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Final report

Small research and development activity

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prepared by	Chris Beadle , CSIRO
co-authors/ contributors/ collaborators	Pham The Dung, Tran Thanh Cao, Kieu Tuan Đat, Pham Van Bon, Le Thanh Quang and Chris Harwood
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2 Executive summary

This small research activity was used to enhance and extend the outputs of an earlier four-year project (FST/2006/087) that was focused on developing silvicultural systems for producing saw logs from *Acacia* hybrid plantations. This project established three Core (large) and seven Satellite (small) trials in which thinning and fertiliser-at-thinning treatments were represented. In addition, one Stock-type trial was established. Seven Technical Information Sheets which describe activities associated with soil and stand management for sawlogs were produced, as was a Decision Support System with look-up tables that can be used to evaluate site productivity. A framework for an Economic Model that allows comparative evaluation of financial returns from contrasting silvicultural systems, including for sawlogs, was also developed. There was a very strong response of tree diameter to thinning, at either age two or age three years, to 600 or 450 stems/ha which became statistically significant as early as six months after thinning. This response increased with intensity of thinning and showed that inter-tree competition for resources is very high in these fast-growing acacia plantations.

The main activity of this Small Research Activity was a training workshop for Extension Officers servicing smallholder acacia-based forestry and Technical Staff servicing company-based acacia forestry. It was given by local ACIAR project staff using the materials developed by FST/2006/087. Just before this workshop, a demonstration plantation was established that was used to train workshop participants in the use of the silvicultural skills required for the establishment and management of acacia plantations for sawlog production. Crucially, the additional resources provided through this Small Research Activity have facilitated the continued measurement of the Core Trial established at Phan Truong Hai in Binh Phuoc province in 2008 so that a proper appreciation of the economic credentials of sawlog production from *Acacia* hybrid could be gained by allowing the measurement program to be extended to age six and age seven years. The resources have also allowed the continued maintenance and measurement of eight of the other ten trials established by the original project and enabled their continued use for supporting post-graduates studies through John Allwright Fellowships as well as adding value to anticipated publications from the large project.

The 2.5-day training workshop for 27 Extension Officers and Technical Staff servicing small-holder and company-based acacia forestry was held at the Southern Centre for Application of Forest Technology and Science (SCAFTS). At registration, participants were given a hard copy of the Final Report on FST/2006/087 (in Vietnamese) and a USB which contained all the presentation material and EXCEL software used at the workshop. On Day 1 there were presentations on soils, site preparation, weed control and fertiliser application, and pruning and thinning. This session was used to train participants in the use of the Technical Information Sheets developed by FST/2006/087. In the afternoon, three interactive sessions introduced and trained participants in the use of the EXCEL spreadsheets to support data collection, the Decision Support System and the Economic Model. The structure allowed for questions and discussion after each presentation and a general discussion at the end of the afternoon session. On Day 2, the practices of site preparation, planting, chemical weed control, fertiliser application, pruning and thinning were demonstrated at the Tan Phu Field Stations. On Day 3, VAFS leading expert on cutting practice from clonal hedges explained the history of clonal development of *Acacia* hybrid and *A. auriculiformis*. The hedge garden was then used to illustrate cutting practice and clonal-hedge management. A 40-minute DVD of the workshop has been posted on the VAFS and National Extension Centre's websites: http://www.youtube.com/watch?v=6-ZY10ygi_Y

The demonstration plantation was established by The Southern Centre for Application of Forest Technology and Science (SCAFTS) to serve two purposes. The first was for practical training to workshop participants in establishment techniques for acacia plantations that are to be managed for sawlogs. SCAFTS are now managing this trial in the long term to support their mission which is to provide professional assistance and advice to smallholders and companies in the public and private sector who want to develop sawlog plantations. To create a wider interest, both *Acacia* hybrid and *A. auriculiformis* are represented in the plantation.

The nine experimental trials established by FST/2006/087 still present were measured at least once during the period of this Small Research Activity. The owners of the four plantations on private land gave their support to the continued measurement programs until these were completed, for example at Phan Truong Hai for the economic analysis until July 2015. All Satellite trials on public land remain secure; four are still being used by two John Allwright Fellows. All the data is recorded on Master Spreadsheets that were developed during the tenure of FST/2006/087.

Study of the supply chain in South-east Vietnam confirmed demand for three wood products: pulpwood (4-10 cm diameter), small sawlogs (10-18 cm) and large sawlogs (>18 cm and at least 2.2 m in length). Prices for standing timber calculated at the mill-gate after subtracting harvesting and transport costs averaged USD32.1/m^3 for pulpwood, USD39.2/m^3 for small sawlogs and USD85.1/m^3 for large sawlogs. At Phan Truong Hai, standing volume remained higher in the unthinned (1143 stems ha^{-1}) than the thinned (600 and 450 stems ha^{-1}) treatments at either age two (2y) or three (3y) years through to age 5.9 y. At this age the estimated mean annual increment of the unthinned experimental treatment was 23.6 m^3/ha. However, the thinned treatments yielded greater volumes of large sawlog than the unthinned treatment. At age 5.9 y, the 600-3y treatment had the highest NPV (USD2176/ha) under the base assumption of a 5.3% real interest rate. The NPV of the unthinned treatment was slightly lower at USD2016/ha. Sensitivity analysis for the unthinned and 600/3y treatments was carried out by varying interest rate (6%, 10% and14%) and evaluating three actual product price scenarios (median product prices, lowest price and highest price for the three types of wood). In the least favourable scenario, in which log prices were lowest and interest rate was 16%, the NPV of the unthinned treatment was still positive (NPV = USD223 / ha) at age 5.9 y. Based on projected stand value at age 6.9 y, profit growth in the seventh year of stand growth would be much higher than the opportunity cost of the capital obtainable by harvesting at age 5.9 y, because of the substantial increases in volumes of large sawlogs for all experimental treatments.

Advanced drafts of two papers, the first on tree growth to age two years and thinning response to age three years, at the seven Satellite trials, the second based on the economic analysis based on the Core trial at Phan Truong Hai, were prepared. Both require further development before submission; in the case of the economic analysis, it was decided that a stronger paper would emerge if it also incorporated data collected from the Satellite trials.

3 Introduction

The smallholder sector in Vietnam manages approximately half the total area of its plantation forests. The most widely planted species are tropical acacias; the majority of the wood produced is pulpwood. While these new plantation resources were being established, Vietnam also rapidly developed what has become a very successful export furniture industry, much of it based on acacia wood; however the majority of this wood has been and remains imported. The current policy of the Government of Vietnam is to increase self-sufficiency in sawlog supply (MARD 2010).

A financial analysis (Blyth and Hoang 2013) showed that there may be significant economic advantages for typical smallholders of sawlog over pulpwood production. On this basis, Project FST/2006/087 investigated the suitability of silvicultural systems that optimise the production of sawlogs from the most commonly planted species, *Acacia* hybrid (*Acacia mangium* × *Acacia auriculiformis*), by exploiting its very high early growth rates and minimising the length of rotation required to attain a commercial log size.

Project outputs of FST/2006/087 included a package of extension materials: (i) a Decision Support System (DSS) with look-up tables that can be used to evaluate site productivity; (ii) a template for Economic Analyses that allows comparative evaluation of financial returns from contrasting silvicultural systems, including for sawlogs; and (iii) seven Technical Information Sheets giving advice on soils and the management of silvicultural inputs for sawlog production. The key audience for these materials is Extension Officers who service the smallholder sector at provincial and district levels.

This Small Research Activity (SRA), which follows on from FST/2006/087 aims to extend the scientific knowledge on growing Acacias for sawlogs in Vietnam. This is achieved through two objectives:

Objective 1: To train 24 Extension Officers in the use and dissemination of seven technical information sheets (TIS), a decision support system (DSS) and an economic model (EM) developed by ACIAR Project FST/2006/087

Objective 2: Maintain trials and conduct annual measurements in experimental plantations established during tenure of FST/2006/087; submit two papers for publication in regional journal

The Forest Science Institute of South Vietnam (FSIS) of the Vietnamese Academy of Forest Sciences (VAFS), the major Vietnamese partner in FST/2006/087, created a new facility at the end of the project period called “The Southern Centre for Application of Forest Technology and Science (SCAFTS)”; its brief was to manage FSIS’ field stations. Its first Director (until 1st October 2015 when he was appointed Director FSIS) was Dr Kieu Tuan Dat who was latterly Co-ordinator responsible for all experimental sites established by FST/2006/087. Part of this brief is to promote the findings of the project with companies and growers of plantation acacias.

ACIAR supports research for development and therefore it is important that outputs of research projects are made available in an appropriate manner to the intended users of the information, in this case the Extension Officers and smallholders. A recommendation from FST/2006/087 was that “VAFS should hold ‘Train-the-trainers workshops’ for Extension Officers in the practice of silviculture for acacia sawlog production”. The primary teaching aids would be the extension materials referred to above. This form of workshop became the primary focus of this Small Research Activity (FST/2014/017). A crucial requirement for the promotion new forestry practices by Extension Officers to smallholders is being able to demonstrate their benefits. To meet this requirement, and as part of this workshop, a Demonstration Trial would be established that would be used as a learning resource for the Extension Officers attending the workshop, and also as a model plantation that SCAFTS can use to illustrate management practices for sawlog plantations to their prospective clients.

The Economic Analysis developed by FST/2006/087 was based on data collected during the project period (2008-2012) at the Core Trial at Phan Truong Hai which had been established in August 2008. To ensure that this analysis was based on real data that was current and closer to the anticipated harvest date, FST/2014/017 would encompass this activity. In addition a commitment was given to remeasure the other ten other trials, two Core and eight Satellite, established by FST/2006/087, as well as providing resources for their continued maintenance. At the last Business and Planning Meeting of FST/2006/087 in September 2012, a commitment was made to the writing of up to ten scientific papers based on outputs from the project. Some of these papers were reliant on continuation of the measurement program until at least 2016; some are linked to postgraduate students on John Allwright Fellowships at the University of Tasmania. This SRA commenced in May 2014 and concluded in December 2014.

