project team addressed these priorities through preparation of, and contribution to, several manuscripts that explore productivity of acacias and eucalypts under different management and explore the transition from acacias to eucalypts, including:

Hardie M, Akhmad N, Mohammed C, Mendham D, Corkrey R, Gafur A, Siregar S. 2017. Role of site in the mortality and production of *Acacia mangium* plantations in Indonesia. Southern Forests: A Journal of Forest Science 80:37–50

Mendham DS and White DA (2019). A review of nutrient, water and organic matter dynamics of tropical acacias on mineral soils for improved management in SE Asia. Australian Forestry, 82(sup1), pp.45–56.

Nambiar E, Harwood C, Mendham D. 2018. Paths to sustainable wood supply to the pulp and paper industry in Indonesia after diseases have forced a change of species from acacia to eucalypts. Australian Forestry 81:148–161.

Siregar STH, Nambiar EKS, Mendham DS, Untung S, Sahputra I (2019). Comparative productivity of *Acacia mangium* and *Eucalyptus* hybrid under different nutrition management regimes in Riau, Indonesia. Manuscript in preparation.

White DA, Battaglia M, Ren S, Mendham DS. 2016. Water Use and Water Productivity of Eucalyptus Plantations in South-East Asia. ACIAR Technical Reports Series No. 89. Australian Centre for International Agricultural Research, Canberra.

7.2 Objective 2. Developing an appropriate soil management strategy for eucalypts, including managing the nitrogen economy.

Early work during the review phase and in discussion with industry led us to the conclusion that the stand and soil management strategy was likely to be more important than the nitrogen economy, resulting in a range of additional experimentation being established, and slightly less emphasis placed on the N and P economy. A site and stand management network was established among the project partners, with the aim to help the partners to support each other to solve their own site and stand management problems rather than imposing a solution.

7.2.1 Establishment and maintenance of up to 4 experiments in Sumatra to explore the response to N and P fertilizer at mid rotation.

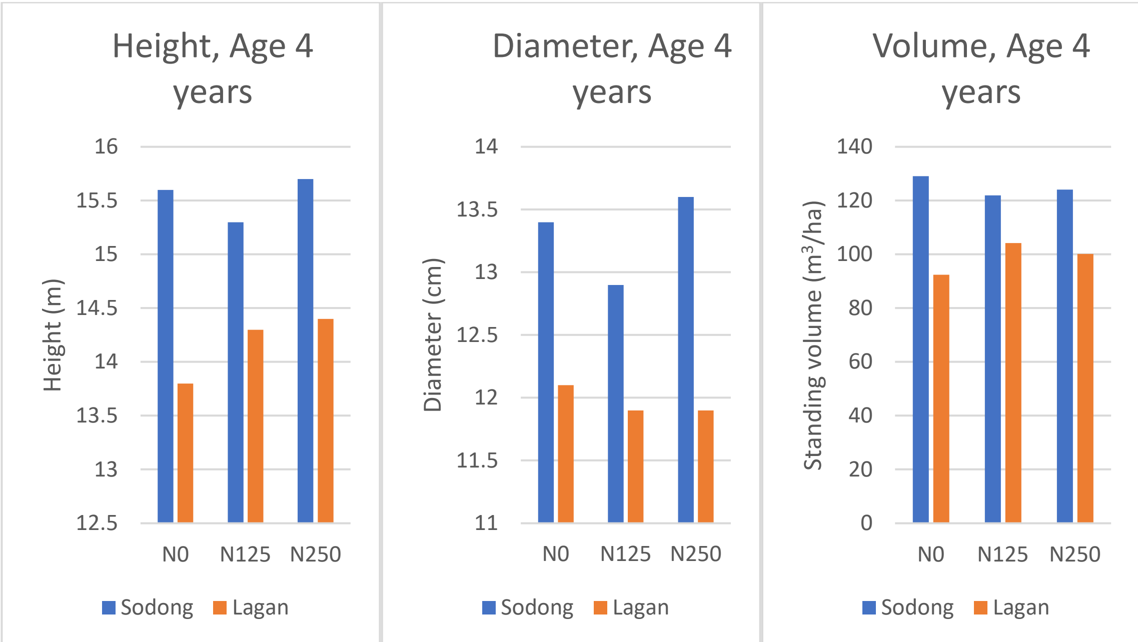
As noted above, the review process resulted in us placing a lesser focus on N and P at mid-rotation, and more focus on other management (see section below), so a total of 3 experiments were established: two experiments in South Sumatra with MHP and one experiment in Riau with APRIL as follows:

South Sumatra

In summary, two experiments were established in South Sumatra (in partnership with MHP) at 2 contrasting sites, Sodong and Lagan. Both sites had previously carried 2.5 rotations of *A. mangium*. Sodong is classed as a good quality site (100-150 cm of soil over an impeding layer), while Lagan is classed as a poor site (impeding layer less than 25 cm below the soil surface). The experiments included a weed control factor to explore the interactions between weed control and N fertilizer response.

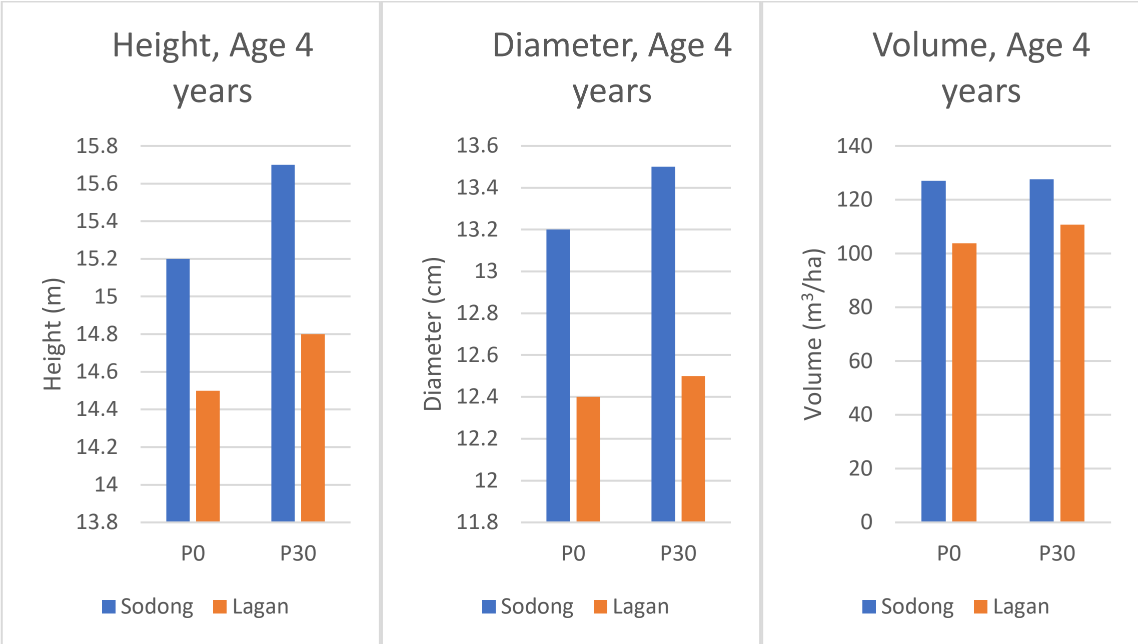
There was no significant response by 4 years in either height, diameter or volume to N or P application at age 9 months (Figs. 1 and 2), though it is worth noting that there was a trend for response to N fertilizer at the lower productivity site for both height and volume.

Fig. 1 – Height and diameter response at age 4 to N fertilizer applied at 9 months at Sodong and Lagan. Note: Differences were not significant.



In this experiment the basal fertilizer was 10 kg P/ha, applied at planting in all plots, and the additional application of P at age 9 months at these sites also did not significantly increase height, diameter or volume at age 4 years, so the recommendation going back to the company is that there is no requirement for P fertilizer beyond the establishment phase.

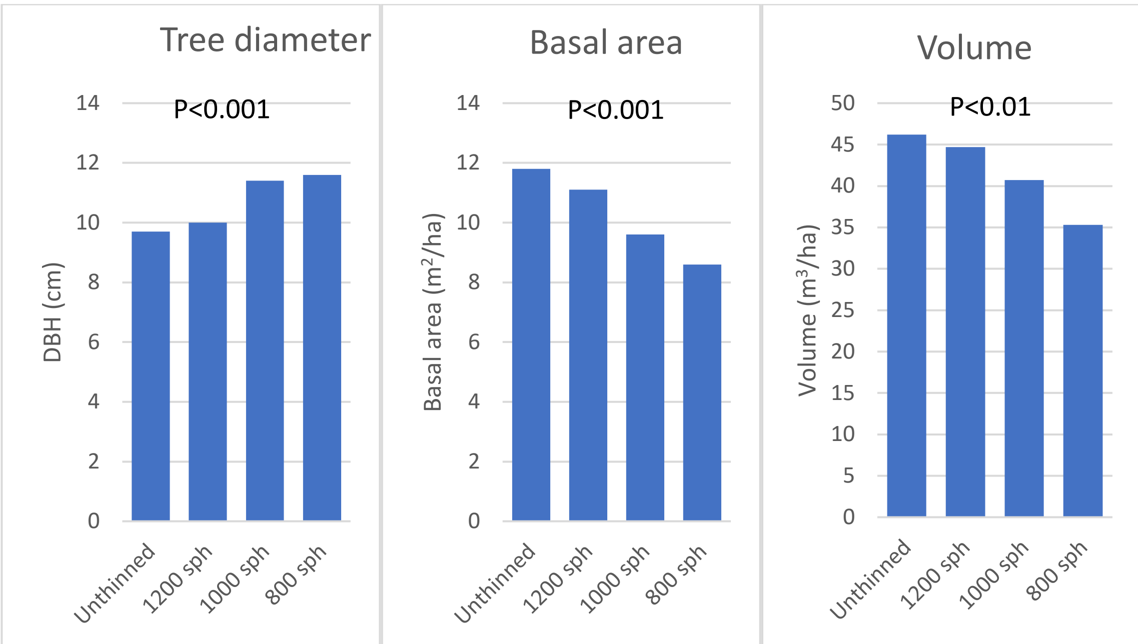
Fig. 2 - Height and diameter response at age 4 to additional P fertilizer applied at 9 months at Sodong and Lagan. Note: Differences were not significant.



Riau

An experiment to help understand the resource constraints at mid-rotation was established in partnership with RAPP at Teso East in Riau. The experiment tested 4 thinning treatments (non-thinned, and thinned to 1200, 1000 and 800 stems/ha) at 16 months. Two fertilizer treatments were overlaid into the design, with no fertilizer, or complete macronutrient fertilizer at 100g ammonium sulfate, 200g of triple superphosphate, 100g of KCl, and 1000g of dolomite per tree. At 14 months after thinning (tree age of 30 months), the thinning treatment had significantly increased height and DBH, but at the cost of lower stand volume (Fig. 3). There was no significant response to fertilizer, or any significant interactions between thinning and fertilizer.

Figure 3 – Response of height, basal area and volume to thinning at age 30 months (16 months after thinning treatment imposed)



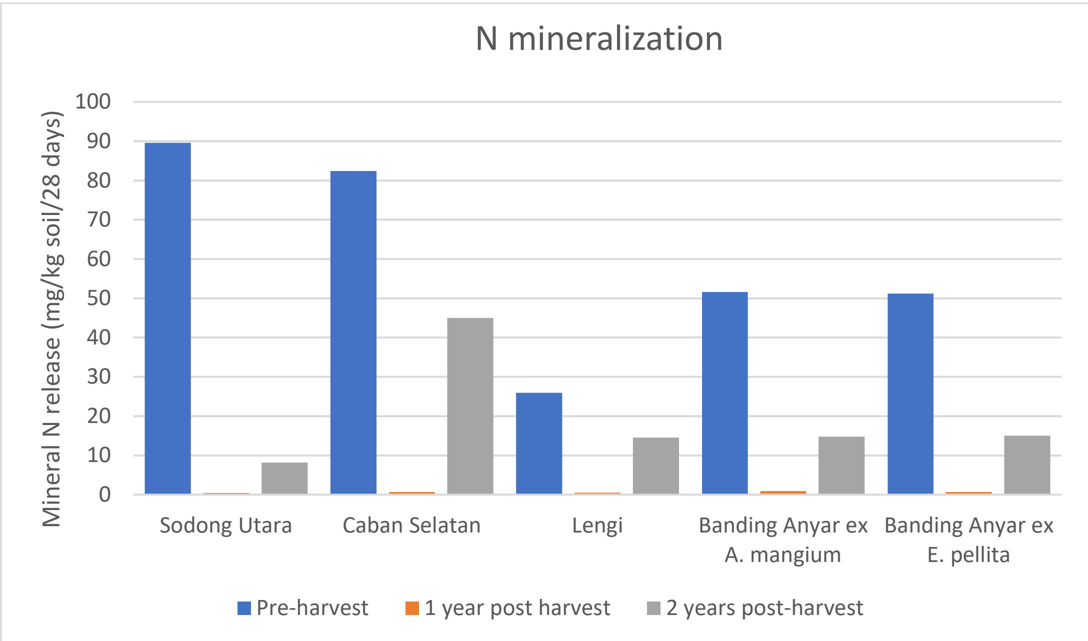
The thinning treatment substantially increased individual tree height and diameter, suggesting that competition effects for light and/or water are the cause of the marked slowdown in volume growth, rather than competition for nutrients. This effect may be more prevalent in eucalypts compared to acacias. The loss of volume during the thinning operation was not likely to be recovered by the end of the pulpwood rotation unless the rotation age is increased.

7.2.2 Monitoring of soil nitrogen cycling dynamics at 2 key sites on an annual basis

Soil N mineralisation dynamics were monitored at 4 ex-*A. mangium* sites in South Sumatra, Sodong Utara, Caban Selatan, Lengi, and Banding Anyar, and 1 ex-*E. pellita* site, also at Banding Anyar. Each site was sampled before harvest in 2016, and annually between 2017 and 2019. A total of 18 cores were collected from each site at each sampling time, in pairs from 9 locations within a 3 m radius of a centre point. The top 10 cm of soil was collected from each site using 50 mm PVC cores. One of each pair was extracted immediately (day 0), while the 2nd core from each pair was incubated at room temperature for 28 days in an aerobic environment before extraction. Samples were extracted with 1N K_2SO_4 after shaking end-over-end for 1 hour.

N mineralization was highest pre-harvest across the 5 sites, and then declined to nearly zero at 1 year after harvest and re-establishment. At 2 years post-harvest, N mineralization rates had increased again, but not back to that of the first measure (Fig. 4). There were no significant differences in N mineralization pattern between the two former plantation species (*A. mangium* or *E. pellita*) at the Banding Anyar site, suggesting that the dynamics of N mineralization were not affected by the previous plantation species. The drop in N mineralization at year 1 is likely to be because N is being utilised in the decomposition of coarse woody debris with a high C:N ratio. As this material is decomposed, more N is released back into the system, as was observed in year 2. It may be that the coarse woody debris harvest residue loads at Sodong Utara were higher than at Caban Selatan. Further monitoring of these sites is required to understand the dynamics of N over time in these systems.