4 Workshop and Field Demonstration for Extension Officers

Programme

The 2.5-day training workshop for Extension Officers and Technical Staff servicing smallholder and company-based acacia forestry, respectively, for high-value wood products was based at the Southern Centre for Application of Forest Technology and Science (SCAFTS, **Plate 4.1**), Thu Dau Mot town. Delivery was in Vietnamese by staff involved in FST/2006/087 (Dr Kieu Tuan Dat and Mr Pham Van Bon, formerly FSIS, HCMC but now based at SCAFTS) and Dr Pham The Dung, Mr Tran Thanh Cao, Mr Le Thanh Quang and Mr Vo Trung Kien (FSIS, HCMC).

At registration, participants were given a hard copy of the Final Report on FST/2006/087 (in Vietnamese) and a USB which contained all the presentation material and EXCEL software used at the workshop (**Plate 4.2**)

Day 1 (9^{th} September): In the morning, Dr Dung and Dr Chris B (translated by Mr Quang) addressed the objectives of Project FST/2006/087 and the development of acacia-based plantation forestry for solid-wood products. This was followed by presentations on soils (Mr Quang), site preparation (Mr Kien), weed control and fertiliser application (Mr Dat) and pruning and thinning (Mr Bon). This session was used to train participants in the use of the Technical Information Sheets. In the afternoon, three interactive sessions introduced and trained participants in the use of EXCEL spreadsheets to support data collection (Mr Bon), the Decision Support System (Mr Dat) and the Economic Model (Mr Cao) (**Appendix 9.1**). Participants had the relevant software open on their laptops during these sessions so that they could follow instructions. The structure allowed for questions and discussion after each presentation and a general discussion at the end of the afternoon session.

Day 2: The practices of site preparation, planting, chemical weed control (mixing and application of herbicide), fertiliser application, pruning and thinning were demonstrated at FSIS's Tan Phu and Phu Binh Field Stations. The results from three trials at Phu Binh (**Appendix 9.2**) were used to illustrate the effects of various silvicultural treatments and best practice on growth and productivity of *Acacia* hybrid and *A. auriculiformis*.

Day 3: The participants were taken to FSIS Trang Bom. Mr Nguyen Van Chien, VAFS leading expert on cutting practice from clonal hedges explained the history of clonal development of *Acacia hybrid* and *A. auriculiformis*. The hedge garden was then used to illustrate cutting practice and clonal-hedge management.

Plate 4.1: SCAFTS, Le Hong Phong Street, Thu Dau Mot City, Binh Duong province, where Day 1 of the workshop was held; **Plate 4.2**: FST/2006/087 Final Report and USB containing workshop presentations and software developed by project.

Participants

The 27 participants were drawn from three adjacent provinces, Binh Duong, Binh Phuoc and Dong Nai that are strongly associated with acacia-based plantation forestry in Vietnam (**Table 4.1**). Thirteen participants were from the public sector, eight of which were Extension Officers, and the others technical staff from government enterprises. Twelve technical staff from the private sector represented seven companies investing in acacia forestry. This participant mix best represented the regional interest in the outputs that were developed by FST/2006/087. The mission of SCAFTS is to develop these outputs as part of MARD policy to expand the proportion of Vietnam's plantation estate managed for sawlogs. Two of the trainers at the workshop, Mr Dat and Mr Bon, are based at SCAFTS and are, respectively, Director and scientist responsible for further developing planting stock that is best suited to sawlog production. This workshop was therefore an important forum for putting SCAFTS on the map and illustrating to potential clients its knowledge and skills for helping to deliver on MARD policy.

The "other" participants were Mr Ngô Văn Đây, the Deputy Head of the National Extension Centre in South Vietnam and Mrs Đào Thị Kim Tuyết, a lecturer at Nong Lam Agroforestry University, HCMC. They were invited to Day 1 of the workshop so that they could be made aware of these new developments in plantation forestry, and also to gain their support for further dissemination of this knowledge. Mr Trần Thanh Sơn was also in attendance on Day 1 so that he could report on the workshop in Agriculture News.

Mr Lê Văn Hà and his assistant were engaged to make a 40-minute DVD of the workshop.

http://www.youtube.com/watch?v=6-ZY10ygi_Y

This DVD has been posted on the VAFS and National Extension Centre's websites.

Table 4.1: List of participants

Name	Organisation
Binh Duong	
Nguyễn Văn Tấn	Department of Agriculture and Rural Development - Binh Duong
Nguyễn Văn Thế	Binh Duong Extension
Đậu Hoài Thanh	Binh Duong Extension
Nguyễn Thị Thanh Thảo	Department of Science and Technology - Binh Duong
Binh Phuoc	
Trần Thị Hằng	Binh Phuoc Forestry Department
Liêu Lý Bình	Binh Phuoc Extension
Nguyễn Trường Sơn	Binh Phuoc Extension
Nguyễn Văn Đắc	Binh Phuoc Extension
Dong Nai	
Vũ Văn Dũng	Dong Nai Forestry Department
Vũ Quốc Ái	Dong Nai Extension
Nguyễn Trọng Tài	Dong Nai Extension
Tô Bá Tiến	Dong Nai Extension
Kiều Phương Anh	South-East Centre for Forest Research and Experiment - Dong Nai
Companies	
Nguyễn Sơn	Hai Vuong Joint Stock Company - HCM
Đào Nguyên Sinh	Hai Vuong Joint Stock Company - HCM
Kim Dong Hyuk	Sangrim Johap Vina - Korea
Trần Văn Định	Sangrim Johap Vina - Korea
Vũ Văn Nhiên	La Nga Forestry Company (Vinafor)
Đặng Văn Hiện	Xuan Loc Forest Management Board
Trần Tín Hậu	Eco Board Vina - Japan
Phùng Hồng Phúc	Eco Board Vina - Japan
Nguyễn Hoàng Thụy	Khai Vy Agro - Forest Company
Đỗ Quang Trường	Binh Duong Forest Company
Other	
Ngô Văn Đây	Director, National Extension Center, HCMC
Đào Thị Kim Tuyết	Agro-Forestry University, HCMC
Trần Thanh Sơn	Reporter of Agriculture News
Lê Văn Hà	Binh Duong TV Reporter

The Heads of FSIS's Ecology and Environment (MSc. Hoàng Văn Thơi), Silviculture (MSc. Phùng Văn Khen) and Tree Breeding (MSc. Nguyễn Văn Thiết) Departments, two FSIS researchers (MSc. Nguyễn Thị Hải Hồng and MSc. Đặng Phước Đại), the Deputy Director of SCAFTS (MSc. Trần Đức Thành) and SCAFTS Head of Technical Section (MSc. Kiều Mạnh Hà) also attended Day 1 of the workshop. Mrs. Quyên (FSIS) provided administrative support.

Discussion on Day 1 (Plates 4.3, 4.4 and 4.5)

Plate 4.3: A break for some English; Dr Chris Beadle answering a question from the floor; **Plate 4.4**: A questioner raising a discussion point; **Plate 4.5**: Mr Cao addressing the Economic Model to his audience.

Vigorous discussion was encouraged and there was no shortage of questions. **Table 4.2** summarises the issues and concerns raised by participants at the formal session on Day 1. Participants had the opportunity to learn how to implement the silvicultural practices discussed on Day 1 and their benefits at the Field Demonstration on Day 2 of the workshop.

From this discussion, the following emerges:

- There is no consensus on slash retention during site preparation. While research trials indicate a benefit in terms of yield increase and sustainability of yield, risk of termite damage and fire risk tend to prevail and burning remains the preferred option. These risks need to be quantified and advice provided on managing these risks. This includes minimising the perceived fire risk following slash retention during thinning. Good information needs to be disseminated of best practice for slash management that includes expected rates of litter breakdown.
- The arguments for using chemical weed control, which is considered expensive *vs*. other approaches to weed control e.g manual and ploughing need further consideration. Ploughing exposes soil to erosion, destroys fine roots and interferes with nutrient cycling. Manual weed control is not effective against highly competitive weeds like bamboo. Weed control was not a specific focus of FST/2006/087. To provide the best current advice, a Technical Information Sheet could be developed that uses existing information from other projects. However more research may be required to fully understand the potential negative effects of ploughing on yield.
- At age 6 years, the NPVs of the experimental regimes differ by a maximum of 12%. The higher stockings, greater number of sawlogs, and higher value of thinned trees combined to make the 600/thinned at age 3 years regime financially the most attractive, and more attractive than pulpwood or the 450 regimes. It is not yet clear how this may change in later years.
- The DSS is a work-in-progress. Its accuracy will improve with time and it will be updated as information from new experiments and new environments becomes available. In its current form it provides the best possible estimates of how soil type and silvicultural inputs affect yield and log distribution. It is meant to be a guide only and to help Extension Officers and Technical Staff provide the right advice to growers. This should be done in combination with the Economic Model.
- Tree breeding of acacias in Vietnam has been focused to date on selection for pulpwood. Preferred wood properties for saw-logs differ from those for pulpwood.

Table 4.2: List of questions and answers from Discussion sessions on Day 1.

No	QUESTIONER	QUESTION	ANSWER
1	Mr Định – Sangrim Johap Vina - Korea	Slash retention is associated with increased risk of termite damage. How is this risk minimised?	Yes, this is correct though we have not quantified this risk. On sites where the risk is considered high, a termaticide (Lenfos 50EC with Chlorpyrifor Ethyl 500g/litter) is applied up to age three months.
2	Mr Dũng – Dong Nai, DARD	Slash retention is also associated with increased fire risk. How can this risk be minimised?	Yes, this is correct. In Vietnam, plantation areas are often intermixed with residential areas so fire risk must be understood. Another issue is the collection of slash for firewood. MARD is developing policy advice on suitable land-use technologies for minimising fire risk.
3	Mr Hiện – Xuan Loc Forest Management Board	What are the economic costs of slash retention?	As you will see tomorrow, at age 6 years, slash retention in an *A. auriculiformis* plantation was associated with an increase in MAI > 4 m^3/ha/year. The costs of retaining slash and added forest protection are much less than the value of an additional 24 m^3 of wood at harvest.
4	Mr Ái – Dong Nai Extension	The report shows the method of fertiliser use at planting only; how about post-planting fertilser application?	Yes, the project used both methods and application of fertiliser at thinning is discussed in the Final Report. However, there were no responses to P addition at thinning at sites in this region.
5	Mr. Đây – Director, National Extension Centre, HCMC	If application of P is not effective, what is the recommendation?	There is a response to P application at all sites when applied at planting. There is also a response to P application and to other nutrients at thinning at some sites. So the recommendation is site dependent for applications at thinning.
6	Mr.Thế – Binh Duong extension office	Application of herbicide up to three times for bamboo control is expensive. Is this justified?	This is only necessary on sites where bamboo is highly competitive, for example at the project's Phan Truong Hai site. At age six years the standing volume in an experiment receiving this treatment was 18% greater than in the adjacent commercial plantation where bamboo was not controlled. However bamboo control was just one factor contributing to this difference.
7	Mr Hiện – Xuan Loc Forest Management Board	How about thinning time? Will the thinned trees create a fire risk?	Thinning is undertaken in July in the middle of the rainy season to ensure a rapid response to thinning. The stems are harvested for pulpwood and the slash is retained but breaks down quickly.