Fig. 4 – N mineralisation rates pre and post harvest across the 5 study sites

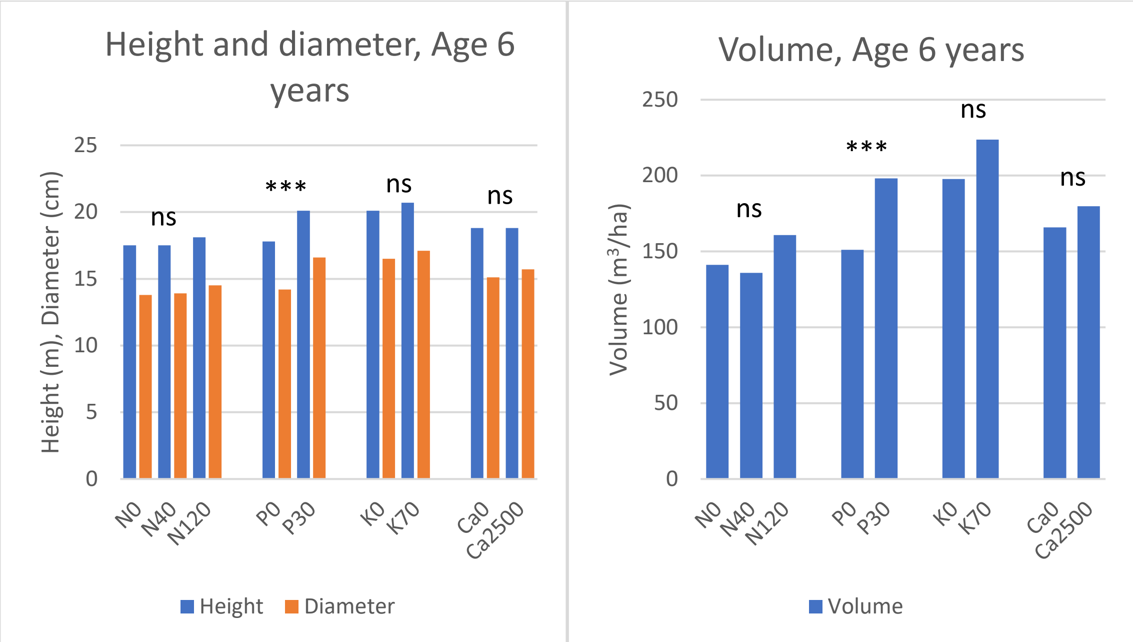


7.2.3 Re-treatment and maintenance of up to 2 existing core experiments in Sumatra up to rotation age (age 6)

Core experiment – South Sumatra

The core experiment, located in Subanjeriji, South Sumatra explored the rotation-length impacts of addition of N, P, K and Ca on productivity. The only nutrient that gave a significant response through to the end of rotation was P (Fig. 5). This experiment was also originally designed to allow comparison of productivity between *A. mangium* and *E. pellita*, but the *A. mangium* had almost complete mortality due to wilt disease caused by *Ceratocystis fimbriata* by around age 3 years.

Fig. 5 – Impacts of nutrient treatment at establishment on height and diameter (a), and volume (b) at age 6 years at the core site in South Sumatra.



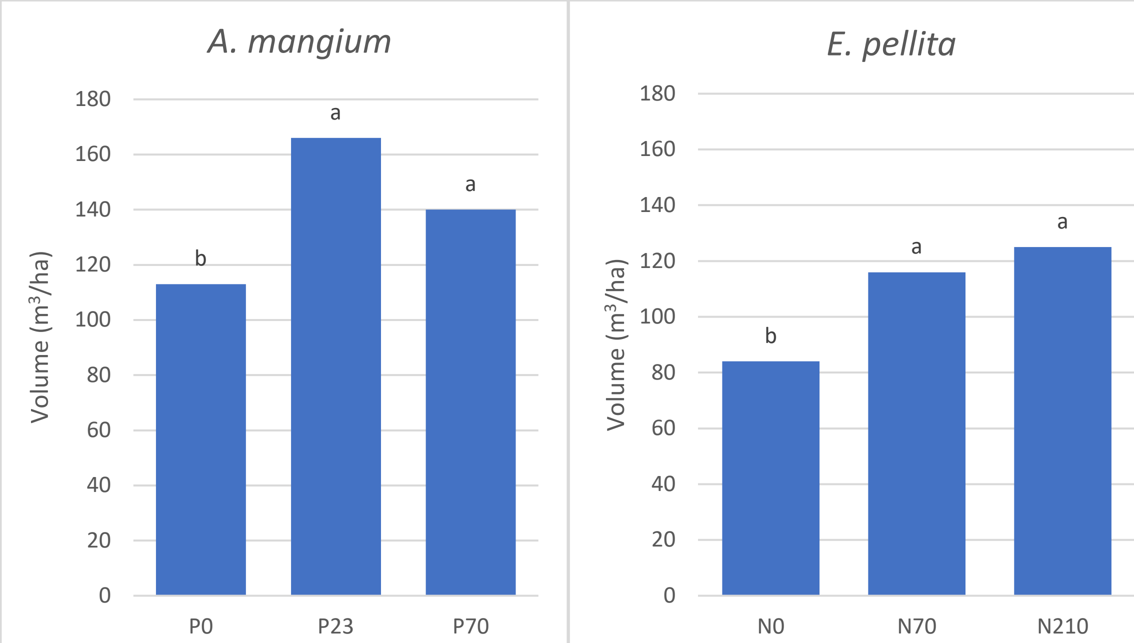
The results from this experiment and the satellite experiments have been written up by Alen M. Inail (PT MHP) into a manuscript that has been published in the journal Forests:

> Inail, M.A., Hardiyanto, E.B. & Mendham, D.S., 2019. Growth responses of *Eucalyptus pellita* F. Muell plantations in South Sumatra to macronutrient fertilisers following several rotations of *Acacia mangium* Willd. *Forests*, 10(12), p.1054.

Core experiment – Riau

A core experiment in Riau was maintained by RAPP through to end of harvest. This was conducted at Teso East, with two adjacent experiments, one *A. mangium* with 3 P fertilizer treatments (0, 23 and 70 kg/ha), and one *E.* hybrid (*grandis* × *pellita*) experiment with 3 N treatments (0, 70 and 210 kg N/ha). In both species, the fertilized treatments had significantly higher standing volume than the unfertilized treatments, but there was no difference between the fertilized treatments (Fig. 6). At the end of the rotation, despite higher mortality, *A. mangium* still gave comparatively higher productivity than *E.* hybrid.

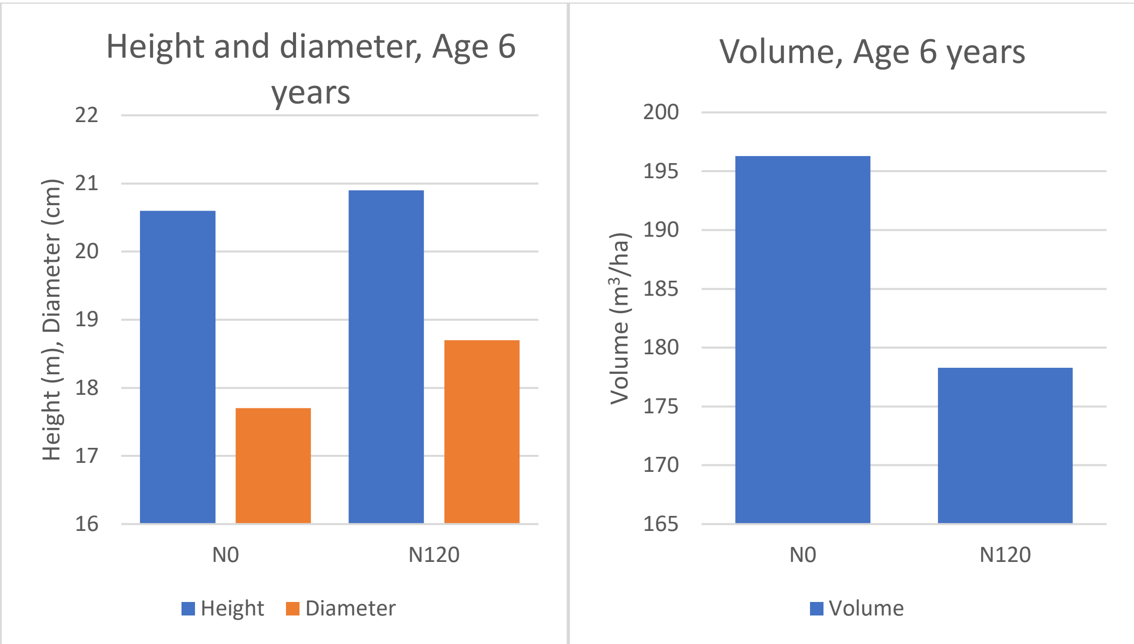
Figure 6 – Full rotation (age 5 years) standing volume responses of *A. mangium* to P (a) and *E.* hybrid to N (b) in adjacent experiments at Teso E, Riau.



Satellite Experiments

A satellite experiment was established in South Sumatra with key treatments from the core experiment to understand if there was any response of *E. pellita* to N fertilizer when grown on an ex *E. pellita* plantation. No responses were obtained to N fertilizer in this experiment either (Fig. 7), suggesting that N supply is sufficient to maintain productivity of at least 2 rotations of *E. pellita* in these systems.

Figure 7 – *E. pellita* standing volume response at 6 years to N fertilizer applied at establishment in the ex-*E. pellita* satellite experiment, South Sumatra. Treatment responses were not significantly different.



7.2.4 Development of site and soil management guidelines for farmers

This activity produced different outputs for different audiences. For farmers in Java who are still growing *A. auriculiformis*, a manual has been written for use by smallholder farmers. With the partner companies, they have been incorporating new knowledge into their own planning and management protocols. A fact sheet on site and soil management guidelines was prepared and is available on the project website.

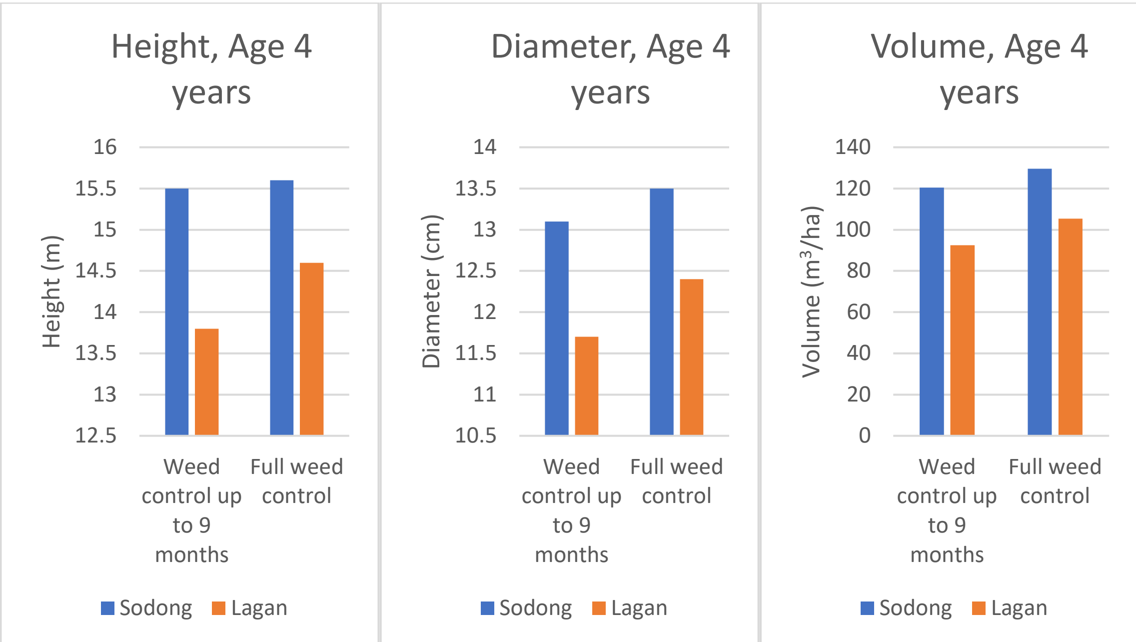
7.2.5 Additional activities in Objective 2

With the decreased likelihood of the value of N and P management, additional site and stand management options were explored to maximise the productivity of these plantations, including coppicing, time of N fertilizer application, weed control interaction with nutrient management, and clone by site interactions to better understand if *E. pellita* needed site specific management.

Weed control x nutrient management

In addition to the 9-month N and P addition treatment above, two weed control regimes were explored to better understand the requirement for ongoing weed control, and to explore potential interactions between weed control and nutrient addition. This was to test the hypothesis that competition from weeds for nutrients may be offset by application of additional nutrients. The two treatments employed were weed control up to 9 months, or full weed control up to age 4. There was a significant response of diameter to weed control treatment ($P<0.05$) at both Sodong and Lagan (Fig. 8). Treatment effects on height and volume were also significant at Lagan ($P=0.009$ and $P=0.003$, respectively), but not at Sodong ($P=0.84$ and $P=0.13$, respectively). However, there were no significant interactions between weed control and N or P addition, suggesting that the reduced tree growth with weed competition was not associated with nutrients.

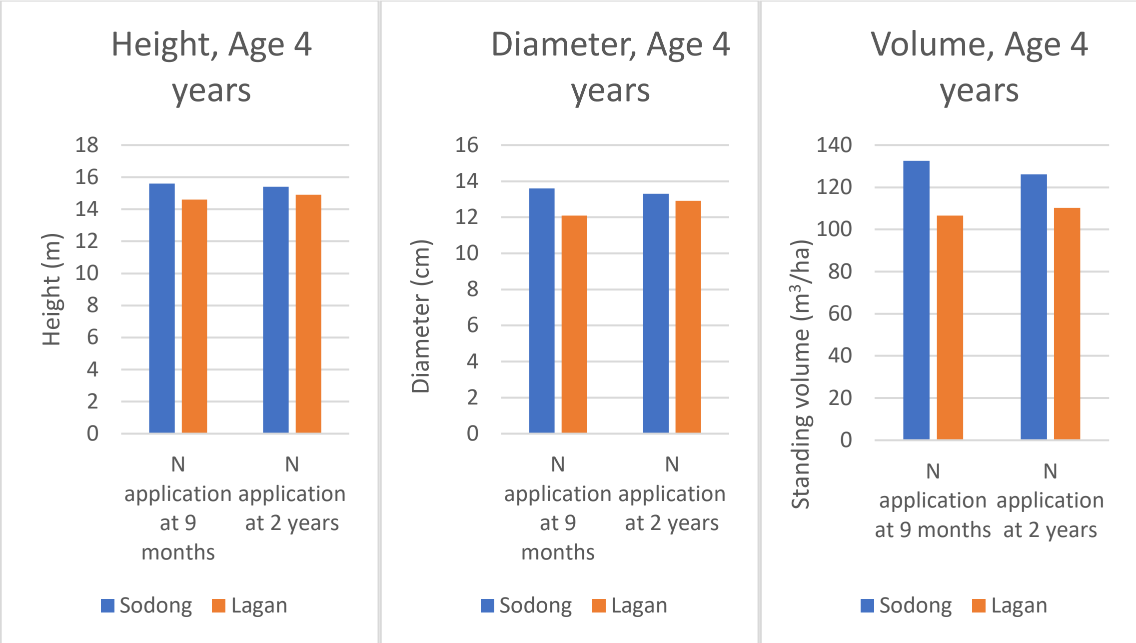
Figure 8 – Effects of weed control up to 9 months only, and for the full 4 years on height and diameter at age 4.