8	Mr Hiện – Xuan Loc Forest Management Board	Was the wood from thinned trees included in the economic analysis?	Yes, it is included and this contributes to the 600/3 treatment having the greatest NPV at age 6 years.
9	Mr Đại – FSIS	Does the product value of thinned trees compensate for the harvesting cost?	Yes it does as but as noted above, its contribution to NPV is much larger if thinning is delayed until age three years.
10	Mr Sơn – Hai Vuong Joint Stock Company – HCM	Does thinning damage retained trees?	No, thinned trees can easily be cut so that they fall into the inter-row area.
11	Mr Nhiên – La Nga Forestry Company (Vinafor)	Please explain how lift pruning is undertaken?	Lift pruning is always done in the dry season to minimise risk of decay entry, and, on each occasion, the length of live crown removed is ≤ 30%.
12	Mr Hà – SCAFTS and Ms Hồng – FSIS	The project has not studied selection of clones suitable for saw-logs. Why was AH7 selected as this clone was developed for pulpwood?	There has been no specific selection of clones for sawlog production, unless you are able to advise otherwise. Clone AH 7 has good stem form and small branches; this was why it was selected for project experiments. Selecting good clones for sawlogs is a new challenge that needs to be addressed.
13	Mr Sơn – Binh Phuoc Extension	If I want to use the DSS in another province (e.g. Dong Nai) is this OK? At the moment it lists only Binh Phuoc in the south.	The DSS is based on site conditions that were experienced by the project's experiments. Yes, you can apply it to sites with similar site conditions. The Binh Phuoc option would be the best for Dong Nai.
14	Mr Tài – Dong Nai Extension	Does that mean opportunities for using the DSS remain limited? How does a grower use the DSS on their land?	Please note above answer. The DSS is currently best suited to people like yourselves. The information provided is meant to be a guide only. Extension Officers can use it to provide the best current advice to growers.
15	Dr. Dũng – FSIS	The economic analysis is currently based on a 5.9 year rotation before harvesting for sawlogs. Does the analysis include the cost of land hire?	Choice of final stocking and rotation age should be based on required product outcomes; use the DSS to help you understand how this works. Yes, we included cost land hire in the economic analysis.
16	Mr. Tiến – Extension from Dong Nai	The economic risk of growing hardwood plantations is considered low compared with rubber or pepper. In Dong Nai, acacia species are considered best suited for production forest. We are pleased to be able to examine this option more closely using this economic analysis.	No answer required - this is a comment to share

17	Mr Anh – South-East Centre for Forest Research and Experiment	Why does your project not consider longer rotations e.g.13 or 14 years? Would these not create much higher value?	Such a long-term plantation is not suitable for farmers and small companies. Our project focused on suitable regimes for smallholders on low incomes. They need to generate income in the shortest possible time.
18	Mr Anh – South-East Centre for Forest Research and Experiment	What size log is considered a sawlog? In this analysis large saw-logs have minimum diameter, D of 18 cm.	This analysis was based on the most recent information available which links price with log size. Larger logs with D >25 cm do exist but are currently not popular in the market. As will be noted, the current analysis considers three log types, large and small sawlogs and pulpwood.
19	Mr Đại – FSIS	In your conclusion, total wood productivity, sawlog productivity and NPV index are referred to. Of the three, do you think NPV is most importance index?	Wood and saw-log productivity are technical indicators; NPV is the important index that determines the potential return on investment.

Field Demonstration (Day 2) (Plates 4.6-4.8)

Plate 4.6: Mr Dat demonstrating correct planting practice; **Plate 4.7**: A participant practices lift pruning; **Plate 4.8**: Participants debating selection of trees to be thinned.

The Demonstration Trial (Section 5) was established at Tan Phu ahead of the workshop. This was used to demonstrate site preparation and slash retention. 1000 m^2 adjacent to the plantation had been set aside and this was used to demonstrate and practice digging planting holes, applying at-planting fertiliser, planting and weed control. An adjacent 14-month-old AH7 plantation was used to teach participants the art of form and lift pruning. At Phu Binh, participants were taught how to select trees to be harvested when thinning to 600 stems/ha. They were then divided into four groups and their skills at doing this tested in a 48-tree plot. The trainers had previously decided which trees were to be retained. One group selected all the correct trees.

Three trials at Phu Binh were then used to illustrate the effects of slash management and thinning and pruning treatments on stands which were now either five or six years of age (**Appendix 9.2**). This information was prepared by Mr Vu Dinh Huong who is using two of these three trials for his JAF PhD Program.

FSIS Trang Bom – Cutting Practice (Day 3)

Mr Chien told participants that taking cuttings was easy, but making sure that cuttings were of high quality was more difficult. Production companies were often careless and this has resulted in large numbers of unsuitable planting stock being released onto the market.

Clonal hedges should not be kept for more than three years. In the south where growth rates are high, each hedge plant will produce 8-10 cuttings per harvest, and there could be up to 20 harvests per year. Thus each hedge plant had the capacity to produce 600 cuttings in its lifetime.

Participants were given a tour of the tissue culture laboratory and then taken to the hedge garden for a demonstration of cutting practice (**Plates 4.9-4.11**).



Plate 4.9: Tissue culture laboratory at Trang Bom; **Plate 4.10**: Mr Chien demonstrating the taking of cuttings; **Plate 4.11**: The clonal hedge orchard.

5 Demonstration Plantation

Objective

Using knowledge gained during FST/2006/087, establish a Demonstration Trial for growers in Binh Duong, Binh Phuoc and Dong Nai provinces to visit, study and use as a model for establishing new commercial plantations for sawlogs. The trial to be maintained by the Southern Centre for Application of Forest Technology and Science (SCAFTS).

Background

Consideration was given to the establishment of the trial on smallholder property, but it was not going to be possible to guarantee long-term access or permission to maintain a range of treatments over its expected life. The trial was therefore established at FSIS's Tan Phu Field Station. Its rapid establishment after the SRA was funded was essential, because the end of the planting season was approaching; it was also important that the trial was established before the workshop. A suitable 0.8 ha site was selected in mid-July; the clonal stock sourced from FSIS's Trang Bom station was planted on 3rd August, approximately one month before the workshop (**Plates 5.1, 5.2**). As noted in Section 4, a 0.1 ha area at one end of the plantation was set aside and this was used to demonstrate and practise digging planting holes, apply at-planting fertilizer, planting and weed control.

This demonstration trial will continue to be managed using the practices developed by ACIAR Project FST/2006/087 and used by SCAFTS to illustrate these practices for managing acacias for sawlogs to their developing client base.

Plate 5.1: The site Demonstration Plantation at Tan Phu one month after planting; note the slash retention parallel to the planting rows; **Plate 5.2**: The sign summarising the establishment details and planting stock.

Trial Details:

Location	Block: Ia4 of Tan Phu forest experimental station belonging to and operated by SCAFTS
Area	0.8 ha
Planting stock	Clones AH7 (*Acacia* hybrid) and AA9 (*A. auriculiformis*). Selected as superior clones; recognised by MARD in Decision No: 3905/QĐ-BNN-KHCN dated 11/12/2007

Experimental design and plots

For each clone, there are three treatments: pulpwood only (T1); pulpwood and sawlog (T2); and sawlog only (T3); the density at planting is 1111 stems ha^{-1} (3 m × 3 m) (Table 5.1).

Table 5.1: Layout of the trial.

A. auriculiformis (AA9)			*Acacia hybrid* (AH7)		
Planting stock: 1111 trees/ha	Planting stock: 1111 trees/ha. Year 2: 833 trees/ha	Planting stock: 1111 trees/ha Year 2: 833 trees/ha Year 3: 600 trees/ha	Planting stock: 1111 trees/ha	Planting stock: 1111 trees/ha Year 2: 600 trees/ha	Planting stock: 1111 trees/ha Year 2: 600 trees/ha Year 3: 450 trees/ha
Pulp wood	Pulp + saw-log	Saw-log	Pulpwood	Pulp + saw-log	Saw-log

- Pulpwood regime (R1): Density 1111 tree ha^{-1} maintained to end of rotation;
- Pulpwood + saw-log (R2): Density reduced to 833 trees ha^{-1} for *A. auriculiformis* and 600 trees ha^{-1} for *A. hybrid* near the end of year 2.
- Saw-log regime (R3): Thinning will be implemented twice: Near the end of year 2 as for R2. Near end of Year 3, density reduced to 600 tree ha^{-1} for *A. auriculiformis* and 450 tree ha^{-1} for *A. hybrid.*

The gross plot for each treatment is 891 m^2 (11 rows × 9 trees); the measurement plot is 49 trees (7 rows × 7 trees/row). There is a two-row is buffer (**Figure 5.1**).

Silvicultural management

1. Site preparation

The experimental site was prepared by manpower. Residual vegetation was slashed into parts of maximum length 1-1.5 m and arranged in rows parallel to the planting holes (**Plate 5.1**). Planting hole size was 40 × 40 × 40 cm; tree spacing was 3 m × 3 m (1111 trees ha^{-1}). The clonal stock was planted on 3rd August 2014. On 1st August, pre-planting herbicide (4 L ha^{-1} of Round-up 480SCcontaining 0.48 g L^{-1} and 1.92 kg ha^{-1} *Glyphosate isopropylamine* salt) was applied.