Timing of N application

Nitrogen was applied at either 9 months, or at 2 years at Sodong to test the effect of timing of N addition on *E. pellita* productivity. However, there were no differences in height, or volume between the N addition treatments (Fig. 9).

Figure 9 – Effect of timing of N application on height and diameter of *E. pellita* at age 4 years. Note that there were no significant effects of N application time on height or diameter at either site.



Clone × site interaction

A trial of clone-site interactions was established in February 2017 on 4 sites in South Sumatra. On every site 4 common clones were planted, arranged in a randomized complete block design, 49 trees (25 measured trees) per plot replicated 4 times. Trees were fertilized with 100 g of TSP per tree at planting time. Soil properties at the trial sites area shown in Table 3, while the soil profiles for the 4 sites are depicted in Fig 10.

Table 3. Soil properties of the site of clone-site interaction experimental sites

Description	Site			
	Caban Utara	Sodong Selatan	Lengi	Banding Anyar
Depth of impending layer (cm)	83	>100	43	94
Soil Texture				
- Clay (%)	57.7	30.6	51.3	60.1
- Silt (%)	14.7	19.7	34.9	13.2
- Sand (%)	27.6	49.6	13.7	26.7
pH (H_2O)	4.3	4.4	4.5	4.6
Organic C (%)	2.3	2.4	2.5	3.0
Total N (%)	0.19	0.17	0.23	0.21
C/N Ratio	12.2	15.0	10.7	14.6
P-Bray (mg kg^{-1})	0.9	1.1	1.2	0.7
CEC (cmol kg^{-1})	9.3	9.6	15.1	10.2
Exch. cations (mg kg^{-1})				
- K	55.1	43.9	97.2	75.0
- Ca	100.3	49.1	210.3	67.0
- Mg	22.8	14.7	50.6	31.4
- Na	5.2	6.1	7.5	6.9

Figure 10a. Soil profile in Banding Anyar

Horizon and depth (cm)	Description
Ap 0 – 14/17	Very dark grayish brown (10 YR 3/2), clear boundary, subangular blocky, loam, slightly firm, many fine roots
Bt1 14/17 - 60	Dark yellowish brown (10 YR 4/6), gradual smooth boundary, subangular blocky, clayey loam, firm, many fine roots, rare medium root
Bt2 60 - 94/100	Yellowish brown (10 YR 5/8),clear boundary, subangular blocky, clayey loam, very rare fine root
Bt3 94/100 - 120	Yellowish red 95 YR 4/60, clear boundary, subangular blocky, clayey loam, iron concretion(<5 mm), mottling grayish red

Figure 10b Soil profile in Caban Utara

Horizon and depth (cm)	Description
Ap 0-11	Dark brown (10 YR 3/3), clear boundary, subangular blocky, loam, firm, many fine roots
Bt1 11-40	Strong brown (7.5 YR 5/6), clear boundary, subangular blocky, clayey loam, friable, few medium roots (2-20%) and coarse roots (< 2%)
Btv1 40-83	Red (2.5 YR 4/8), clear boundary, subangular blocky, clayey loam, friable, few fine roots (2-20%) rare coarse root
Btv2 83-120	Red (2.5 YR 5/8), smooth boundary, subangular blocky, clayey loam, friable, few fine root, some mottling reddish browns (< 5mm)

Figure 10c Soil profile at Lengi

Horizon and depth (cm)	Description
Ap 0-21	Dark grayish brown (10 YR 4/2), clear boundary, subangular blocky, clayey loam, friable, many fine and coarse roots
E 21-43	Strong brown (7.5 YR 5/8), clear boundary, subangular blocky, clay, firm, many fine roots, few medium root, fine mottling
Btv1 43-70	Strong brown (7.5 YR 4/6), clear boundary, subangular blocky, clay, very firm, mottling red, plintite
Btv2 70-100	Pinkish gray (5 YR 6/2), clear boundary, clayey, very firm, hematite, plintite
Btg 100-120	Reddish gray (2.5 YR 6/1), clear boundary, subangular blocky, clay, gley,

Figure 10d. Soil profile at Sodong Selatan

Horizon and depth (cm)	Description
Ap 0-21	Very dark grayish brown (10 YR 3/2), clear boundary, subangular blocky, sandy loam, slightly friable, many fine roots, few coarse root
Bt1 21-102	Brown (7.5 YT 4/4) clear boundary, subangular blocky, sandy clay loam, friable, many fine roots
Bt2 102-120	Yellowish red (5 YR 4/6), smooth boundary, subangular blocky, clayey loam, friable, mottling red

At age 2 years, site had a significant influence on growth ($p=0.0001$). Differences between clones in growth were also significant ($p < 0.0001$). Clone-site interactions were detected for diameter ($p=0.059$) and stem volume (0.029) but not for height ($p=0.32$) (Table 4). The type B correlation, $r_B = \sigma^2$ clone/(σ^2clone + σ^2 clone-site), calculated from variance component estimates (Table 5), suggested that the correlations between sites for diameter ($r_B = 0.84$) and stem volume ($r_B = 0.80$) were high, indicating that the clone-site interactions were actually of less importance; the clone ranks were similar at different sites, suggesting that high performing clones can be grown across different sites without running the risk of losing growth. The 2-year growth data (Table 6) demonstrates that the high performing clones performed the best across all sites.

Table 4. Analysis of variance for growth of *Eucalyptus pellita* in the clone-site interaction trial at age 2 years

Source	df	Height (m)		Diameter (cm)		Stem Volume (m^3)	
		Mean square	Pr>F	Mean square	Pr>F	Mean square	Pr>F
Site	3	13.05	<0.0001	3.48	<0.0001	0.00048	<0.0001
Rep (site)	12	3.81	<0.0001	2.24	<0.0001	0.00027	<0.0001
Clone	6	5.26	<0.0001	4.52	<0.0001	0.00039	<0.0001
Clone x site	18	0.47	0.35	0.74	0.047	0.00004	0.037
Error	68	0.42		0.45		0.0002	

Table 5. Variance component estimates for growth

Vari component	Height	Diameter	Volume
σ^2 site	0.333	0.036	8.817
σ^2 rep (site)	0.497	0.288	27.866
σ^2 clone	0.312	0.262	19.729
σ^2clone x site	0.014	0.048	4.841
σ^2 error	0.419	0.257	23.636

Table 6. Growth of clones on different sites at age 2 years

Site	Clone ID	Mean height (m)	Mean diameter (cm)	Stem volume (m^3)
Banding Anyar	A	10.2	8.8	0.031
	B	10.3	8.3	0.028
	C	9.6	8.5	0.027
	D	9.5	8.6	0.028
	E	10.1	9.7	0.037
	F	10.9	8.7	0.032
	G	11.1	8.8	0.033
Caban Utana	A	11.4	8.7	0.034
	B	11.8	9.4	0.040
	C	11.4	8.5	0.032
	D	9.9	8.4	0.038
	E	12.2	9.9	0.046
	F	11.7	8.3	0.032
	G	11.5	8.2	0.031
Lengi	A	9.6	8.0	0.024
	B	10.7	8.8	0.034
	C	9.9	8.1	0.027
	D	9.1	8.2	0.027
	E	10.6	9.0	0.035
	F	10.7	7.9	0.027
	G	10.8	7.7	0.027
Sodong Selatan	A	10.8	8.7	0.032
	B	11.9	9.5	0.042
	C	11.0	8.7	0.034
	D	10.5	9.2	0.035
	E	11.6	11.5	0.062
	F	11.53	8.1	0.031
	G	12.2	8.7	0.038

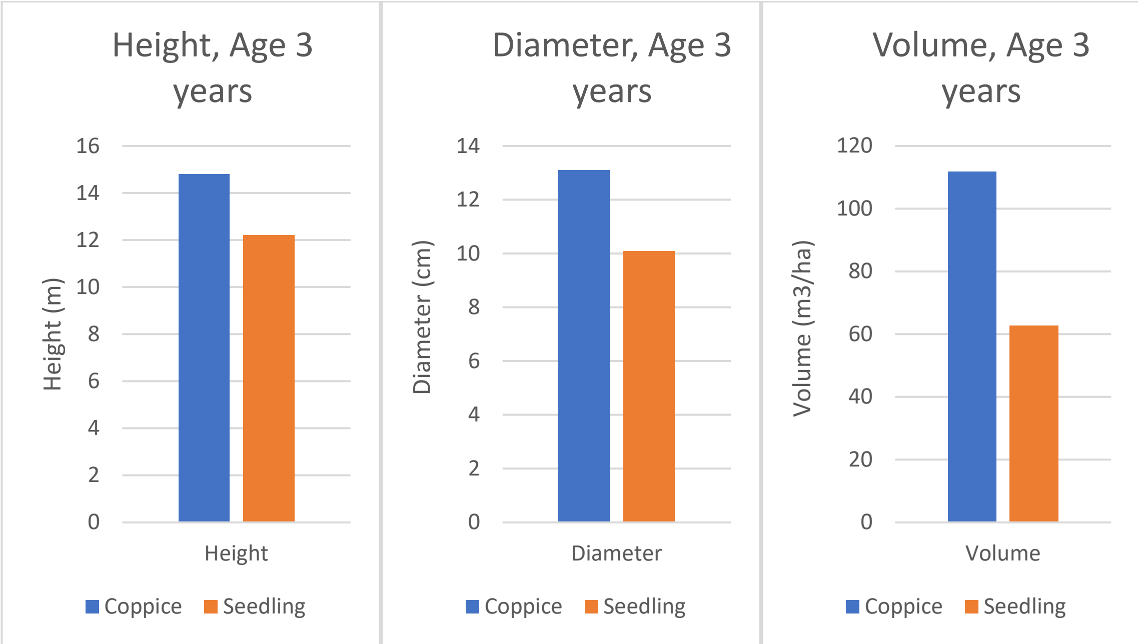
Coppice 2nd rotation

A coppice and seedling comparison experiment was established on an ex-*E. pellita* site in November 2015. Treatments explored were (1) comparison of coppice and seedling re-establishment methodologies, (2) effects of N (0 and 250 kg/ha) and P (0 and 30 kg/ha) fertilizer on coppice growth, (3) effects of singling time (1 and 4 months) on coppice growth and survival.

Coppice vs seedlings

At age 3, coppice had a significantly greater height and diameter compared to seedlings (Fig. 11), and coppice also had close to double the standing volume of the seedling re-established material.

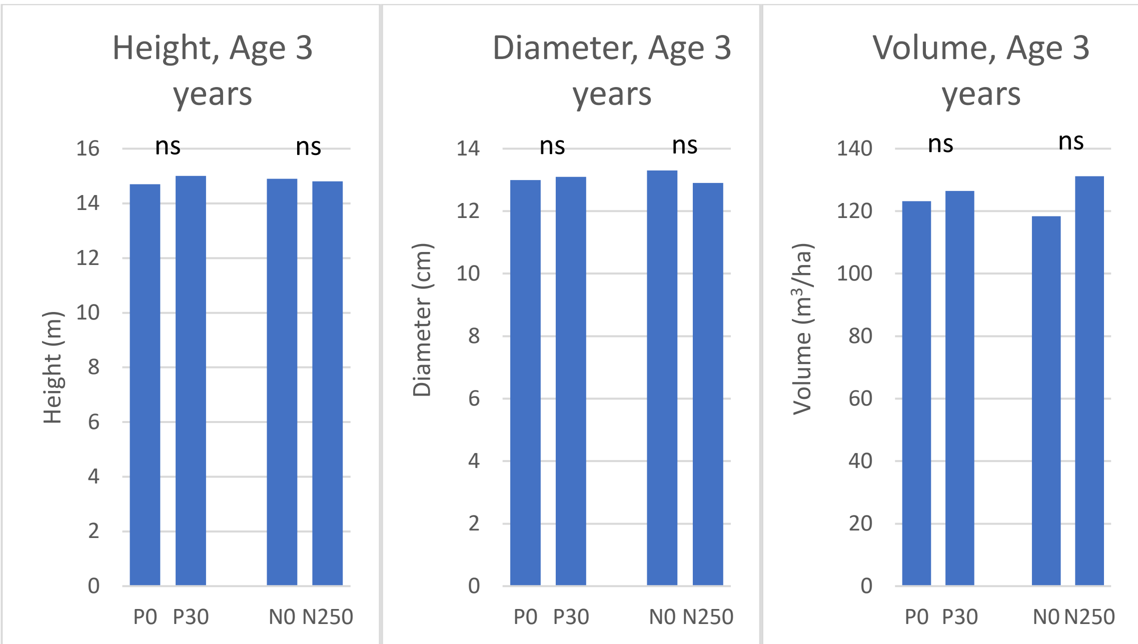
Figure 11 – Impacts of coppice and seedling re-establishment method on height and diameter



N and P management impacts on coppice growth

Phosphorus application did not significantly increase either height, diameter, or volume of the coppice regrowth at age 3 years (Fig. 12), and similarly N addition also had no significant impact on height, diameter or volume.

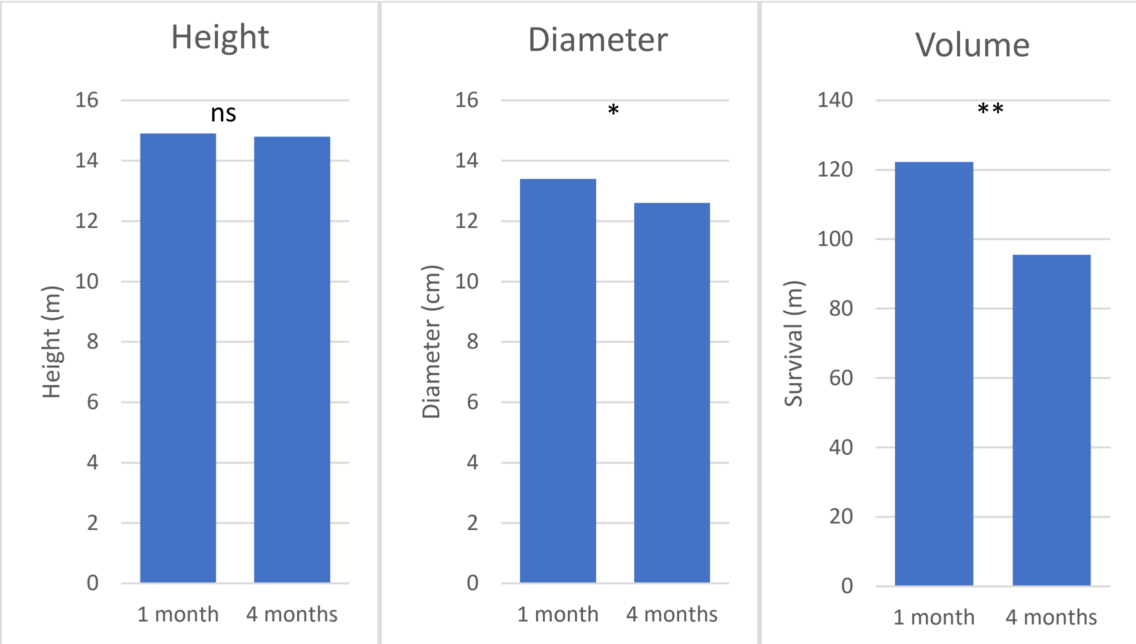
Figure 12 – N and P treatment effects on coppice height and diameter at age 2 years



Singling time effects on coppice regrowth

Singling time did not significantly influence height, but the later singling time (4 months vs 1 month) did significantly reduce diameter of the regrowth coppice at age 3 years. It also impacted on survival, such that the standing volume was much greater in the 1-month singling compared to the 4-month singling (Fig. 13).