2. Fertiliser at planting

- 375 g tree^{-1} superphosphate (= 30 kg P ha^{-1}) (using Superphosphate Lam Thao 16.5% $P_2 0_5$ (7.2 % P).
- Application as follows:

  + Make planting hole (40 × 40 × 40 cm)

  + Place fertiliser at bottom of the pit

  + Cover with soil

3. Weed control

- Year 1: Two times using manpower;

  + Time 1: 30 days after planting (all regeneration slashed);

  + Time 2: 90 days after planting (all regeneration slashed and cultivated soil placed around tree stem – done to provide additional support in dry season);

  Years 2 & 3: Herbicide (4 L ha^{-1} of Round-up 480SC) applied each year with shielded sprayer.

4. Singling and form pruning

Singling and form pruning will be applied as in FST/2006/087 but only in the sawlog regimes (R2 and R3). Singling is carried out at age 3 - 4 months after planting when leader stems are clear.

Method used is tip pruning, retaining best stem, while competing stems/branches will be cut 50 per cent of length. Form pruning, the removal of undesirable competing stems and branches, is an essential silvicultural requirement if the stand is to be managed for saw logs. First form pruning will be undertaken at age 8 months; second and third pruning will be carried out around age 14 and 18 months respectively.

General experimental management

- Plots to be maintained in weed-free condition (**Plate 5.3, 5.4**).
- Trees in the measured plot to be numbered so that the growth of individual trees can be tracked during the trial (see **Figure 5.1**).

A 6-m width fire-break was prepared around the trial area. This was done and will be maintained by ploughing using a contractor.

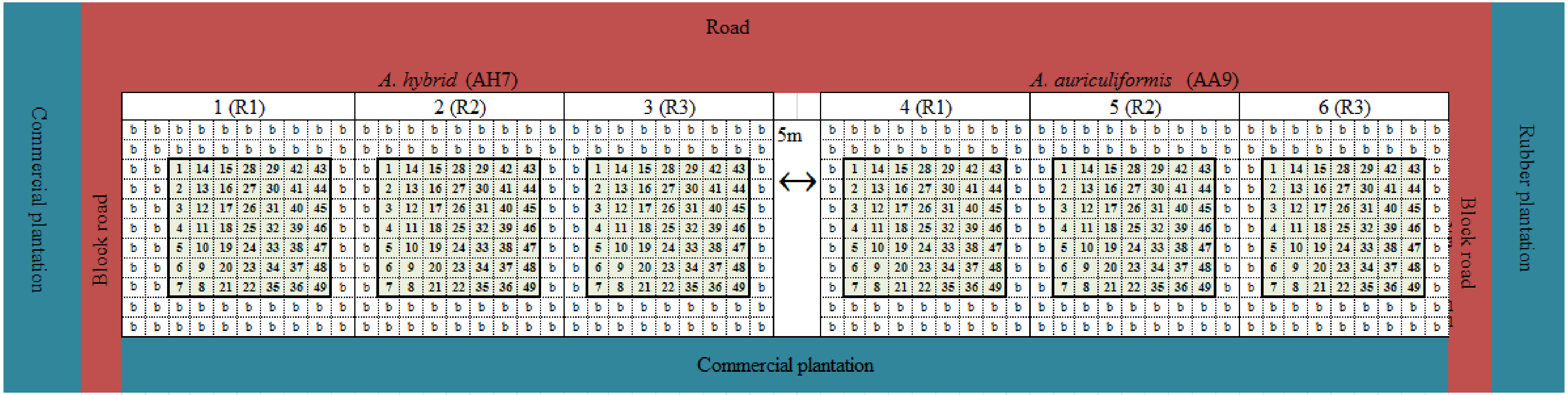
Plate 5.3, 5.4: The Demonstration Plantation at Tan Phu six months after planting

Measurement

Table 5.2: Survival rate (%) and height growth (m) at age 6 months

Clones	Hvn			Mean
	R1	R2	R3	
AH7	2.0	2.5	2,.0	2.2
Min	*0.4*	*1.3*	*0.4*	0.7
Max	*3.1*	*3.3*	*2.9*	3.1
SD	*0.5*	*0.5*	*0.6*	0.6
Survival	98.0	98.0	95.9	97.3
AA9	1.6	1.6	1.7	1.6
Min	*0.3*	*0.4*	*0.5*	0.4
Max	*2.3*	*2.4*	*2.8*	2.5
SD	*0.5*	*0.5*	*0.5*	0.5
Survival	95.9	91.8	87.8	91.8

Figure 5.1: Layout of the trial and allocation of treatments to plots.



R1: Pulpwood
R2: Pulpwood and sawlogs
R3: Only sawlogs

6 Growth to 2014 for Listed Trials

Objective

Measurements of height and diameter growth, form and survival to be undertaken at all FST/2006/087 trials. Additional notes to be taken on tree health (stem/branch breakage; pests and diseases). Fire breaks to be re-established where necessary, and where on private land, continued use of the area for the experimental plantation until at least July 2016 to be negotiated.

1. The FST/2006/087 trials

FST/2006/087 established 11 trails; three Core Trials; seven Satellite trials and one Stock-type trial (**Table 6.1**).

Table 6.1: List of FST/2006/087 trials and status in November 2015

Location	Trial type and date established	Ownership	Current status
Phan Truong Hai	Core (Oct 08)	Private	Harvested June 2015
Ba Vi (fertiliser and thinning)	Core (May 10)	VAFS	Harvested May 2014
Ba Vi (thinning)	Core (May 10)	VAFS	Harvested May 2014
Phu Thanh	Satellite (Aug 09)	Private	Standing
Nghia Trung	Satellite (July 09)	VAFS	Standing
Ba Vi	Satellite (July 09)	VAFS	Standing
Tuyen Quang	Satellite (June 09)	Private	Standing
Dong Ha	Satellite (Aug 09)	VAFS	Standing
Phu Binh	Satellite (July 10))	VAFS	Standing
Xuan Loc	Satellite (July 10))	Private	Standing
Nghia Trung	Stock type	VAFS	Standing

2. Trials on private land

2.1 - Phan Truong Hai: Owner Hai Vuong Joint Stock Company

Although the company harvested the plantation (of approximately 40 ha) in which the trial was located in late 2014, they agreed to exclude the trial area (3 ha); three additional rows on either side of the trial were also retained to protect the trial from high winds after harvesting. This has enabled:

- A final measurement at age seven years in late May 2015 (**Figure 6.1**); the need for this measurement was identified by the economic analysis undertaken in this project (**Appendix 9.1**);
- A second harvest of 81 trees by John Allwright Fellow (JAF) Tran Thanh Trang for the second paper he is developing for his PhD Thesis on heart rot. This was done in the week starting 25th May 2015, just ahead of the company harvesting the trial.

2.2 - Phu Thanh: Owner Hai Vuong Joint Stock Company

This trial is on very productive land and is scheduled for harvesting.

2.3 - Tuyen Quang: Owner An Hoa Paper Material Joint Stock Company

The company have agreed that the trial can remain in place until 2016. It currently serves two purposes:

- Use of the *Acacia* hybrid stand by JAF Trieu Thai Hung for his PhD studies;
- Enables a comparison between *Acacia* hybrid and *Acacia mangium* on the same site (**Plate 6.2**).

Measurements are undertaken by Mr Lam (Vu Tien Lam) on behalf of Mr Hung.

2.4 - Xuan Loc: Owner: Gia Huynh Forest Enterprise

The company are currently supporting retention of this trial which currently serves the following purpose. The trial was taken over by Mr Huong (Vu Dinh Huong) in 2012 and is being used to develop one of the papers he is developing for his PhD Thesis.

3. Trials on VAFS land

The intention is to maintain all current trials, at least until their current needs are fulfilled. Annual measurements have been maintained at all trials since the completion of FST/2007/087 in 2012.

3.1 - Ba Vi

- The Core trials were harvested in April/May 2104. The Satellite trial has been used on a continuous basis by Mr Hung for his PhD studies.


Plate 6.1: Mr Dat and tree in 450 stems/ha treatment at Phan Truong Hai. The mean diameter at breast height in this treatment was >20 cm at age 7 years; **Plate 7.2**: Boundary between *A. mangium* (left and straight trees) and *A.* hybrid (right and bent trees).

3.2 - Dong Ha

This trial was badly damaged by a typhoon in late 2012. However a decision was made in favour of its retention, although its capacity to provide useful information about responses to treatments has been totally compromised. Annual measurements have been maintained at the site by Mr Dinh (Pham Xuan Dinh).

3.3 - Phu Binh

- The trial was taken over by Mr Huong (Vu Dinh Huong) in 2012 and is being used to develop one of the papers for his PhD Thesis.
- Following the completion of these measurements, the trial will be used by Mr Hai (Nguyen Xuan Hai), Site Manager of the Tan Phu Forest Research Station to support his Master's thesis.

3.4 - Nghia Trung

- The Satellite trial is being maintained until FSIS require this area for other purposes. It was used by JAF Tran Thanh Trang for the first paper he is writing for his PhD Thesis on heart rot.
- The Stock-type trial received its last measurement in August 2015 prior to the final analysis of the data collected and publication of the findings by Mr Bon and Dr Chris Harwood.

Master data sheets

Master data sheets that were initiated by Dr Chris Harwood have been developed and maintained for all trials, most recently by Mr Bon, Mr Dinh and Mr Lam. Besides the 2014 measurements covered by the current ACIAR Project, a 2015 series of measurements is currently under way in the south.

Copies of the Master data sheets are held by Drs Chris Harwood and Chris Beadle in Australia, and all key staff involved in the project in Vietnam. Representative growth measurements made in 2014 at age 6 years at the Phan Truong Trial Core Trial are in **Appendix Table 9.1.4** and **Appendix Figure 9.1.4**; and for the Satellite Trial at Phu Binh in **Appendix Tables 9.2.1** and **9.2.2**. Information about comparative growth of the Satellite Trials at age 2 years is given in **Appendix 9.3**.

7 Conclusions and Recommendations

7.1 Conclusions

This SRA has enabled the further development of outputs from FST/2006/087. Through the workshop and the DVD of the workshop proceedings, these outputs were formally transferred as resources that can be accessed through the National Extension Centre. In addition to the four points below, the creation of SCAFTS and its leadership by Dr Kieu Tuan Dat, a key player in both projects, has enabled the uptake and further development of these outputs that has been further benefited by continuing support from ACIAR.

- An economic analysis of *Acacia* hybrid managed in a sawlog rotation to age six years has shown that at sites in southern Vietnam, NPV can be maximised in stands thinned to 600 stems/ha at age three years. Compared to unthinned stands and stands thinned at age two years, this was because of the greater proportion of large sawlogs, and the greater value of thinned trees if the thinning was undertaken at age three years, respectively. There was some indication that a lighter first thinning at age three years would result in the best financial performance for the sawlog prices used in this analysis.

- A workshop for Extension Officers servicing the small-holder sector and technical staff servicing private companies that have interests in sawlog production were trained in the use of best practice silviculture and the use of software developed by FST/2006/087 that enables users to estimate potential yield and value of their plantations. They were also introduced to the importance of high quality planting stock and the techniques required for taking cuttings from, and the management of, hedge gardens. A demonstration plantation was established which enabled field training of workshop participants and the creation of a model plantation for illustrating silviculture for sawlogs to interested parties.

- Nine out of eleven of the experimental plantations established by FST/2006/087 were measured at least once during the period of FST/2014/017. The two Core trails established at Ba Vi had been harvested and were last measured in late 2013..

- Two papers were prepared as advanced drafts in a form suitable for submission. Both papers require further development before submission. Data from trials other than PhanTroung Hai will be used to increase the value of the economic analysis in a sawlog context.

7.2 Recommendations

Sustainability of production remains a crucial goal for acacia plantations in Vietnam. For plantations managed for sawlogs in particular, the capture of good form appears highly dependent on the quality of the planting stock. Systematic studies of how these values are best captured are warranted. Understanding the relationship between soil properties and the supply of and demand for nutrients remains a challenge and should form at least part of investigations into sustainability.

8 References

8.1 References cited in report

Blyth MJ, Hoàng Liên Sơn (2013). Socio-economic factors influencing smallholder production of acacia sawlogs in Vietnam. Unpublished report from ACIAR Project FST/2007/025, ACIAR, Canberra.

MARD (2010). Vietnam forestry development strategy 2006-2010. Ministry of Agriculture and Rural Development, Hanoi.

8.2 List of publications produced by project

Eyles, A, Drake, P, Quang, LT, Mendham, D, White, D, Dat, KT, Dung, PT, Beadle, C (2015). Ecophysiology of Acacia species in wet-dry tropical plantations. Southern Forests. DOI: 10.2989/20702620.2015.1063030.

9 Appendixes

9.1 Financial Analysis for Solid-wood Production from *Acacia* hybrid Plantations

Abstract

This report compares the financial performance of different silvicultural regimes for *Acacia* hybrid tested in the Core experiment of ACIAR Project FST/2006/087 at Hai Vuong Joint Stock Company's Phan Truong 2 Estate in Binh Phuoc province. Three experimental stockings (unthinned at 1143, and thinned to 600 and 450 trees/ha) and two thinning times (at age 2 or age 3 y) and an adjacent unthinned commercial plantation which had received lower management inputs were evaluated.

Study of the supply chain in South-east Vietnam in 2014 confirmed demand for three different wood products: pulpwood (4-10 cm diameter over bark), small sawlogs (10-18 cm) and large sawlogs (>18 cm and at least 2.2 m in length). Prices for standing timber, calculated from mill-gate prices after subtracting harvesting and transport costs, varied by about USD7/m^3 over the year but averaged USD32.07/m^3 for pulpwood, USD39.15/m^3 for small sawlogs and USD85.14/m^3 for large sawlogs. Allometric relationships were developed from sets of felled trees and used to estimate wood volumes over bark and the proportions of different wood products in each experimental treatment from tree diameters and heights taken at ages 3.9, 4.9 and 5.9 y; a projection of product volumes at 6.9 y was also made.

Standing volume remained higher in the unthinned treatment than the thinned treatments through to age 5.9 y. At this age the estimated mean annual increment of the unthinned experimental treatment was 23.6 m^3/ha. However, the thinned treatments yielded greater volumes of large sawlog than did the unthinned treatment. At age 5.9 y the 600-3y treatment had the highest NPV (USD2176/ha) under the base assumptions of 5.3% real interest rate and current log prices. The NPV of the unthinned treatment was slightly lower at USD2016/ha and the commercial plantation had the lowest NPV, USD1361/ha. Sensitivity analysis for the unthinned and 600/3y treatments was carried out by varying interest rate (6%, 10% and14%) and evaluating three actual product price scenarios in 2014 (median product prices, lowest price and highest price for three types of wood). In the least favourable scenario, in which log prices were lowest and interest rate was 16%, the NPV of the unthinned treatment was still positive (NPV = USD223 / ha) at age 5.9 y. Based on projected stand value at age 6.9 years, profit growth in the seventh year of stand growth would be much higher than the opportunity cost of the capital obtainable by harvesting at age 5.9 years, because of the substantial increases in volumes of large sawlogs, for all experimental treatments. This suggested that forest owners would profit by extending rotation age to at least 7 years.

Glossary

Dbh	Diameter over bark at breast height
IRR	Internal rate of return
NPV	Net present value
BCR	Benefit-cost ratio
P	Price
450/2y	thinning at age 2 y to 450 trees/ha.
450/3y	thinning at age 3 y to 450 trees/ha.
600/2y	thinning at 2 y to 600 trees/ha.
600/3y	thinning at 3y to 600 trees/ha.
PW	Pulp wood
SSL	Small sawlog
LSL	Large sawlog

Introduction

To date, most acacia plantations in Vietnam have been managed on clear-fall rotations primarily for pulpwood, although they yield a proportion of small sawlogs at harvest. Byron (2015) noted that smallholder growers, who manage nearly 50% of Vietnam's 1.2M ha acacia plantations, prefer short rotations of five-to-six years for pulpwood because of the requirement to generate quick returns from wood sales. Larger growers, including government and private companies, often employ rotations of seven-to-ten years that yield a higher proportion of sawlogs.

The log prices that growers receive for pulpwood and small diameter sawlogs (<15-18 cm log diameter) are low, typically about half the price per cubic metre obtained for sawlogs >18 cm diameter. ACIAR Project FST/2006/087 "Optimising silvicultural management and productivity of high-quality acacia plantations, especially for sawlogs" was implemented to research ways of improving the financial attractiveness of growing plantation acacias for smallholders. The project targeted the development of silvicultural practices that used thinning to increase the yield of larger-diameter, more valuable sawlogs. Intensive silviculture to produce high yields of sawlogs requires higher levels of investment than does growing for pulpwood, and the economic benefits remained uncertain. The project therefore needed to compare different silvicultural regimes and rotation lengths to determine which would maximize the financial benefits to the grower. This report presents financial analyses based on: (1) estimates of yields of pulpwood, small sawlogs and large sawlogs from different silvicultural regimes based on measurements made at ages 4.9 and 5.9 years and predictions of product yields at age 6.9 years; (2) an analysis of the financial efficiencies of the different regimes; (3) sensitivity analysis based on changes in product prices and the discount rate; and (4) analysis of the impact of rotation length.

Methods

Trial establishment and design

The ACIAR Project Core trial was established in a second-rotation plantation of *Acacia* hybrid planted in August 2008. The planting stock was a mixture of six commonly planted hybrid clones. The plantation is in Hai Vuong Joint Stock Company's Phan Truong 2 (PT2) Estate, in Binh Long district, Binh Phuoc province, a region of South-east Vietnam that has potential for sawlog production.

The plantation was established at a nominal spacing of 3.5 m × 2.5 m, equivalent to 1143 stems/ha. The experimental trial received fertilizer at planting, equivalent to 50 kg elemental P/ha with additional N and K (**Table 9.1.1**). The adjacent commercial plantation received a lower rate of fertilizer application one year after planting. The techniques used for the experimental trial are shown in **Table 9.1.1**. Form pruning and lift pruning to 2 m were applied in the trial but not in the commercial plantation.

Three thinning treatments were applied in the trial: unthinned (nominally 1143 trees/ha), and thinning to 600 and 450 stems/ha, in combination with two thinning times (at age 2 or 3 y). The net treatment plots were approximately square, 6 rows wide (21.0 m) by 18.5 m, thus containing 40-42 trees at planting (tree spacing varied slightly). Each net plot was surrounded by a buffer row receiving the same experimental treatment, giving a gross plot size of 28.0 m × 22.5 m. For each thinning-by-time combination, three different fertilizer-at-thinning treatments were tested (no fertilizer, 50 kg P/ha and 50 kg P/ha + basal multi-element fertilizer). With three replicates in a randomised complete block design, this gave a total of 54 plots (3 replicates x 3 thinning treatments x 2 thinning times x 3 fertilizer-at-thinning treatments). Three additional unthinned plots of the same size were established for monitoring in the commercial plantation, which was located immediately adjacent to the experiment trial.

Fertilizer applied at thinning had no effect on subsequent growth, so the data from the three fertilizer-at-thinning treatments were combined to give greater replication for the comparisons of the thinning intensity and time-of-thinning treatment effects.

Table 9.1.1: Planting, maintenance and thinning treatments applied at Phan Truong 2

Regimes	Site preparation	Planting	Fertiliser	Maintenance and weed control	Pruning and thinning
Commercial	Cut and remove all vegetation	Stock: *Acacia* hybrid cuttings. Pit planting: 30 x 30 x 30 cm hole	Fertilizing at planting: none Fertilizing after planting: 80 kg NPK (16-16-8)/ha in 1st year.	1st year: Combination of ploughing and manual weeding (twice) 2nd year: 4 l glyphosate/ha Ploughing (twice) 3rd year: 4 l glyphosate/ha Ploughing (twice)	1st year: Singling 2nd year: No 3rd year: No
Control 1,143 trees/ha	Cut and remove all vegetation	Stock: *Acacia* hybrid cuttings. Pit planting: 30 x 30 x 30 cm hole	Fertilizing at age 2 months: 440 kg $P_2 0_5$ 16.5% + 114 kg 16-16-8 NPK/ha.	Combination herbicide and manual 1st year: 4 l glyphosate (twice) 2nd year: 4 l glyphosate (twice) 3rd year: 4 l glyphosate	1st year: Singling 2nd year: Tip pruning and lift pruning 3rd year: Lift pruning
600 trees/ha; age 2 y thinning					1st year: Singling 2nd year: Tip pruning and lift pruning 3rd year: Lift pruning and thinning
600 trees/ha; age 3 y thinning					1st year: Singling 2nd year: Tip pruning and lift pruning 3rd year: Lift pruning 4th year: Thinning
450 trees/ha; age 2 y thinning					1st year: Singling 2nd year: Tip pruning and lift pruning 3rd year: Lift pruning and thinning
450 trees/ha; age 3 y thinning					1st year: Singling 2nd year: Tip pruning and lift pruning 3rd year: Lift pruning 4th year: Thinning

Data collection and analysis

For each tree, diameter at breast height over bark (Dbh) was measured using diameter tapes and height using 12 m height poles; the heights of trees >12 m were estimated approximately. Dead trees with unsound, rotten or termite-attacked wood were excluded when calculating product volumes. A few trees had broken tops; for these trees the height of the main stem below the break was recorded to enable product volumes to be adjusted. Growth data from ages 3.9, 4.9 and 5.9 y after planting are examined in this report.