Figure 13 – Impacts of singling time on height, diameter and volume of coppice regrowth at age 3 years.



Comparison of A. crassicarpa and Eucalyptus and response to fertilizer on ex A. mangium and ex-Eucalyptus sites

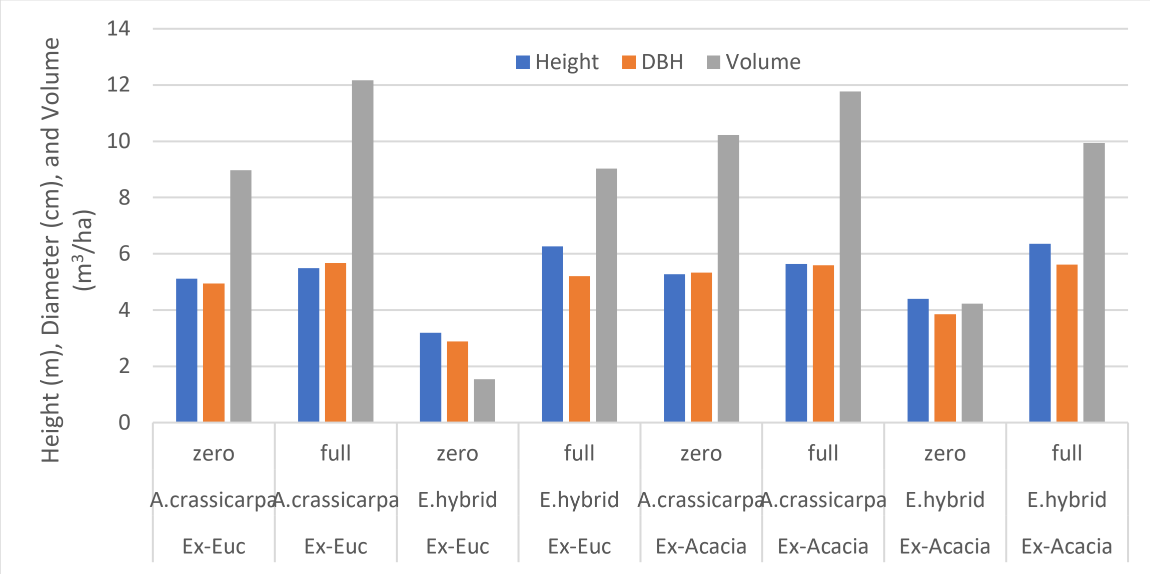
Two experiments were established in July 2017 on adjacent sites, in the Teso East region of Riau. Both sites were the 4th rotation, with one site having 3 previous consecutive *A. mangium* rotations, and the 2nd site having 2 *A. mangium* rotations followed by a *Eucalyptus* rotation.

Treatments applied to each experiment were:

1. *A. crassicarpa* with no fertilizer
2. *E*. hybrid with no fertilizer
3. *A. crassicarpa* with 50g Ammonium nitrate, 100g triple superphosphate and 40g KCl/tree at planting
4. *E*. hybrid with the same fertilizer as treatment #3.

There was a response to fertilizer in both species, but the *E*. hybrid with zero fertilizer had much lower productivity compared to the *A. crassicarpa* with zero fertilizer, especially on the ex-eucalyptus site (Fig. 15).

Figure 15 – Impact of fertilizer, species and land use history on height (m), diameter (cm), and volume (m³/ha).



Mixed A. crassicarpa and Eucalyptus

An experiment was established at Teso East in March 2016 to explore the impacts of mixed *A. crassicarpa* and *E*. hybrid on productivity. The treatments installed were:

- Pure *A. crassicarpa* (100% acacia)
- 3 rows of *A. crassicarpa* with 1 row E. hybrid (75% acacia)
- 2 rows of each species (50% acacia)
- 1 row acacia and 3 rows *E*. hybrid (25% acacia)
- Pure *E*. hybrid (0% acacia)

Both species were fertilized with 100g/tree of triple superphosphate and 40 g/tree KCl, and the eucalypts were additionally fertilized with 80g/tree of Ammonium sulfate.

At age 24 months, there was no significant effect of treatment on plot survival or growth though survival in the *A. crassicarpa* was marginally lower and dbh marginally higher. This study has demonstrated that there is potential for mixed species stands, and that the experiment should be monitored through to the end of the rotation to fully understand the impacts and trade-offs.

Manuscripts

Manuscripts arising from work in this objective included:

Hardie M, Mendham D, Corkrey R, Hardiyanto E, Maydra A, Siregar S, Marolop R, Wibowo A. 2018. Effects of eucalypt and acacia plantations on soil water in Sumatra. New Forests 49:87–104.

Inail MA, Hardiyanto EB, Mendham, DS (2019). Growth responses of Eucalyptus pellita plantations in South Sumatra to macronutrient fertilizers following several rotations of *Acacia mangium. Forests* 10(12) p.1054.

Mendham D, Hardiyanto E, Wicaksono A, Nurudin M. 2017. Nutrient management of contrasting *Acacia mangium* genotypes and weed management strategies in South Sumatra, Indonesia. Australian Forestry 80:127–134.

Siregar STH, Nambiar EKS, Mendham DS, Untung S, Sahputra I (2019). Comparative produtvitity of *Acacia mangium* and *Eucalyptus* hybrid under different management regimes in Riau, Indonesia. *Manuscript in preparation*

Bich NV, Eyles A, Mendham D, Dong T, Ratkowsky D, Evans K, Hai V, Thanh H, Thinh N, Mohammed C. 2018. Contribution of Harvest Residues to Nutrient Cycling in a Tropical *Acacia mangium* Willd. Plantation. Forests 9:577.

Bich NV, Mendham D, Evans KJ, Dong TL, Hai VD, Van Thanh H, Mohammed CL. 2019. Effect of residue management and fertiliser application on the productivity of a *Eucalyptus* hybrid and *Acacia mangium* planted on sloping terrain in northern Vietnam. Southern Forests: A Journal of Forest Science:1–12.

7.3 Objective 3. Improving the management options for eucalypt and acacia plantations.

This objective focussed on understanding options for farmers to receive higher returns in both Indonesia and Vietnam.

7.3.1 Establishment and maintenance of up to 6 new experiments in Java, South Vietnam and North Vietnam with thinning and fertilizer treatments.

Vietnam

Four experiments/demonstration plots were established in Vietnam. Each experiment had slightly different aims to respond to the needs in each location as follows:

- Hoa Binh in northern Vietnam was established as a demonstration plot to compare different product types, from pulpwood to sawlogs
- Hue in central Vietnam was established to explore *A*. hybrid and *A. auriculiformis* and 2 fertilizer regimes
- Tan Lap in Southern Vietnam, exploring thinning options in *A*. hybrid plantations, and
- Song May in Southern Vietnam, exploring thinning options in *A. auriculiformis* plantations

Demonstration plot – Karangmojo

The University of Gadjah Mada team established a demonstration plot of *A. auriculiformis* in January 2016 in Karangmojo, Gunungkidul District, Java (the demonstration plot aged 3 years is shown in Fig. 16). Two contrasting seedlots (North Queensland and PNG origin) were established to show farmers the value of fast-growing ‘straight’ acacias, and the potential differences between seedlots. The Karangmojo demonstration plot has been extensively used during the training sessions with farmers and extension officers.

Many farmers have visited this site and they have been uniformly impressed with the growth and form of the demonstration planting. This has stimulated quite a bit of interest, both among those farmers who have participated in field days on site, and from the locals in the area, and has led to farmers planting their own acacia plots nearby that can be seen from the road driving in to the site.

Figure 16 – Karangmojo demonstration plot of acacia, age 3, in January 2019

Demonstration plot – Pacitan

A demonstration plot was established by FOERDIA in Pacitan district to encourage farmers in that region of East Java to grow straight acacias.

Community demo plots – Ibu Sarmi and others

A total of over 9000 seedlings were distributed to over 100 farmers in Gunungkidul, with the intention of creating a large number of living demonstration plots. Ibu Sarmi is a female farmer from Namberan village who was very keen to champion straight acacias, and was given 1714 seedlings to plant in her demonstration plot. Ibu Sarmi's plot has a number of agricultural crop plants growing in it, including maize, cassava, peanuts, soybeans and chillis, as well as her acacias (Fig. 17).

Figure 17 – Ibu Sarmi's acacia plot , age 1, in January 2019

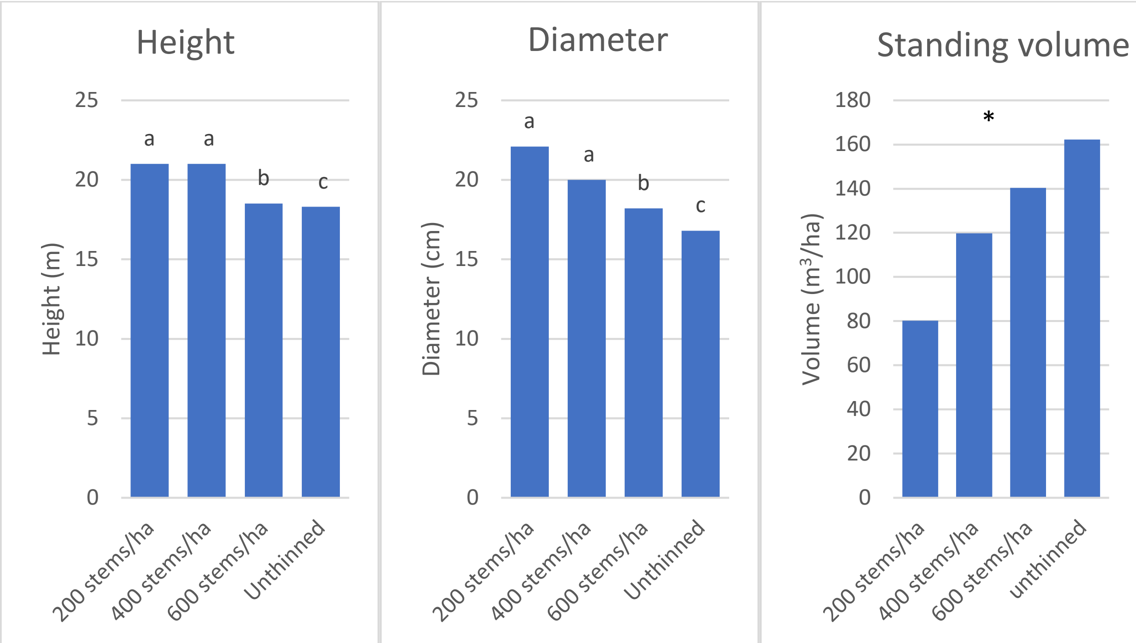
7.3.2 Maintenance of key high value thinning experiments through to the end of the rotation.

A number of experiments that were at mid-rotation were carried through to the end of rotation through this project for further analysis and study. One site that did not make it to the full rotation was Tuyen Quang (north Vietnam), that was flooded and salvage harvested before we could conduct any wood quality assessments. Key sites that were focussed on included the following:

E. pellita thinning experiment – South Sumatra

This experiment was established in South Sumatra in January 2013 under FST/2009/051. Thinning treatments were control (unthinned), as well as thinning down to 600, 400 and 200 stems/ha. The first thinning to 600 stems/ha was conducted at age 21 months (in September 2014), while the next thinning treatments, to 200 and 400 stems/ha, were conducted at age 3 years (in December 2015). The latest measure was taken at age 5 showed a strong response to thinning (Fig. 18).

Figure 18 – Mean height, diameter and standing volume under the different *E. pellita* thinning treatments



A selection of trees from this experiment were harvested and processed to better understand the value of thinning and pruning for producing peeling and/or sawing material from the thinned treatments. The harvest was conducted in early 2019, and Dr David Blackburn visited South Sumatra in April 2019 to train the local staff on assessment and grading of both veneer and board quality. Key outcomes from this study were:

- Harvest at age 6 years resulted in relatively low sawlog yield of 36.2 to 37.2%. Most of the recovered boards were Category C, followed by Category B. There were no Category A boards. Most of the defect of sawn board on category C was due to dead/loose knots, while on category B was due to discolouration or few numbers of knots. There was a tendency that less stand stocking yielded higher percentage of better veneer grade. It has been known that *E. pellita* does not shed its dead lower branches easily and when the log of these trees is processed, the boards will have many dead/loose knots.
- Thinning and pruning are of paramount importance for sawn board and veneer product. In *E. pellita*, thinning to 600 trees/ha seemed the best option as 50% of the trees at age 6 years already had diameter greater than 20 cm. At this stand stocking, delaying for 2-4 more years for harvest could improve the volume, yield and grade of these two products. Proper pruning (green pruning) resulted in board or veneer free of loose or dead knots.
- Pruning, peeling technique, transport and drying of veneer had high influence in veneer quality if sent for peeling. Improving these procedures will likely increase the percentage of veneer with grade A or B while reduce the percentage of grade C or D.

A. auriculiformis thinning experiment, South Vietnam

The Phu Binh *A. auriculiformis* thinning experiment was maintained through to age 10 years, and was used as one of the key sites for understanding the impacts of thinning on wood quality. Logs from this experiment were used to test (1) the effects of thinning on wood quality, and (2) the differences in wood quality between 8 year old *A.* hybrid and 10 year old *A. auriculiformis*. Key findings from the study included:

- *A. auriculiformis* timber at age 10 had significantly higher mechanical and physical properties than *A.* hybrid (age 8), and was suitable for hard-wearing flooring products.

- Thinning of *A. auriculiformis* resulted in greater hardness and density compared to unthinned trees.

The report on this study is available on the CSIRO publications repository.

Report citation:

> Blackburn, D., Huong V.D., Thanh, N.D. and Mendham, D.S., 2019. *Solid wood property variations in early-age Acacia plantations grown in southern Vietnam*. CSIRO, Sandy Bay

A. hybrid thinning experiment, South Vietnam

The Phu Binh *A*. hybrid thinning experiment was maintained through to age 8, and, similarly to the *A. auriculiformis* experiment (above), was used to compare the wood quality of (1) older A. hybrid logs with A. auriculiformis logs, (2) older and younger *A*. hybrid, and (3) thinned and unthinned *A*. hybrid. The full details are in the report as noted above. Additional key points arising from these comparisons included:

- Older *A*. hybrid (8 years) had slightly improved timber properties over the younger (5 year) *A*. hybrid logs, but wood from both age plantations would be of sufficient quality for architrave and furniture making.
- The proportion of sapwood, which has lower mechanical and physical properties, is much higher in younger logs.
- Thinning did not appear to make a substantial difference to *A*. hybrid wood quality parameters by age 8 years.

Demonstration plot – Playen

Background

Acacia auriculiformis was introduced into Java in the 1930s using an unknown seed source, perhaps from Maluku. The species was grown mostly along the roadside. It was also recommended as a cover crop for forest plantations on poor soils at low altitudes where lamtoro (*Leucaena leucocephala*), a cover crop widely planted in forest plantations in Java, did not grow well (Wiersum and Ramlan 1982). *Acacia auriculiformis* has also been grown by small-holder farmers in some parts of Java, for example Madura, Pacitan, Wonogiri and Gunungkidul, since the 1970s as part of a regreening program launched by the government. It is considered as a preferred species for saw-log production because it has suitable wood characteristics for sawn timber, furniture and construction. It also can be harvested at young age, around 7-8 years old. At this age *A. auriculiformis* wood has superior wood density, shrinkage, colour, and termite resistance properties than teak (*Tectona grandis*).

The objectives of the trial were 1) to find the optimal stocking density for saw-log plantation of *A. auriculiformis*, 2) to demonstrate the saw-log plantation regime of *A. auriculiformis.*

Site information

The site (07°98'S 110°51'E, 158 m elevation) is located in Playen Subdistrict, Gunungkidul District, Yogyakarta Province. The mean monthly temperature (2011 – 2015) is 25 ± 1 °C and the mean annual rainfall is 1826 mm. This site has a long dry season (May to October); long-term average rainfall is < 60 mm in the four-month period from July to October. In the rainy season (November to April) average rainfall is > 100 mm per month.

The soils are derived from marine limestone and are classified as Mollisols, Entisols or Vertisols (Figure 19). Across the site, surface texture varies between silty clay loam and silty clay, whilst soil depth varies between 40 and 70 cm. Soil bulk density at 0 - 30 cm depth ranged from 0.94 to 1.16 g cm^{-3}. At 0 - 10 cm depth, organic carbon ranged from 1.35 to 2.00 %, total nitrogen from 0.12 to 0.17 %, available phosphorus from 1.42 to 2.37

mg kg^{-1}, and pH-H_2O from 7.5 to 8.1; base saturation was dominated by calcium (88 to 95 %).

Plot establishment and assessment

Three saw-log regimes were tested: final stockings 400 trees/ha (thinned twice) and 600 trees/ha (thinned once) and a pulpwood regime, using 4 different seed sources: Seed orchard in Subanjeriji, South Sumatra (AA1), Seed orchard in Bau Bang Vietnam (AA2), wild seed in Mibini, Papua New Guinea (AA3) and wild seed in Far North Queensland (AA4). The trial was established in February 2013, arranged in a randomized complete block, replicated 2 times (due to limited land). The total plot size was 121 trees/plot, including 2 buffer rows. The initial spacing distance was 3 m x 3 m.

Figure 19. Photos of the site which was used for the trial.

The first thinning (1111 to 600 trees/ha) was conducted in October 2016 (at age 43 months), and the second thinning for the plot of 400 trees/ha was carried out in October 2019 (at age 78 months). Trees were measured for height (*h*) and diameter at 1.3 m (*d*) at age 1 year, 2 , 3 years, 50 months, 67 months and 78 months. Individual tree volume was calculated as follows:

$v = 0.25\,\pi\, dbh^2\, h\, f$ where f is a form factor = 0.475 (Huong et al. 2015).

In December 2019 (at age 81 months) stem form (axis persistence and stem straightness) was assessed. Stem persistence was scored using six classes:

1= double or multiple stems from ground level
2= axis loses persistence in the first (lowest) quarter of the tree
3= axis loses persistence in the second quarter of the tree
4= axis loses persistence in the third quarter of the tree
5= axis loses persistence in the fourth quarter of the tree
6= complete persistence

Stem straightness was scored up to the height where the stem starts to have multi-leaders using six classes:

1= not vertical with more than two bended
2= roughly vertical with more than two bends
3= not vertical with one to two bends
4= roughly vertical with one to two bends
5= roughly vertical and straight
6= completely vertical and straight

Growth response of seedlot

In general differences between seedlots or seed sources were not significant, except for height at age 1 and 3 years. Trees originating from seed orchards in Vietnam and S. Sumatra had higher growth than those from wild populations (QLD and PNG), indicating that genetic selection had improved growth (Table 8). The seed orchards in Vietnam and South Sumatra were established as progeny tests which were then progressively converted into seed orchards by removing genetically individual trees within every family tested.

Table 8. The mean height, mean diameter and volume of different seedlots at age 3 years (before first thinning)

Seedlot	*h* (m)			*d* (cm)		*v* (m^3/ha)	
	1 yr	2 yr	3 yr	2 yr	3 yr	2 yr	3 yr
AA2 (Vietnam)	3.6a	7.5a	8.9a	6.5a	10.4a	12.8a	36.2a
AA1 (S.Sumatra)	3.5a	7.2a	7.9ab	6.1a	9.9a	11.0a	29.1a
AA4 (QLD)	2.9ab	6.9a	7.8ab	5.8a	9.3a	9.8a	26.7a
AA3 (PNG)	2.7b	6.4a	6.9b	5.4a	8.7a	8.6a	21.3a

Note: Numbers having the same letter within the same column are not significantly different according to Duncan Multiple Range Test at 0.05

The highest axis persistence score was in the AA2 seedlot followed by AA4 seedlot, while AA1 and AA3 seedlots had the same score of 3.4. Stem straightness was best for AA2 seedlot (Vietnam) followed by AA1 (S. Sumatra) , while the AA4 and AA3 seedlot had the same score (3.5) (Table 9).

Table 9. The mean scores for axis persistence and stem straightness

Seedlot	Axis persistence	Stem straightness
AA2 (Vietnam)	3.7	3.8
AA1 (S.Sumatra)	3.4	3.7
AA4 (QLD)	3.7	3.5
AA3 (PNG)	3.4	3.5

Growth response to first thinning

A significant response in diameter to first thinning only occured at age 43 months (measurement in April 2017), while the the first thinning did not significantly affect the mean diameter at age 67 and 78 months, as well as the diameter increment between age 43 and 67 months and between age 67 and 78 months (Table 10). Nonetheless, lower stocking density tended to have greater mean diameter and diameter increment (Table 11).

Diffences between seedlots in diameter and diameter increment were not significant at all of the assessment times (Table 10), suggesting that all seedlots had a similar diameter response to thinning.

Table 10. ANOVA of diameter and diameter increment at various ages (after first thinning)

Source	df	Significant level (*p* value)				
		d43	*d67*	*d78*	*d43-67*	*d67-78*
Main-plot						
Rep	1					
Thinning	2	0.01	0.12	0.06	0.13	0.13
Error (a)	2					
Sub-plot						
Seedlot	3	0.13	0.13	0.11	0.50	0.19
Thinng x seedlot	6	0.16	0.14	0.17	0.43	0.38
Error (b)	9					

Note: d-43: diameter at 43 months (Oct.16), d-67: diameter at 67 months (Oct.18), d-78: diameter at 78 months (Sept.19), d43-67: diameter increment betwen Oct.16 and Oct.18, d67-78m: diameter increment between Oct.18 and Sept.19.

Table 11. The mean diameter (cm) and diameter increment (after first thinning)

Treatment	*d43*	*d67*	*d78*	*d43-67*	*d67-78*
Thinning regime					
Pulpwood	11.2	12.0	13.9	0.8	1.8
Sawlog-600	10.4	12.2	14.3	1.8	2.0
Sawlog-400	11.2	13.1	15.8	1.8	2.3
Seedlot					
AA2	11.8	13.2	15.4	1.3	2.2
AA1	11.3	12.6	14.6	1.3	1.8
AA4	10.6	12.3	14.8	1.7	2.2
AA3	10.2	11.7	13.9	1.5	1.9

Note: d-43: diameter at 43 months (Oct.16), d-67: diameter at 67 months (Oct.18), d-78: diameter at 78 months (Sept.19), d43-67: diameter increment betwen Oct.16 and Oct.18, d67-78m: diameter increment between Oct.18 and Sept.19.

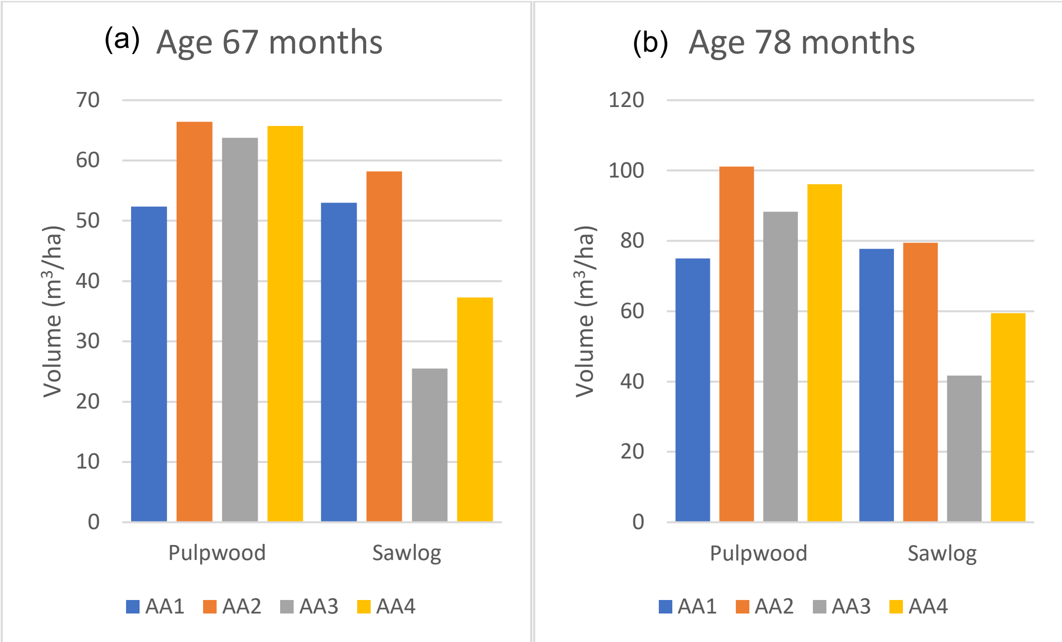
The standing tree volumes at age 67 months between unthinned and thinned to 600 trees/ha were 61.9 m^3/ha and 43.2 m^3/ha respectively (p=0.06), while those at age 78 months were 91.1 m^3/ha and 64.4 m^3/ha respectively (p=0.01). The response of standing volume to thinning differed (p=0.04) at age 67 months and the gap closed such that the difference was less significant (p=0.07) at age 78 months (Table 12), however it was likely more affected by lower survival rate of AA1 and AA3 seedlots in replication 1, namely 68.5 and 72.7% respectively. At age 67 and 78 months the trees from seed orchard AA2 (Vietnam) and AA1 (South Sumatra) had greater standing volume than those from unimproved populations (AA4-Queensland and AA3-Papua New Guinea, Figure 20).

Table 12. ANOVA of the standing volume (m^3/ha) at age 67 and 78 months

Source	df	Sinificant level (*p* value)	
		V67	V78
Main-plot			
Rep	1		
Thinning	1	0.06	0.01
Error (a)	1		
Sub-plot			
Seedlot	3	0.08	0.07
Thinng x seedlot	3	0.04	0.07
Error (b)	6		

Note: V67: standing volume at 67 months (Oct.18), V78: standing volume at 78 months (Sept.19)

Figure 20 Standing volume of different seedlots in unthinned (pulpwood) and thinned (sawlog600) plot: (a) at age 67 months, (b) at age 78 months



Economic implications

At the latest assessment (aged 78 months old in September 2019) the diameter class distribution between unthinned (pulpwood) and thinned to 600 trees/ha (sawlog-600) was only slightly different. The number of stems in the 10-15 cm diameter class in the unthinned plot was 8.4% higher than thinned plot, while in the diameter class of 15-20 and 20-25 cm, the thinned plot had 2.7% and 3.8% greater stem numbers than unthinned plot, respectively (Figure 21). However, the volume of trees in the unthinned and thinned treatments was quite different, at 61.9 m^3/ha and 43.2 m^3/ha for unthinned and thinned plot respectively. The current price of logs in the local market for diameter of 10-14 cm is IDR 650,000/m^3, while that of diameter of 15-20 cm is IDR 900.000/m^3 at the factory gate. Consequently, harvesting the plantation at around 6 years old for thinned stand (lower log volume) with the majority of diameter less than 20 cm will be less attractive fincancially for farmers as it would yield less income than that of unthinned stand (greater log volume).

The cost of thinning needs to be considered even though thinned log is already marketable in Gunungkidul, in which logs with a size of at least 10 cm can be used for cattle housing. The best price for sawlogs are obtained at log diameter of ≥ 30 cm (A_3 log class), which is currently priced at about IDR 1.35 million/m^3 at the factory gate. Small-furniture industties like in Trucuk, Klaten (Central Java) are processing more than 90% *A. auriculiformis* log (Hardiyanto et al. 2019). To attain the diameter of 30 cm, trees should be harvested at rotation of at least 10 years old. For small-holder farmers the rotation age of 10 years is considered quite long from a financial stand point, harvesting at 7-8 years old seems acceptable with the expected average stem diameter of around 20 cm. The current price of *A. auriculiformis* log with diameter of 20-29 cm (A_2 log class) is IDR 1.2 million/m^3 at the factory gate in Klaten.

Fig. 21. Diameter class distribution of pulpwood (unthinned) and sawlog-600 (thinned to 600 trees/ha)

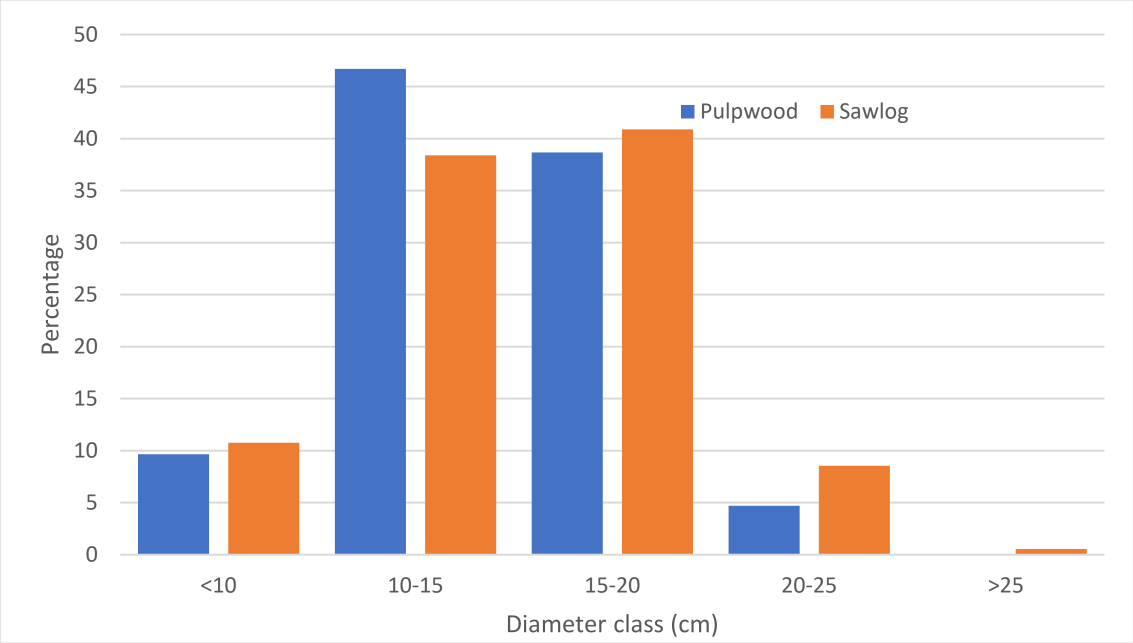


Figure 22. Sawlog trial of *Acacia auriculiformis* in Gunungkidul at age 81 months

7.3.3 Modelling and economic analysis of different land use options and plantations for higher value products and/or pulpwood.