Allometric relationships

To predict volumes of pulpwood, and small and large sawlogs from each individual tree, allometric relationships were developed. A total of 23 trees from an *Acacia* hybrid plantation at Dong Ha, in Central Vietnam, and 12 trees from buffer rows in the PT2 experimental plantation with Dbh spanning the range 9 – 25 cm were felled. Stem diameters over bark were measured at heights of 1, 1.3, 2, 4, 6, 8…m, up to total tree height. If forking occurred, diameters of all leaders above the fork were recorded, down to a small-end diameter of 4 cm over bark.

The volume over bark of the first stem section (0–1 m) was calculated as a cylinder with diameter equal to that at 1 m. Volumes of the section from 1 to 2 m, and of subsequent 2 m sections were calculated as conic sections using Smalian's formula. The uppermost section containing commercial wood was typically less than 2 m in length. Section volumes were summed to give total stem volume to 4 cm diameter. A power function fitted to a graph of Dbh versus total stem volume over bark (**Figure 9.1.1**) explained 98.6 % of total variance over the range of diameters sampled. The smaller trees from Dong Ha and the larger trees from PT2 aligned well. This relationship was used to predict individual tree wood volumes of all trees in the trial and the commercial plots, at each measurement age under study. For trees with stems that were broken below 10 m, volume of the intact stem below the break was estimated using sectional volume data from those trees of similar diameter that had been sampled for constructing the allometric relationship.

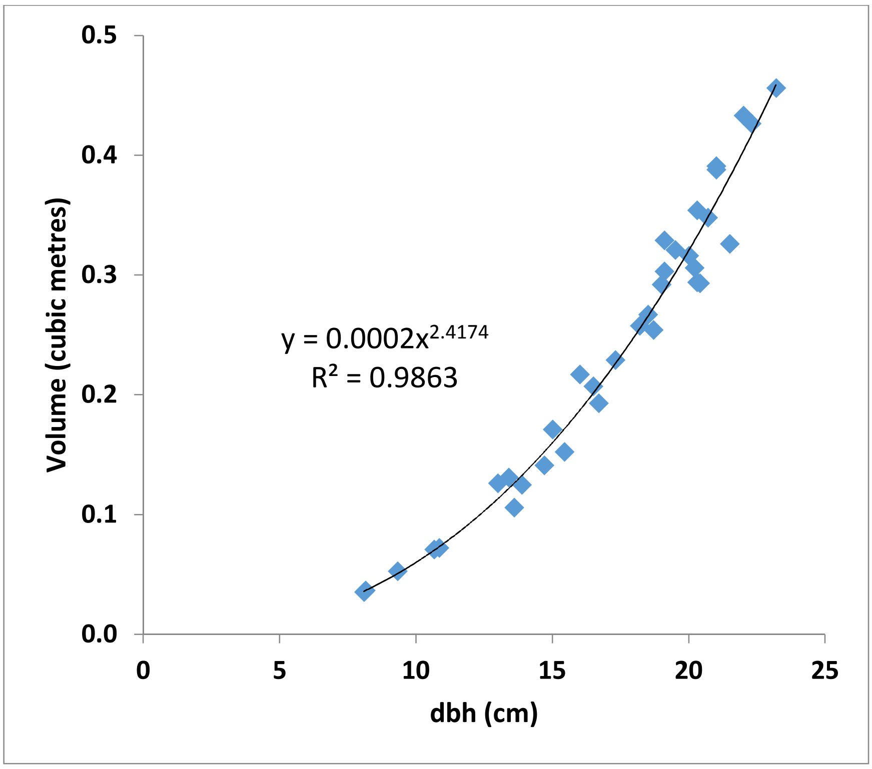


Figure 9.1.1: Allometric relationship between Dbh and total volume over bark to 4 cm small-end diameter, for 35 sampled trees

The volume of pulpwood was calculated for each felled tree. The proportion of pulpwood within the 2 m stem section within which diameter fell below 10 cm was estimated from the ratios of the end diameters of this section, relative to 10 cm, using the formula: proportion of pulpwood = $(10 - d_s)/(d_l - d_s)$,where d_l and d_s are the large- and small-end diameters of the section respectively. The volume of pulpwood within this section was then calculated, and added to the volumes of all pulpwood stem sections with diameter <10 cm to give total pulpwood volume between 10 and 4 cm diameter. Pulpwood volume as a percentage of total wood volume was calculated for each tree and the relationship between Dbh and pulpwood percentage was graphed for trees in the Dbh range 10-20 cm (**Figure 9.1.2**). Again, a power function was found to be the most appropriate allometric relationship, and accounted for 88% of the variance in this diameter range. Trees with Dbh <10 cm were classed as having 100% pulpwood. Larger trees (>20 cm Dbh) had varying percentages of pulpwood, ranging from 7.6 to 21.6% with an average of 12.3%.

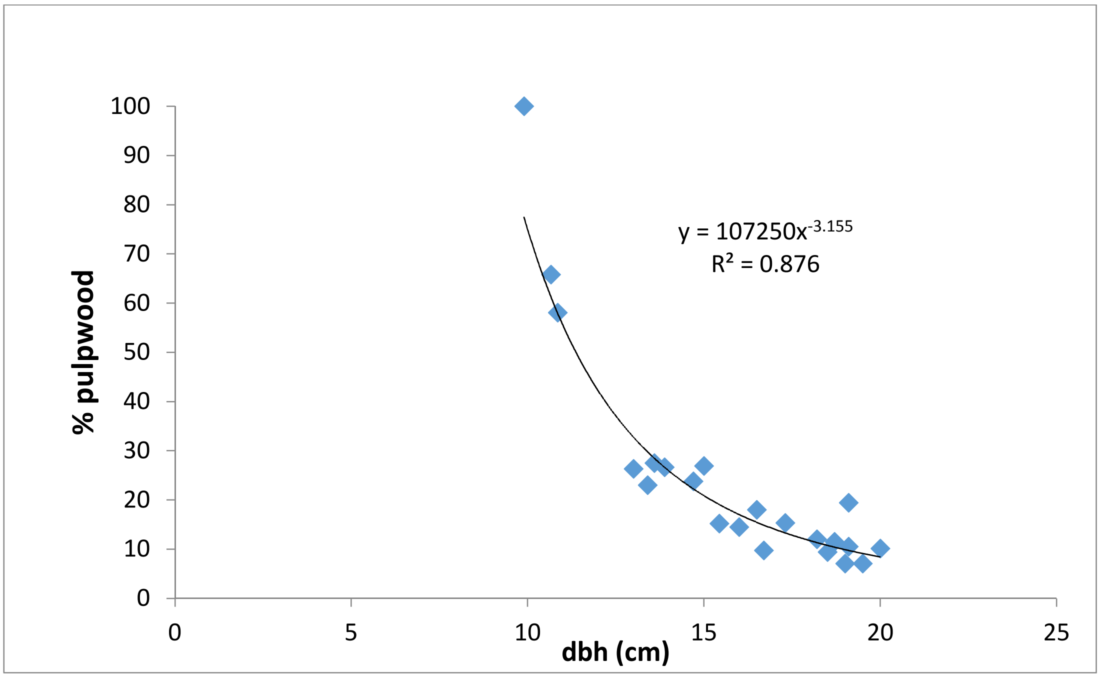


Figure 9.1.2: Allometric relationship between Dbh and % pulpwood for trees in the diameter range 10-20 cm

Pulpwood percentage for each individual tree was calculated according to the following rules:

- if tree Dbh <10 cm, pulpwood = 100% of total tree volume
- if 10 cm ≤ tree Dbh <18 cm, pulpwood % = 107250 * Dbh ^ -3.155
- if tree Dbh ≥18 cm, pulpwood = 12.3% of total volume

The volume of large sawlog (≥18 cm log diameter) was calculated for each sampled tree. Sawlog buyers typically buy large sawlogs of standard length (2.2 m). The minimum mid-point diameter accepted for a large sawlog is 18 cm, while the minimum small-end diameter accepted is 17 cm, provided the mid-point diameter criterion is satisfied. Taper over the height range 1.3 m to 2 m for trees in the 18-20 cm Dbh range averaged 1.0 cm per metre, so 18.0 cm was set as the minimum Dbh for a tree that would yield one large sawlog of 2.2 m length with small-end diameter >17 cm. Trees with Dbh <18 cm were classed as yielding no large sawlog. For trees with Dbh ≥18 cm, volume of large sawlog was estimated in a similar way to that of pulpwood.

Volumes of all log sections with small-end diameter ≥18 cm were summed. The length of large sawlog in that log section within which diameter fell below 18 cm was calculated as 2 m * ((d_l – 18)/(d_l - d_s)) where d_l and d_s are the large- and small-end diameters of the 2 m log section. This log length was used to calculate the volume of large sawlog ≥18 cm within the section. This volume was added to the summed volume of all 2 m sections with small-end diameter ≥18 cm. The percentage of total wood volume that was large sawlog was then calculated. This method results in various total lengths of large sawlog above the height of 2.2 m, rather than tallying all 2.2 m large sawlogs extractable from the tree. It was assumed that if substantial volumes of large sawlog were produced by a grower, buyers would be found who would take a proportion of large sawlogs with log length in the range 2.3 - 4.3 m, enabling all sawlog volume down to 18 cm small-end diameter to be sold as large sawlog.

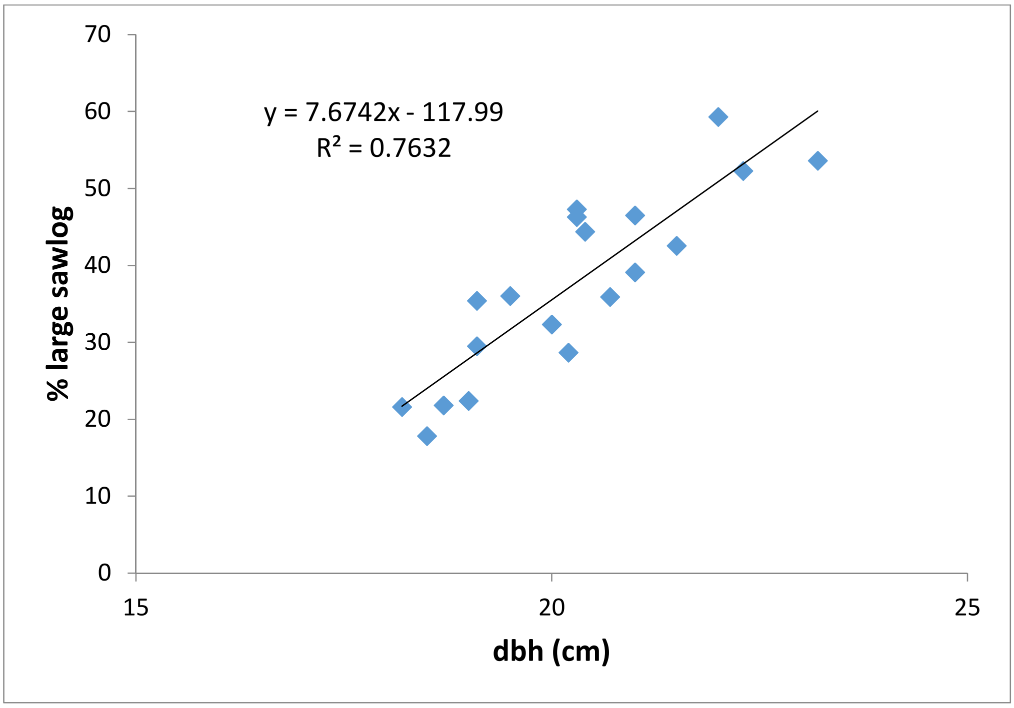


Figure 9.1.3. Allometric relationship between Dbh and percentage volume that is large sawlog

Figure 9.1.3 shows the relationship between Dbh and large sawlog % volume. For 19 trees with Dbh in the diameter range 18.0 to 23.2 cm, the following linear regression accounted for 76% of variance in % large sawlog volume:

% large sawlog = 7.6742 * Dbh – 117.99

This linear relationship must be applied with caution for Dbh above the sampled range. Clearly, it cannot be projected indefinitely; for Dbh >29 cm it would predict >100% of total volume as being large sawlog, which is impossible.

Large sawlog as a percentage of total volume for each individual tree was therefore calculated according to the following rules:

- if tree Dbh <18 cm, large sawlog = 0% of total volume
- if 18 cm ≤ tree Dbh ≤ 26 cm, % large sawlog = 7.6742 * Dbh – 117.99
- if tree Dbh >26 cm, large sawlog = 80 % of total volume

After calculating the volumes of pulpwood and large sawlog in each tree using these relationships, the volume of small sawlog (10-18 cm diameter) for each tree was calculated by subtraction:

Small sawlog volume = total commercial wood volume
– large sawlog volume
– pulpwood volume.

It was assumed that the volumes of pulpwood in the trees that were thinned in the 450 and 600 trees/ha treatments at age 2 and 3 years could be marketed as pulpwood. Volumes of thinnings were included in the corresponding total product volumes for these treatments.

Product volumes were estimated in this way for the assessments made at 3.9, 4.9 and 5.9 years, for each of the five thinning intensity by age treatments in the experiment, and for the commercial plantation.

Projection of product volumes to 6.9 years

Wood volumes at age 6.9 years were projected as follows. The Dbh increment between 4.9 and 5.9 years was calculated for each individual tree in the trial that was still alive at the most recent measurement in July 2014. To project the Dbh of each tree in July 2015, its 2013-2014 Dbh increment was multiplied by a factor of 0.7, and the resulting increment was added to the 2014 Dbh. The factor of 0.7 allows for the normal progressive decline in annual Dbh increment as tree diameter increases, and also for some ongoing mortality over the 12-month period July 2014 to July 2015.

Total commercial volume over bark to 4 cm small-end diameter and the pulpwood, small and large sawlog volumes for each individual tree were then calculated by applying the allometric relationships to the projected Dbh. Stand volume increments for each experimental treatment were checked. The selected growth projection method resulted in an annual volume increment for 2014-2015 very similar to that estimated for 2013-2014 (**see Table 9.4.4**). The projected increment was considered realistic as the experimental stand has remained generally healthy to August 2014. However, it should be treated as an approximation, since the current trends of growth and survival might change during the coming year (e.g. as a result of storm damage or disease).

Financial data

Financial data (**Table 9.1.2**) were collected by interview in 2014 from An Hoa and Nhu Y Ngoc companies located in the Ho Nai area of Bien Hoa City, Dong Nai province. These companies have a long history of saw-milling and are among the biggest in the country and the biggest in South-east Vietnam. The data investigated in Binh Phuoc province included wood prices at the sawmill gate, wages for processing wood, expenditure on harvest and transport, estimated standing wood prices, and historical fluctuations in wood prices.

Table 9.1.2: Financial data for determination of standing log prices

Products	Price at Mill gate (USD/m^3)	Harvest (USD/m^3)	Collection (USD/m^3)	Bark peeling (USD/m^3)	Transport (USD/m^3)	Price standing trees (USD/m3)	Log small end diameter (cm), length (m)	Note
Pulpwood	47.17	4.01	4.01	-	7.08	32.07	04 – 10, 2.2	with bark; transport 100km
Small sawlog	58.96	4.01	4.01	-	11.79	39.15	10 – 18, 1.2	transport 200km
Large sawlog	103.77	3.54	3.30	-	11.79	85.14	> 18, 2.2	transport 200km

Financial Analysis

Comparison of financial effectiveness of different experimental treatments

The economic indicators analysed were net present value (NPV), internal rate of return (IRR) and benefit-cost ratio (BCR) (discounted). Models were developed for the commercial plantation and the five ACIAR experimental treatments. All analyses were carried out using Microsoft Excel software.

Constant second-quarter 2014 prices were used for analysis of all rotations. Wages and costs are for Binh Phuoc province. Wood price is the mode price in Bien Hoa Town, Dong Nai province. Total revenue included revenue from sale of wood from thinnings. Thinning cost was included as a silvicultural cost borne by the grower.

The Real Interest Rate is the Nominal Interest Rate minus Inflation Rate. The nominal interest rate is the commercial interest rate used by commercial banks. In 2014, nominal interest rates in Vietnam were typically 12-13% (average 12.5%) for medium- and long-term commercial loans. In October 2013, the Asian Development Bank (ADB) predicted the expected inflation of Vietnam in 2014 to be about 7.2%. The base real Interest rate used in analyses is therefore 5.3% (12.5% -7.2% = 5.3%).

Sensitivity analysis

Sensitivity analysis of financial returns from each of the unthinned and 600-3y regimes was conducted by evaluating combinations of differing levels of two factors: relative product prices and interest rate, for two harvest ages (**Table 9.1.3**). This gave 18 age x price x interest rate combinations for each of the two regimes. The three product price scenarios evaluated were: *base LSL price* (the current median stumpage prices for PW, SSL and LSL, from **Table 9.1.2**), *low LSL price* (a 10% decline in LSL price while holding SSL and PW prices constant), and *high LSL price* (a 10% increase in LSL price while holding PW and SSL prices constant). These product price scenarios were chosen because change in the relative price of LSL to other products has a major impact on the financial comparison between thinned and unthinned regimes.

Table 9.1.3. Experimental regimes, harvest age, product price and interest rate levels evaluated for sensitivity analysis

Factor	Levels evaluated
Regime	unthinned, 600-3y
Age (y)	5.9 y, 6.9 y
Actual product price scenario (USD/m^3)	
Lowest price	PW 28.5, SSL 36.3, LSL 81.6
Base price	PW 32.1, SSL 39.2, LSL 85.1
Highest price	PW 35.6, SSL 42.0, LSL 88.7
Interest rate (%)	6, 10, 16

Rotation analysis

The effect of a wider range of rotation ages on financial performance was evaluated by financial analysis under the base case assumptions, for 3.9, 4.9, 5.9 and 6.9 y. The marginal profit of extending the 600-3y rotation from 5.9 to 6 9 y was examined, using the method described by Zhang and Pearce (2011), at the baseline product price scenario.

Results

Product yields of pulpwood, small sawlogs and large sawlogs

Stem diameters increased faster in the thinned treatments than the unthinned treatment, with the largest Dbh in the 450 trees/ha treatments (**Table 9.1.4**). Thinning at age 2 y resulted in slightly higher Dbh than thinning at 3 y.