A key activity of the activity was to develop a modelling tool and synthesise the outcomes into a report. This work was focused in Vietnam, where the policy environment substantially favours the development of a sawlog resource. Key highlights from the report were:

- Rotations of 5-6 years of Acacia hybrid tend to maximise financial returns. Younger rotations may not cover costs when the value of money is accounted for
- Thinning at age 3 provides a net positive benefit for harvesting at all ages between 4 and 8 because the early income helps cover the cost of establishment, and thinning promotes the stand to produce larger logs which command premium prices
- Growing the stand on to age 10 years can provide high incomes, especially at highly productive sites, but longer rotations need to be balanced against the higher risks of wind and/or disease damage.
- *Acacia auriculiformis* provides greater returns than *A*. hybrid over longer rotations because the wood is of higher value and the productivity, while initially slower, catches up to *A*. hybrid over longer rotations.

The report is available on the CSIRO publications repository, with the citation:

> Blackburn, D., Huong, V.D. & Mendham, D.S., 2019. *The value of growing Acacias for sawlogs to smallholder farmers in Vietnam*. CSIRO, Sandy Bay.

7.3.4 Additional activities

The following manuscripts were prepared as part of this Objective:

> Huong VD, Mendham DS, Close DC. 2016. Growth and physiological responses to intensity and timing of thinning in short rotation tropical *Acacia* hybrid plantations in South Vietnam. Forest Ecology and Management 380:232–241.

> Huong VD, Mendham DS, Beadle C, Hai NX, Close DC 2019 Growth, physical responses and wood production of an A. auriculiformis plantation in southern Vietnam following mid-rotation thinning, application of phosphorus fertilizer and organic matter retention. *Manuscript in preparation*

7.4 Objective 4. Improving pathways to adoption and diffusion through a better understanding of conditions that influence effective farmer investment in forestry.

7.4.1 Development of training program and user friendly information sheets about growing acacia/eucalypts to suit local growers;

Eucalypts are not yet grown by farmers in Vietnam or Gunungkidul, so the focus of this work was on extending the existing knowledge of acacia management. An *Acacia auriculiformis* growers manual was produced, and summarised into a glossy format for use by farmers in Gunungkidul. This manual was made available to the farmers we contacted during the project, as well as on the project website. A series of Technical Information Sheets were adapted from English to Vietnamese for use in Vietnam as follows:

- How to recognise pests and diseases
- How to select planting stock
- How to undertake planting and spacing
- How to control weeds
- How to prepare land for planting
- How to apply fertilizer at planting
- How to lift prune
- How to tip prune

These fact sheets were also made available on the project website

7.4.2 Analysing existing social capital, through a network survey to identify points of strong social capital that can be leveraged and network gaps that are impediments to improved return from forestry

Note this activity was modified at the mid-term review to focus on understanding farmer mental models. The social networking study was replaced with a series of focus group discussions in both Indonesia and Vietnam to better understand how farmers see their acacia plantations. Everyone brings their own perspective to a situation, and our aim was to understand the points of similarity and difference between the mental models of farmers and researchers. Studies in Indonesia and Vietnam were written up into two reports that are available on the CSIRO publications repository:

- Greenhill MP, Mendham DS, Oktalina SN, Hardiyanto EB (2017). Mental models of farmers performing tree management in Gunungkidul. CSIRO, Canberra
- Greenhill MP, Mendham DS, Dong TL, Thi HL, Tan PT, Hai TA (2018). Growing acacias in Vietnam - A mental model approach. CSIRO, Canberra

These mental models helped to shape our thinking around the training needs and development of further research into understanding the approaches of different training styles (see below).

7.4.3 Implementation of training and evaluation programs with local extension officers and acacia/eucalypt growers to improve farmer livelihoods;

A substantial effort was placed in this activity in both Vietnam and Indonesia. The original plan was to put most of the effort in this activity into Indonesia, but an opportunity arose through partnership with Chris Beadle, through the Crawford Fund, to increase the training and evaluation programs of growers in Vietnam the following series of training and evaluation was conducted as follows:

- In Indonesia, the acacias being promoted by the project in Gunungkidul has raised quite an amount of farmer interest in growing better *A. auriculiformis*. They can see the improvement from their traditional practices (tending of wildlings) to the project practices, with the project material growing faster and with much improved form. They know them as ‘straight acacias’ because the wild-grown seed typically produces trees with very poor form. In Gunungkidul, the following trainings were implemented:
    - Formal training #1 in April 2017 with 27 farmers,
    - Formal training #2 in August 2018 with 59 farmers.
    - Distribution of over 9000 seedlings to over 100 farmers, each of whom have received either formal or informal training in growing ‘straight acacias.’ This training was focussed on encouraging adoption of ‘straight acacias’ and associated enhanced silviculture. The seedlings were distributed to farmers with the intention that they become demonstration plots, and the farmers become ‘champions for the improved acacia management.

  This was followed up with a survey of adoption intention in January 2019 to examine the impacts of training programs and seedling distribution on adoption of acacia silviculture management practices. The research study aims to understand how the number of formal training sessions, and/or informal training and seedling distribution has influenced farmer awareness and adoption. This report on this study is in preparation and will be available on the CSIRO publications repository.
- Eko Hardiyanto led a study tour of a group of 13 farmers and 2 students to a processing plant in Klaten in April 2019, so that they can better target their management towards an understanding of the processors needs.

- Eko Hardiyanto visited one of the major growers not directly involved in the project, PT. Korintiga Hutani in Central Kalimantan in November 2019 to inform them of the project outcomes
- In Vietnam, we established a study to understand the benefits of working with farmer mental models as part of the training process to encourage greater uptake and adoption. This was established as a designed study with the following treatments:
    - "Traditional training" - using a traditional training style, whereby the scientists/extensions staff deliver the best practice information in a lecture/seminar format, followed by a field visit to reinforce key aspects
    - "Active learning" – using an approach that encourages interaction between scientists and farmers to reach a compromise best-practice that adopts the principles from the scientists/extension staff, but also fits with the farmer mental models, so that adoption by the farmer is more readily attained
    - "Control" – untrained group

  This study was conducted in 2 provinces (Hue and Hoa Binh), at 2 villages per province, and separately with male and female farmers. In total, 220 farmers were engaged in the study. A survey of adoption intentions was conducted before and after the training in July 2018, and again at 6 months after the training in January 2019. The study has been drafted into a CSIRO report that will be made available through the CSIRO publications repository.
- Extension officers were trained in Gunungkidul in April 9th by Dr Eko Hardiyanto.
- Extension officers were trained in Hoa Binh in July 2018, when Chris Beadle was conducting the farmer extension training noted above

7.4.4 Improving the capacity of women to benefit more from plantations

After conducting a gender analysis in Indonesia, we proposed that there was a gap in farmers being able to access high quality acacia seedlings in Gunungkidul. Traditional cultivation of acacias was based on farmers allowing wildling acacias to grow in situ, whereas the project team was now demonstrating the value of growing *A. auriculiformis* from selected seed and with best practice management. FOERDIA and UGM recognised the importance of the improved seed and had committed to distributing the seeds from the project seed orchard for free, so we identified that there was a prospective opportunity for female farmers to potentially set up microbusinesses to grow seedlings for sale. In 2018 we worked with a group of around 20 women to train them up in seedling production, but this did not progress to the point where these women could have their own nursery businesses because there was insufficient market for the seedlings at a price point that would see them earning a reasonable profit. Additionally, we found that it was not culturally appropriate to only train the women, so we had to compromise and targeted the same training toward both men and women (but in separate sessions). This fitted within the current cultural norm and was more likely to lead to greater adoption.

The group of women whom we worked with were able to gain the trust of the Ministry of Environment and Forestry and attained accreditation to be part of their community nursery program. In 2018 they received a grand of Rp50,000,000 from MoEF, and produced around 35,000 seedlings for sale. This village has followed up on this and successfully pursued other opportunities to build up their nursery business.

As well as pursuing the nursery/seedling supply chain business opportunity, we focussed on working with women to help them to grow 'straight acacias' on their own farms. Ibu Sarmi from Namberan village showed a lot of interest early on and established a demonstration plot of over 1000 trees in 2018. Ibu Sarmi is a local farmer leader and is now a champion for 'straight acacias'. Around 14 other women were given seedlings to develop their own plantings/demonstration plots.

7.4.5 Preparation of policy briefs based on social study outcomes

Policy briefs have been drafted and will be used by the Indonesian team to improve the policy settings for adoption of acacias in Java.

7.4.6 Collation and synthesis of project outcomes into a full technical report.

The project outcomes have been written into a series of technical reports and manuscripts, which are cited below. There is a range of material that has not been published yet, which has been summarised in the report above.

7.4.7 Additional activities

The following papers were published as part of this Objective:

Greenhill M, Walker I, Mendham D, Permadi D. 2017. West Kalimantan industrial plantation scheme: twenty years on. Forests, Trees and Livelihoods 26:215–228.

Permadi DB, Burton M, Pandit R, Race D, Ma C, Mendham D, Hardiyanto EB. 2018. Socio-economic factors affecting the rate of adoption of Acacia plantations by smallholders in Indonesia. Land use policy 76:215–223.

Permadi DB, Burton M, Pandit R, Race D, Walker I. 2018. Local community's preferences for accepting a forestry partnership contract to grow pulpwood in Indonesia: A choice experiment study. Forest Policy and Economics 91:73–83.

8 Impacts

8.1 Scientific impacts – now and in 5 years

This project has improved our scientific knowledge and understanding in several areas of research, including the following:

- Site and climatic drivers of productivity in *E. pellita* (2 papers and 1 publicly available report)
- The biophysical and social transition from acacias to eucalypts (1 paper)
- Management requirements of *E. pellita*, and acacias to maximise productivity (6 papers/manuscripts)
- Improving yield of sawlogs from acacia plantations in Vietnam and Indonesia (2 papers/manuscripts)
- Effects of thinning, species and harvest age on wood quality (1 publicly available report)
- Economics of sawlog vs pulpwood rotations (1 publicly available report)
- Gender roles in acacia plantations in Indonesia and Vietnam (2 reports)
- Mental models of farmers and scientists regarding tree planting, and the points of connection between the two (2 publicly available reports)
- Impacts of training and training style on intention to adopt improved silviculture (2 reports in preparation)
- Acceptance by farmers of outgrower schemes, and mechanisms to improve farmer engagement with industrial wood production (3 papers)

This is a solid body of work that forms an important basis to support (1) the transition to eucalypts in the industrial estates, (2) improving productivity and profitability of acacias for higher value products, (3) improving adoption of improved silviculture by smallholder farmers. Much of this is quite new and will form the basis for further work that will be conducted in the future.

8.2 Capacity impacts – now and in 5 years

Capacity has been built in several groups of stakeholders through this project, including:

- *Students*. The project and project team have supported at least 5 PhD students, including Murni Greenhill (1-2 years from completion), Gunawan Wibisono (who has submitted his first full draft to the university supervisor), Arom Figyantika (who has submitted in early 2020), Dwiko Permadi (who was awarded his PhD in 2017), and Nguyen Van Bich (awarded his PhD in 2018).
- *Researchers in industry and government*, in both Indonesia and Vietnam. The project has had an inter-disciplinary approach to better understanding and improving both the biophysical environment and management of plantations, and translating this into adoption of outcomes by focusing on understanding farmers and their learning styles. This systems approach of thinking about the best way to reach an outcome and effect change on the ground is challenging in many situations. The scientific team has developed skills in this as the project has proceeded, and it has increased the capacity of research staff from CSIRO (3 scientists), Gadjah Mada University (5 scientists), FOERDIA (2 scientists), VAFS (5 scientists) and the industrial companies (1 scientist in each of the 3 companies). In addition, this project is one of the few forums where researchers from different industrial companies and government agencies can come together to learn from each other. It is worth noting also that many of the papers and reports from this study have been first-authored by Indonesian and Vietnamese scientists.

Research staff from UGM, VAFS, and MHP were also trained in wood quality assessment by David Blackburn.

- *Industrial company managers* in Sumatra have a stronger basis to increase sustainability and productivity of their plantations on mineral soils. Key knowledge derived from this project that has been incorporated into standard operating procedures including (1) nutrient management prescriptions for eucalyptus plantations, (2) weed management regime in eucalyptus plantations, (3) soil mapping and site selection for eucalypts. Management of PT MHP are also considering the potential for sawlogs, and are assessing the cost of thinning, pruning and the price of the solid wood.
- *Farmers in Gunungkidul* have demonstrated that they have a strong interest in learning more about *Acacia auriculiformis*, and especially the 'straight acacias' demonstrated in this project, which are substantially faster growing and with better form than the wild-grown acacias they are used to cultivating. Acacias are traditionally known as the 'tree that grows by itself'. In order to change the farmer perceptions of acacias, it was necessary to distribute seedlings and establish demonstration plots. Training on seed propagation, care and maintenance was required by the farmers because of their perceptions that acacias grew by themselves. They see the timber as having a very similar quality to teak, but it can be grown on rotation lengths less than half that of teak. There is quite a strong interest from farmers in expanding their acacia plantings, and there is already a model in place with Sengon (*Paraserianthes falcataria*) having become very widely grown in many regions in Java because it is fast growing and fills a market niche for peeler logs. Acacias are similarly fast growing, but differ from Sengon in that they can provide wood into the solid timber processing market. A total of 64 farmers received formal training, and around 150 farmers received either formal training, informal training, seeds, or seedlings, or a combination of these. Farmer interest in acacias is high, with over 9000 seedlings distributed, with these farmers becoming acacia champions as their trees grow. Because they could demonstrate their interest and skills in nursery production, the women farmers group that we worked with has since been taken up into the community nursery program by the Ministry of Environment and Forestry to produce seedlings more generally, and in 2018 received a grant of Rp50,000,000, and produced 35,000 seedlings of Sengon. Ibu Sarmi is a key member of this group, and is also an acacia champion who has planted around 1700 of our acacia seedlings on her land, which is visible from the road. This is to raise awareness and interest in 'straight acacia' seedlings and technology amongst others in the area. Other demo plots established and managed by project staff in Karangmojo and Pacitan are proving to be a source of significant interest for those farmers who have either been taken there as part of the formal training, and those farmers around the demonstration plots, who are observing what is happening and are keen to trial it for themselves.
- Farmers in Hoa Binh and Hue have participated in the training and visited the demo plot, including the 166 farmers who have been formally trained, and a further 80 in the control group. Evaluation of these farmers as part of the study on adoption intention showed that they have all significantly increased their knowledge of acacia management and intend to use their improved skills to better manage their plantations.
- *Extension officers*– around 13 extension staff in Gunungkidul were trained in April 2019, and a similar number in Hoa Binh (Vietnam) in July 2018. These staff were trained in the key best practice acacia management, including the importance of good quality seed. They are important for encouraging adoption because they have access to a larger number of farmers than the project team, and are influential in their decision-making.

In 5 years time the capacity building in each of these groups of stakeholders is likely to have continued, though further investment is likely to be important for continuing the capacity building efforts into the future.

8.3 Community impacts – now and in 5 years

The target communities have been positively impacted by the project in a number of ways, including the following economic, social and environmental impacts:

8.3.1 Economic impacts

Key areas for economic impact include:

1. *Improvement in industrial plantations*. The project activities have directly helped the industrial companies to optimise their management of nutrients and control of weeds, with incremental gains in productivity. These might be worth an additional 5 m^3/ha/y, with a stumpage value of $10/$m^3$. Currently, these practices would be affecting a relatively small proportion of the whole estate, but this is likely to increase over time.
2. *Reducing risk of the transition from acacias to eucalypts*. The transition was already occurring as a business necessity, but there has been little knowledge about the comparative productivity of eucalypts and acacias, which this project has helped to address.
3. *Development of nursery businesses in Gunungkidul* – changing the perception of acacias as the 'tree that grows itself' to being a tree that can give good returns if it is managed well has opened up the opportunities for businesses to supply seedlings to the market. Currently there is one nursery business that has been established through the confidence that the project provided to the community in seedling production (they are currently producing sengon, *Paraserianthes falcataria*, seedlings) as a part of the MoEF community nursery program, and there is potential for others to similarly be established in future.
4. Establishment and management of 'straight acacias' in Gunungkidul. The distribution by the project of around 9000 seedlings and increased farmer interest and awareness of acacias and their management for optimal returns will bring a significant benefit to the growers equating to an estimated $200 net additional benefit per hectare per year.
5. *Improving management of acacias by farmers in Vietnam*. The training in improving management practices has resulted in a change of intention to improve farmer management of the 166 farmers involved in the study, and this will increase as the improved management techniques are circulated among other farmers.
6. *Changing from a pulpwood rotation to a sawlog rotation*, and introducing a thinning operation, as suggested by the economic analysis will increase returns by around $130/ha per year. This has not yet been adopted by farmers, but is likely to occur once the project team starts to socialise the outcomes from the economic analysis.
7. *Introduction of* A. auriculiformis *to central Vietnam*. The project demo plot in Hue is the first introduction of *A. auriculiformis* to central Vietnam, and the farmers are very interested in its productivity in comparison to *A*. hybrid. *A. auriculiformis* also has significant potential to be more resistant to damage from both typhoons and disease compared to acacia hybrid, so it presents a lower risk for farmers to grow in this typhoon-prone region. The risks of typhoons and disease on any particular smallholder plantation are difficult to ascertain, but of 10 VAFS plots established across Vietnam between 2006 and 2011 to explore sawlog options, 2 were destroyed, and 1 was badly damaged by typhoons before they had reached 5 years old, while a 4th experiment was badly impacted by pink disease at age 6. Conservatively, if 1 in 10 plantations could be spared from these losses, it would be worth around $30-40/ha/y for the farmers.

8. *Avoided deforestation* – due to improved supply of sustainably sourced timber for processing. The value of natural forest in Riau was estimated by Van Beukering et al. (2003) to be US$382/ha/y.

The estimated impact, both now and 5 years in the future, are shown in Table 13.

Table 13 - Estimated impact now and 5 years into the future for each of the categories above

Case (see above for explanation)	Country	Unit	Value attributable to project ($AUD/unit/y)	Units influenced now	Est. total value now ($M/y)	Units influenced in 5 years	Est. total value in 5 years ($M/y)
1	Indonesia	ha	25	20,000	0.5	200,000	5
2	Indonesia	ha	5	20,000	0.1	200,000	1
3	Indonesia	nurseries	5000	1	0.005	10	0.05
4	Indonesia	ha	200	10	0.002	1,000	0.2
5	Vietnam	ha	200	10	0.002	1,000	0.2
6	Vietnam	ha	130	0	0	10,000	1.3
7	Vietnam	ha	35	0	0	10,000	0.35
8	Indonesia	ha	382	2000	0.764	10,000	3.82
Total					1.373		11.92

8.3.2 Social impacts

The areas of social impact that are arising from this project include:

1. The project has had a focus on empowering women to take part in acacia training and management. In the past both men and women have worked on their acacia plantations, but the focus on training and capacity building has been on the men in both Indonesia and Vietnam. We have given equal priority to both women and men in the training sessions, striving for gender balance in our community engagement activities.
2. Improving smallholder incomes and reducing risk through improved management of their plantations, in both Indonesia and Vietnam will provide greater opportunities for education, healthcare, and development of transport infrastructure
3. Reducing conflict between industry and communities in concession areas through better understanding of productive potential, and better targeting of outgrower schemes.

Reduced need for industrial exploitation of the natural forest, allowing the traditional uses of the natural forest, such as non-timber-forest-product collection, to continue.

8.3.3 Environmental impacts

The environmental impacts include:

1. Optimisation of fertilizer and chemical use in plantation management, reducing off-site effects of excessive applications
2. Reduced pressure on harvesting of the natural forest by improving the capacity of the plantation area to sustainably keep producing wood for the processing plants.
3. Increased carbon sequestration from higher productivity plantations

8.4 Communication and dissemination activities

Several communication and dissemination activities have been held over the course of the project, including the following:

1. Participation of several project staff and multiple presentations at the IUFRO *Acacia* conference in Yogyakarta, July 2017, including keynote speech by the Project Leader, Daniel Mendham
2. Participation of several project staff and presentation at the IUFRO Eucalyptus Conference in Zhanjiang, China, October 2105.
3. Participation of Eko Hardiyanto and presentation at the IUFRO Eucalyptus Conference in Montpellier, France, September 2018.
4. Preparation and publication of at least 17 scientific manuscripts across the project team, as well as at least 5 publicly available reports.
5. Formal training of over 160 farmers in North and Central Vietnam
6. Formal training of over 100 farmers in Indonesia (Gunungkidul)
7. Formal engagement and training of over 100 industry staff in Indonesia
8. Distribution of genetically advanced ‘straight acacia’ seedlings with informal training (knowledge and advice) to over 150 farmers in Gunungkidul
9. Engagement with around 20 extension officers in Gunungkidul
10. Training of around 20 extension officers in North and Central Vietnam
11. Development and distribution of fact sheets. These have been picked up by at least one NGO, Rurality, in South Vietnam, who are using them to train farmers in best practice silviculture techniques
12. Development and distribution of a farmer-friendly *A. auriculiformis* manual
13. Visit of 13 farmers to *A. auriculiformis* processing mills in Klaten, Indonesia
14. Training of at least 5 PhD students

9 Conclusions and recommendations

9.1 Conclusions

This project has successfully delivered on its commitments to improving the sustainability and profitability of fast-growing plantations in Indonesia and Vietnam, and to improve the options and profitability for smallholder farmers in both countries. The project has left a legacy of many farmers who have knowledge and awareness of new and improved practices for growing acacias, and who are keen to adopt these new practices to grow high quality trees that will improve their production and profitability.

9.2 Recommendations

There are a number of recommendations arising from this project as follows:

1. Further work is needed to encourage adoption of ‘straight acacias’ in Gunungkidul. This is promising to fill a much-needed niche in farmers livelihood options across much of Java, but this project has only just started to embed acacias as a promising option in farmers minds. More work is needed to ensure that the adoption continues to reach its potential to improve lives and livelihoods of farmers in Indonesia
2. Industrial forestry in Indonesia continues to require sound scientific input into the productivity and sustainability of the plantation sector. The system is vulnerable to both biophysical and social shocks, because of the dynamic environment, both from a disease and growing environment perspective as well as the changing needs of the population in the areas surrounding the concession areas. Part of this will require researching the gap between R&D and operations, to ensure that the human and biophysical resources are working together to maximise productivity and sustainability
3. The project has developed and maintained a network of silvicultural and soil scientists from industry, government and university stakeholders. This is one of the only fora where these stakeholders can get together in a trusted environment to discuss shared problems and work collaboratively to solve key issues facing both Indonesia and Vietnam. This informal network has substantial value that should be supported and maintained into the future.
4. Support is needed for a scientific workshop to focus on sharing experiences and enhance the sustainability and resilience of tropical acacias and eucalypts, both at industrial and smallholder scale
5. Development of sawlog plantations in Vietnam needs further investment to make sure that it occurs equitably and sustainably. From this project we know that sawlogs can be a good and profitable choice for farmers, but there are risks involved that need further R&D to improve the reward/risk ratio for farmers.

10 References

10.1 References cited in report

Byron, N., 2016. *The Acacia Economy of Viet Nam. An Assessment*, Canberra: The Australian Centre for International Agricultural Research.

FAO, 2010. *Global Forest Resources Assessment 2010: Main Report*, Food and Agriculture Organization of the United Nations.

Fisher, H. & Gordon, J., 2007. *Improved Australian tree species for Vietnam*, Australian Centre for International Agricultural Research.

Harwood, C.E. & Nambiar, E.K.S., 2014. Productivity of acacia and eucalypt plantations in Southeast Asia. 2. Trends and variations. *International Forestry Review*, 16(2), pp.249–260.

Kallio, M., 2013. *Factors influencing farmers' tree planting and management activity in four case studies in Indonesia* Kanninen, Markku, ed., Helsinki, Finland: Viikki Tropical Resources Institute (VITRI).

Lindner, B., 2011. *The Economic Impact in Indonesia and Australia of Investment in Plantation Forestry Research, 1987-2009*, Australian Centre for International Agricultural Research.

Nambiar, E.S., Harwood, C.E. & Kien, N.D., 2015. Acacia plantations in Vietnam: research and knowledge application to secure a sustainable future. *Southern Forests: A Journal of Forest Science*, 77(1), pp.1–10.

Tyynelä, T., Otsamo, R. & Otsamo, A., 2003. Indigenous livelihood systems in industrial tree-plantation areas in West Kalimantan, Indonesia: Economics and plant-species richness. *Agroforestry systems*, 57(2), pp.87–100.

Van Beukering, P.J., Cesar, H.S. & Janssen, M.A., 2003. Economic valuation of the Leuser National Park on Sumatra, Indonesia. *Ecological economics*, 44(1), pp.43–62.

10.2 List of publications produced by project

Bich, N.V. et al., 2018. Contribution of Harvest Residues to Nutrient Cycling in a Tropical *Acacia mangium* Willd. Plantation. *Forests*, 9(9), p.577.

Bich, N.V. et al., 2019. Effect of residue management and fertiliser application on the productivity of a *Eucalyptus* hybrid and *Acacia mangium* planted on sloping terrain in northern Vietnam. *Southern Forests: a Journal of Forest Science*, pp.1–12.

Blackburn, D., Huong, V.D., Thanh, N.D., et al., 2019. *Solid wood property variations in early-age Acacia plantations grown in southern Vietnam*. CSIRO, Sandy Bay.

Blackburn, D., Huong, V.D. & Mendham, D.S., 2019. *The value of growing Acacias for sawlogs to smallholder farmers in Vietnam*. CSIRO, Sandy Bay.

Greenhill, M. et al., 2017. West Kalimantan industrial plantation scheme: twenty years on. *Forests, Trees and Livelihoods*, 26(4), pp.215–228.

Greenhill, M.P. et al., 2018. *Growing acacias in Vietnam - a mental model approach*. CSIRO, Floreat

Greenhill, M.P. et al., 2017. *Mental models of farmers performing tree management in Gunungkidul*. CSIRO, Floreat

Hardie, M. et al., 2018. Effects of eucalypt and acacia plantations on soil water in Sumatra. *New Forests*, 49(1), pp.87–104.

Hardie, M. et al., 2017. Role of site in the mortality and production of *Acacia mangium* plantations in Indonesia. *Southern Forests: a Journal of Forest Science*, 80, pp.37–50.

Hardiyanto, E.B., 2018. *Pelatihan Budidaya Pohon Acacia auriculiformis*, Universitas Gadjah Mada, Yogyakarta.

Huong, V.D., Mendham, D.S. & Close, D.C., 2016. Growth and physiological responses to intensity and timing of thinning in short rotation tropical Acacia hybrid plantations in South Vietnam. *Forest Ecology and Management*, 380, pp.232–241.

Inail, M.A., Hardiyanto, E.B. & Mendham, D.S., 2019. Growth Responses of Eucalyptus pellita F. Muell Plantations in South Sumatra to Macronutrient Fertilisers Following Several Rotations of Acacia mangium Willd. *Forests*, 10(12), p.1054.

Mendham, D. et al., 2017. Nutrient management of contrasting *Acacia mangium* genotypes and weed management strategies in South Sumatra, Indonesia. *Australian Forestry*, 80(3), pp.127–134.

Mendham, D. & White, D., 2019. A review of nutrient, water and organic matter dynamics of tropical acacias on mineral soils for improved management in Southeast Asia. *Australian Forestry*, 82(sup1), pp.45–56.

Nambiar, E., Harwood, C. & Mendham, D., 2018. Paths to sustainable wood supply to the pulp and paper industry in Indonesia after diseases have forced a change of species from acacia to eucalypts. *Australian Forestry*, 81(3), pp.148–161.

Permadi, D.B., Burton, M., Pandit, R., Race, D. & Walker, I., 2018. Local community's preferences for accepting a forestry partnership contract to grow pulpwood in Indonesia: A choice experiment study. *Forest Policy and Economics*, 91, pp.73–83.

Permadi, D.B., Burton, M., Pandit, R., Race, D., Ma, C., et al., 2018. Socio-economic factors affecting the rate of adoption of Acacia plantations by smallholders in Indonesia. *Land use policy*, 76, pp.215–223.

White, D.A. et al., 2016. *Water Use and Water Productivity of* Eucalyptus *Plantations in South-East Asia. ACIAR Technical Reports Series No. 89*, Australian Centre for International Agricultural Research, Canberra.

11 Appendixes

11.1 Appendix 1: Review of tropical *Eucalyptus pellita* performance and response to site and soil conditions

Introduction

There is a perception held by growers that *E. pellita* is more challenging to grow across a range of site types than *A. mangium*. Given the transition that is underway from *A. mangium* to *E. pellita*, this review aims to understand the evidence behind this perception, and look for potential mechanisms to overcome it. The two key commercial species, *A. mangium* and *E. pellita* have been included in the review to understand the contrast between the two and any considerations that a transition from *A. mangium* to *E. pellita* would need to cover. This review is an extension of the review of *A. mangium* responses to nutrients, water and organic matter that was recently published (Mendham and White, 2019).

Natural ranges of E. pellita and A. mangium

Eucalyptus pellita

Eucalyptus pellita naturally occurs in far north Queensland, southern Papua New Guinea (PNG) and in the southern part of the Papua province of Indonesia. It tends to occupy soils with low pH (~5.0), low fertility and which are free-draining sands or loams in Queensland and PNG, and red clays and clay loams in Papua (Doran and Turnbull, 1997). The rainfall in its natural range is 1000-4000 mm. At the lower end of the rainfall spectrum, *E. pellita* occupies water-accumulating parts of the landscape such as lower slopes and alongside streams, but can tolerate dry seasons of up to six months if established in deeper soils (Clarke et al, 2009). The Papua provenances are typically not exposed to a significant dry season. It is therefore perhaps not surprising that there have been several failures of plantations at sites with <1300 mm annual rainfall where soils were shallow with low moisture holding capacity (Clarke et al., 2009).

Acacia mangium

Acacia mangium also naturally occurs in far north Queensland and into PNG and Papua, but it also extends further north and west than *E. pellita* into western West Papua, and the islands of Aru and Ceram (Boland et al., 2006). It is typically found in open forest that is on the fringes of rainforest.

Responses of E. pellita and A. mangium to site and soil in planted stands

There are few published studies that have specifically explored the impact of site and soil characteristics on the productivity of *E. pellita* or *A. mangium*. However, the 'community rainforest reforestation program (CRRP)', which was established in north Queensland in 1993, has provided a valuable mix of species and environments, which have been analysed in a range of studies (Bristow et al., 2005, Erskine et al. 2005, Manson et al. 2013). Bristow et al. (2005) found that *E. pellita* was fast growing (classified as >2 cm/y diameter at breast height [dbh] increment) in almost all combinations of rainfall and soil types, including those of basaltic, metamorphic and alluvial origin, although *E. pellita* in the alluvial soils also fell into the 'moderate' growth category of 1-2 cm/y. *Acacia mangium* was not as well represented across the measured plots, but it had the highest diameter growth in the two situations where it was represented: rainfall of 1500-2500 mm/y, in both metamorphic and alluvial soils. Manson et al. (2013), in a more detailed analysis of the CRRP dataset, also found that *E. pellita* productivity was not influenced by any of the soil parameters they assessed, including soil type, texture, water holding capacity or saturated conductivity. The only factor that appeared to be significantly correlated with *E. pellita* productivity in the study of Manson et al. (2013) was the average number of raindays per month.

Nurudin et al. (2013) explored the relationships between site and soil characteristics and productivity of *A. mangium* across nine sites in South Sumatra. Low productivity sites were characterised by poorer subsoil drainage linked to shallower depths of soil to plinthic horizons; productivity was classified as high in profiles that had at least 75-100 cm of well-drained soil. A follow-up study in Riau did not find similar relationships between productivity and soil characteristics (Siregar et al., in Mendham et al. 2015), probably because the soils in Riau are more uniform and typically better drained than those that were studied in South Sumatra.

Genotype x environment interactions in A. mangium and E. pellita

From the studies presented above, there appears little evidence of high site specificity in either of *A. mangium* or *E. pellita*, with the exception of lower productivity at waterlogged sites with *E. pellita*. However, the question arises as to whether there may be an interaction between site, genotype and management that explains some of the observed variation in growth across different site types. Harwood and Williams (1991) reported on the performance of planting material from five provenances of *A. mangium* across several trial sites in Malaysia, northern Australia, Thailand, China, Taiwan, Fiji and Bangladesh. Although the seed sources were not exactly the same at all of the sites, there were consistent differences in performance across the experiments, with greater growth rates for provenances from Papua New Guinea, and far north Queensland than Eastern Indonesia. Higher productivity was observed at sites closer to the equator and there was a site × provenance interaction, suggesting that there may be scope to improve productivity through matching genotypes to sites. However, a later study (Harwood et al., 2015) concluded that G × E effects were mostly only evident at very contrasting sites with improved seed and selected clones of *A. mangium*, *A. auriculiformis* and *A. crassicarpa*, for example those in north *vs* south Vietnam; within a narrower range of sites e.g. central *vs* north Vietnam, G × E effects were not as pronounced, and high performing material tended to exhibit high performance across most sites.

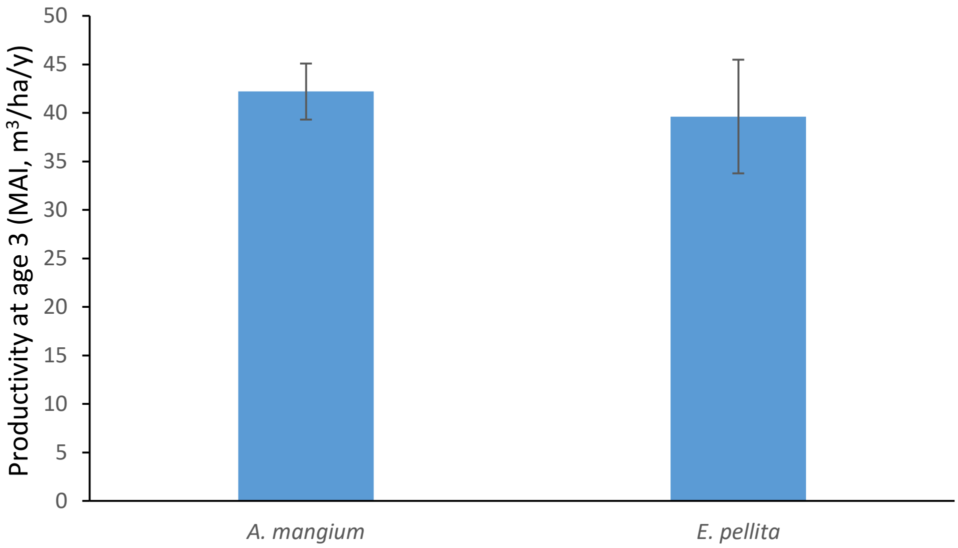
Eucalyptus pellita has been studied less than acacias. Leksono (2008) found that there was a consistent difference between unimproved material from a seed orchard with no selection and improved material from a 2nd-generation seed orchard, across four sites in Sumatra and Kalimantan up to age 3 y, suggesting no G × E interaction across those sites. Perhaps reflecting a greater contrast of site types, a smaller multi-site provenance study found that PNG provenances performed better than Queensland provenances at sites in Malaysia and on Melville Island in northern Australia, but this was less evident at a site in Queensland (Harwood et al., 1997). Harwood et al. (2015) has suggested that clones may be more sensitive than seedlings for detecting differences of genetic material in their responses to environment, but no literature as yet appears to explore G × E interactions with *E. pellita* clonal material. It also needs to be recognised that specific traits can be an important component of G × E response in some environments. For example, Luo et al. (2006) found that *E. pellita* derived from Queensland provenances was much more resistant to typhoon damage in China than material that was derived from PNG and Indonesian provenances, presumably associated with the regular occurrence of cyclonic winds Queensland.

Productivity potential in South Sumatra and Riau

When site, genotype, silvicultural management, and disease factors are managed appropriately, both acacias and eucalypts grown in Sumatra have the potential for very high productivity by world standards. For example, the mean annual increments (*MAI*) of the best performing treatments in experiments that have been established under ACIAR projects (see Mendham et al. 2011, 2015) with *Acacia mangium* (n=8) and *Eucalyptus pellita* (n=5) were both close to 40 m^3/ha/y (Fig. A1), although eucalypt yields were more variable. However, while this reported productivity of *A. mangium* is high, it needs to be recognised that these levels are often no longer achievable because of *Ganoderma* root-rot and *Ceratocystis* fungal wilt diseases. Thus there have been instances in South Sumatra and Riau where survival of *A. mangium* has been so low that by the end of the rotation the plantation is no longer commercially harvestable. As *E. pellita* was the species of choice to replace *A. mangium*, much of the information reported on *E. pellita* here is for the first rotation. Genetic material and management strategies for *E. pellita* are currently undergoing rapid development and potential yields are improving.

As the pulp productivity (t of pulp per t of wood) of *A. mangium* is less than that of *E. pellita*, the volume productivity of *A. mangium* needs to be significantly greater than that of *E. pellita* to provide the same yield of end product. Mendham et al. (2015) indicated that the pulp productivity of improved *E. pellita* in the Perawang pulp mill in Riau is around 30%, (i.e. 300 kg of air dry pulp is produced per tonne of wood) while for *A. mangium* it was around 20%. Thus around 50% more *A. mangium* wood was required to yield the same amount of pulp compared to *E. pellita* wood. Key factors driving this increase in pulp productivity are the higher wood density of *E. pellita*, and its higher pulp yield.

Fig. A1 – Average productivity of A. mangium and E. pellita across the experiments established through the ACIAR projects. Experiments are in both South Sumatra (n=7) and Riau (n=5) provinces in Sumatra.



Although the productivity of both species across a range of experiments was around 40 m^3/ha/y (Fig. A1), these were typically obtained under ideal management conditions. The actual productivities achieved on an operational basis are and will remain lower because of the lower intensity of management, greater site variability, and exposure to disease than tends to be the case on experimental sites. Harwood and Nambiar (2014) reported operational-level *MAI* of *A. mangium* to be around 27-30 m^3/ha/y in the 1st and 2nd rotations across six subregions in Sumatra, but that 3rd-rotation *MAI* was around 11 m^3/ha/y, primarily due to disease. They also reported average first rotation *E. pellita MAI* of around 17 m^3/ha/y, though clearly *E. pellita* has potential for much higher yields if managed appropriately (Fig. A1). It needs to be recognised also that the Harwood and Nambiar (2014) data represent industrial plantations in Sumatra. Other studies have found a bigger gap between potential yield and that achieved by smallholder growers; for example Mendham et al. (2011) found that the average *MAI* of *A. mangium* grown by smallholders in South Sumatra was around half that of the nearby industrial grower because of poorer attention to management.

Wood supply requirements to meet processing capacity

There are currently five major pulp mills in Indonesia and four are in Sumatra; an additional new mill is expected to be commissioned in South Sumatra in 2016 (Casson et al., 2015). The combined stated pulp production capacity of these mills is around 9.1 Mt of air dried pulp per year (Table 1). If losses due to processing (harvesting and transport) and fire of 25% i.e. the difference between standing volume and volume entering the mill gate, and conversion rates of 3.35 t of *E. pellita* wood and 4.90 t of *A. mangium* wood to 1 t of air-dried pulp, are assumed, this pulp capacity equates to a total annual requirement of either 40.8 Mt of *E. pellita* wood, or 59.7 Mt of *A. mangium* wood. A total planted area of around 2.0 Mha of either species or a mix of the two could be obtained if productivity levels of 20 m^3/ha/y for *E. pellita*, or 30 m^3/ha/y for *A. mangium* are assumed (Table A1). This estimate of the required area aligns well with the approximately 1.68 Mha of industrial timber plantations that were established between 2006 and 2011 (Casson et al. 2014). The Indonesian government has a 2030 Forestry Masterplan to increase the contribution of the forestry sector to GDP by 300%. The plan also calls for an increase in the timber plantation area to 14.7 Mha and greatly expanded processing capacity (MoF, 2012). While the existing and proposed areas of plantations are large by world standards, consideration should be given to ensuring that newly established plantations are founded on a sustainable basis. One of the key concerns for sustainability of these systems internationally has been the reliance on drainage and afforestation of large areas of peat (Miettinen et al., 2012). Without contributing to the discussion around the sustainability of peat, it is clear that future acceptability of plantation systems will demand that mineral soils are the main focus of new planting areas.

Table A1 – Assumptions and calculations to estimate area of plantations required to meet Indonesian national pulp production capacity

Species	*A. mangium*	*E. pellita*
Plantation productivity (m^3/ha) [A]	30	20
Pulp productivity (t air dry pulp per green tonne of wood) [B]	4.9	3.35
Losses between stand and mill (due to eg. harvest and processing) (%) [C]	25	25
Existing and planned pulp capacity (Mt/y) [D]	9.1	9.1
Standing timber required to meet existing and planned pulp production capacity of 9.1 Mt/y (Mt/y)	59.7	40.8
Area of each species to meet the full pulp production capacity (M ha)	1.99	2.04

Conclusions

E. pellita has a track record of lower volume productivity than *A. mangium* across the industrial estates of Sumatra, but we conclude that there is no systematic evidence to suggest that *E. pellita* is more site specific than *A. mangium*, or that it has lower inherent capacity to produce pulp. There is, however, substantial differences in genetic potential of *E. pellita* that has been deployed, which may or may not interact with the site characteristics, but this has yet to be explored.

References

Boland DJ, Brooker MIH, Chippendale G, Hall N, Hyland B, Johnston R, Kleinig D, McDonald M, Turner J. 2006. Forest trees of Australia. CSIRO publishing.

Bristow M, Erskine PD, McNamara S, Annandale M. 2005. Species performance and site relationships for rainforest timber species in plantations in the humid tropics of Queensland. In: Erskine, PD, Lamb, D. and Bristow, M., editor. Reforestation in the tropics and subtropics of Australia: Using rainforest tree species. Canberra: RIRDC. p. 84–100.

Casson A, Muliastra Y, Obidzinski K. 2015. Land-based investment and green development in Indonesia: Lessons from Berau district, East Kalimantan. Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Casson A, Muliastra YIKD, Obidzinski K. 2014. Large-scale plantations, bioenergy developments and land use change in Indonesia. Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Clarke B, McLeod I, Vercoe T. 2009. Trees for farm forestry: 22 promising species. RIRDC.

Doran JC, Turnbull JW. 1997. Australian trees and shrubs: species for land rehabilitation and farm planting in the tropics. Canberra: Australian Centre for International Agricultural Research (ACIAR).

Erskine PD, Lamb DD, Bristow M. 2005. Reforestation in the Tropics and Subtropics of Australia Using Rainforest Tree Species: A Report for the RIRDC/Land & Water Australia/FWPRDC/MDBC Joint Venture Agroforestry Program. Canberra: Rural Industries Research and Development Corporation.

Harwood C, Williams E. 1991. Review of provenance variation in growth of *Acacia mangium* Willd. Forest Genetic Resources Information (FAO).

Harwood CE, Hardiyanto EB, Yong WC. 2015. Genetic improvement of tropical acacias: achievements and challenges. Southern Forests: a Journal of Forest Science 77:11–18.

Leksono B, Kurinobu S, Ide Y. 2008. Realized genetic gains observed in second generation seedling seed orchards of *Eucalyptus pellita* in Indonesia. Journal of forest research 13:110–116.

Manson DG, Schmidt S, Bristow M, Erskine PD, Vanclay JK. 2013. Species-site matching in mixed species plantations of native trees in tropical Australia. Agroforestry systems 87:233–250.

Mendham DS and White DA (2019). A review of nutrient, water and organic matter dynamics of tropical acacias on minerali soils for improved management in SE Asia. Australian Forestry *in press*

Mendham DS and White DA (2019). A review of nutrient, water and organic matter dynamics of tropical acacias on mineral soils for improved management in SE Asia. Australian Forestry *in press*

Mendham D, Rimbawanto A. 2015. Increasing productivity and profitability of Indonesian smallholder plantations. Final Report (FR2015-17). Australian Centre for International Agricultural Research, Canberra, Australia.

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 Agricultural Research.

Miettinen J, Hooijer A, Wang J, Shi C, Liew SC. 2012. Peatland degradation and conversion sequences and interrelations in Sumatra. Regional environmental change 12:729–737.

MoF. 2012. rencana kehutanan tingkat nasional (rktn) tahun 2011-2030. Indonesia: Ministry of Forestry.

Nurudin M, Ohta S, Hardiyanto EB, Mendham DS, Wicaksono A, Heriyanto J, Watanabe M. 2013. Relationships between soil characteristics and productivity of *Acacia mangium* in South Sumatra. Tropics 22:1–12.