Table 9.1.4: Product volumes estimated for each experimental treatment

Age	Treatments	stocking	Dbh (cm)	Volume (m^3/ha)					
				Large sawlog	Small sawlog	Pulpwood	Pulpwood thinnings	Total volume	MAI (m3/ha/y)
3.9	450/2	403	15.8	2.3	50.6	11.6	9.3	73.7	18.9
	450/3	412	15.1	-	46.5	12.0	22.7	81.2	20.8
	600/2	563	14.8	0.2	59.9	16.7	7.8	84.7	21.7
	600/3	575	14.3	-	55.4	17.4	19.4	92.2	23.7
	1143	**864**	**13.3**	**-**	**65.3**	**27.7**	**-**	**92.9**	**23.8**
	Commercial	884	12.1	-	48.6	29.8	-	78.3	20.1
4.9	450/2	395	17.2	11.0	56.1	11.4	9.3	87.8	17.9
	450/3	401	16.7	6.9	56.2	11.4	22.7	97.2	19.8
	600/2	555	16.0	5.2	71.2	16.0	7.8	100.1	20.4
	600/3	**569**	**15.8**	**2.9**	**72.3**	**16.3**	**19.4**	**110.9**	**22.6**
	1143	845	14.3	1.1	81.8	26.0		108.8	22.2
	Commercial	858	13.1	0.5	63.6	27.5		91.6	18.7
5.9	450/2	395	19.4	36.0	55.2	13.5	9.3	114.0	19.3
	450/3	389	19.0	29.7	54.4	12.6	22.7	119.5	20.2
	600/2	549	17.9	26.8	77.1	16.8	7.8	128.5	21.8
	600/3	563	17.7	23.5	77.6	16.6	19.4	137.0	23.2
	1143	**830**	**16.0**	**15.7**	**99.1**	**24.7**		**139.5**	**23.6**
	Commercial	858	14.4	5.8	85.5	26.5		117.9	20.0
Projection 6.9	450/2		20.9	60.9	49.7	15.9	9.3	135.8	19.7
	450/3		20.6	55.0	49.5	15.1	22.7	142.3	20.6
	600/2		19.3	53.1	73.4	19.1	7.8	153.4	22.2
	600/3		19.0	48.7	76.0	19.2	19.4	163.3	23.7
	1143		**17.2**	**38.2**	**103.8**	**26.2**		**168.3**	**24.4**
	Commercial		15.4	16.1	95.5	26.9		138.5	20.1

At age 5.9 y, the unthinned treatment had a greater total volume of wood than did the thinned treatments (**Table 9.1.4, Figure 9.1.4**).The mean annual increment (MAI) of commercial wood volume for the unthinned treatment at this age was 23.6 m^3/ha. The volume of small sawlogs at 5.9 y was also greatest in the unthinned treatment, but the volumes of large sawlogs were greater in the thinned treatments. The 450-2y treatment yielded the greatest volume of large sawlogs (36.0 m^3/ha, versus 15.7 m^3/ha for the unthinned treatment).The adjacent commercial plantation had a commercial wood volume and hence MAI at age 5.9 y that was 18% less than that of the unthinned treatment in the ACIAR experiment.

The volume projection to 6.9 y (**Table 9.1.4**) gave an MAI of 24.4 m^3/ha for the unthinned treatment, very similar to that at 5.9 y. By 6.9 y, substantial volumes of large sawlog (49-61 m^3/ha) were projected to accrue in the four thinned treatments, with lower large sawlog yields of 38 m^3 in the unthinned treatment and 16 m^3/ha in the commercial plantation.

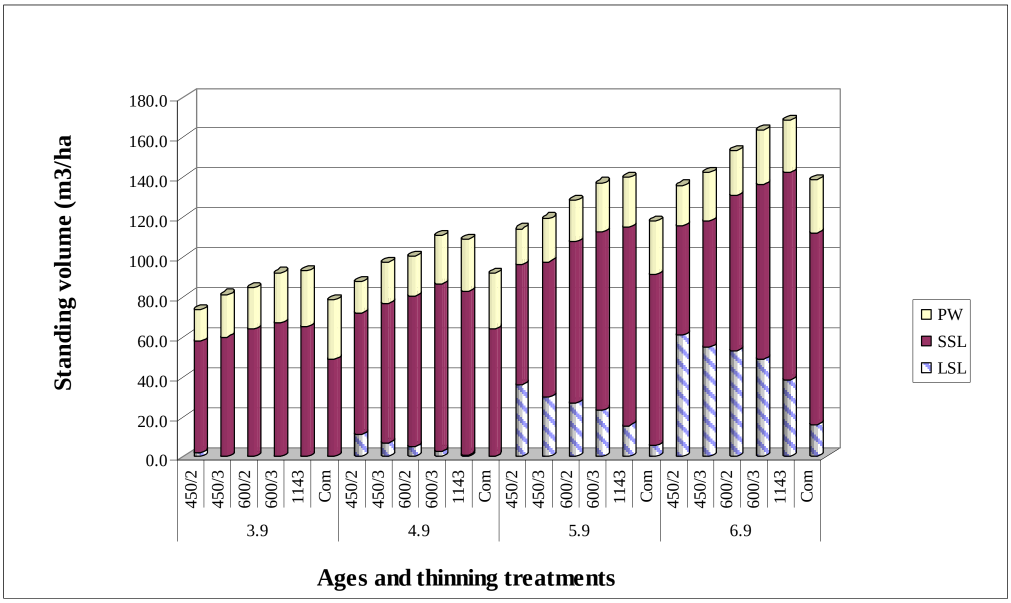


Figure 9.1.4: Comparison of product and total wood volumes from different treatments at age 3.9, 4.9 and 5.9 y, and the projected volumes at 6.9 y. PW = pulpwood, SSL= small sawlog and LSL = large sawlog

Financial returns from different treatments

Under the baseline scenario, financial efficiencies of the experimental treatments differed substantially (**Table 9.1.5**). At age 3.9 y, the unthinned experimental regime had the best financial performance and the 450-2y the worst, because of the cost and volume loss associated with early, heavy thinning in this treatment. At ages 4.9, 5.9 and 6.9 y, the 600-3y treatment had the best financial performance (**Table 9.1.5, Figure 9.1.5**). By 5.9 y, NPV for 600-3y was USD2176/ha, and IRR 23.0%, compared with a slightly poorer performance, NPV USD 2016 and IRR 20.6%, for the unthinned treatment. At all assessment ages, the 450-2y and 450-3y treatments had inferior financial performance to the 600-2y, 600-3y and control treatments, while the commercial plantation had increasingly poorer performance from age 4.9 y.

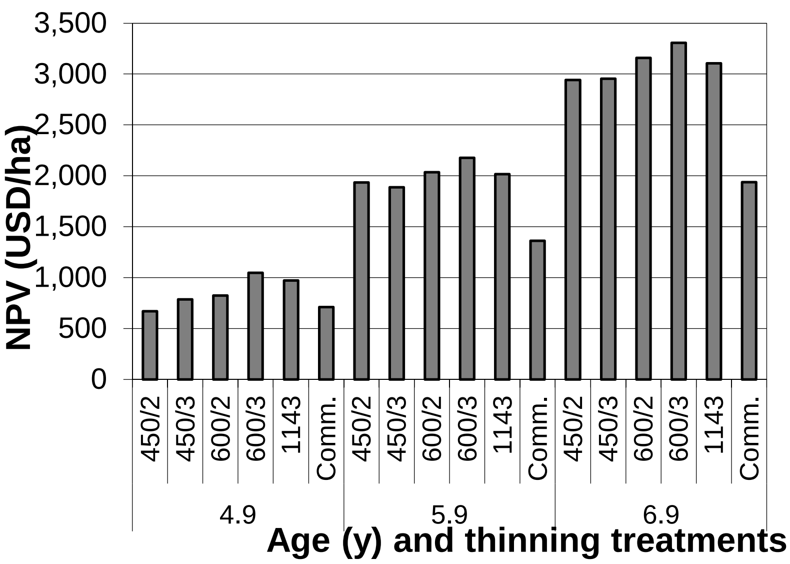


Figure 9.1.5: Comparison of NPV of different experimental treatments at three ages under base assumptions for interest rate (5.3%) and base product prices scenario

Fiscal year (*)	Treatments	Indices		
		NPV (USD/ha)	IRR (%)	BCR
5 years	450/2	190	8.6	1.1
	450/3	292	10.5	1.1
	600/2	434	12.5	1.2
	600/3	631	15.7	1.3
	1143	**720**	**16.3**	**1.4**
	Commercial	531	15.2	1.3
6 years	450/2	669	13.5	1.3
	450/3	784	15.2	1.4
	600/2	824	15.0	1.4
	600/3	**1,047**	**17.8**	**1.5**
	1143	971	16.0	1.5
	Commercial	710	14.8	1.4
7 years	450/2	1,934	20.8	1.8
	450/3	1,886	21.5	1.8
	600/2	2,034	21.3	1.9
	600/3	**2,176**	**23.0**	**2.0**
	1143	2,016	20.6	1.9
	Commercial	1,361	18.2	1.7
Projection 8 years	450/2	2,940	22.6	2.2
	450/3	2,954	23.8	2.2
	600/2	3,158	23.3	2.3
	600/3	**3,308**	**24.9**	**2.4**
	1143	3,106	22.5	2.4
	Commercial	1,939	19.2	2.0

Table 9.1.5: Comparison of financial efficiencies of experimental treatments at four harvest ages, for the baseline scenario (real interest rate 5.3%, median 2014 product prices). NB Fiscal year = age of plantation + 1 year; thus projected values for age 6.9 years are equivalent to fiscal 8 years; measured values for age 5.9 years to fiscal 7 years….etc.

Sensitivity analysis

The financial performance of both the 600-3y and unthinned experimental treatments remained positive over the range of product price and interest rate assumptions that were evaluated (**Table 9.1.6**). The financial performance of the 600-3y treatment was slightly superior to that of the unthinned treatment under all combinations of stand age, interest rate and product price scenario (**Table 9.1.6**).

Table 9.1.6. NPV for different combinations of rotation age, interest rate and log price scenarios (see Table 4.3), for the 600-3y and unthinned experimental treatments

Age (y)	Interest rate (%)	Lowest price scenario		Base price scenario		Highest price scenario	
		unthinned	600-3y	unthinned	600-3y	unthinned	600-3y
5.9	6	1576	1780	1863	2024	2143	2263
	10	901	1099	1123	1288	1351	1472
	16	224	407	376	537	525	664
6.9	6	2537	2783	2869	3072	3196	3357
	10	1511	1748	1758	1962	2001	2175
	16	520	735	681	876	840	1015

Under the least favourable combination of factors (lowest log prices and 16% interest rate at 5.9 y), the NPV of the unthinned treatment remained positive at USD224/ha. Under the most favourable scenario of 6% interest rate and high product prices, the projected NPV was highest for the 600-3y treatment at 6.9 y at USD3357/ha (**Table 9.1.6**). Varying interest rate over the range 6 to 16% had a greater impact on NPV than did varying product prices from the lowest to the highest price scenario.

Rotation analysis

For all experimental treatments, NPV increased with increasing stand age from 3.9 to 6.9 y, under the base assumptions for interest rate and product prices (**Figure 9.1.5**); other indicators of financial performance (IRR and BCR) also increased progressively with increasing stand age (**Table 9.1.5**). Also for all five experimental treatments, NPV increased by over USD1000/ha by extending the rotation from age 5.9 to 6.9 y; the corresponding increase for the commercial plantation was USD578. Net present value increased from age 5.9 y to 6.9 y for both the unthinned and 600-3y treatments under all nine combinations of interest rate and product price scenario that were examined. The increase was lowest under the combination of high interest rate and low product price scenario (**Table 9.1.6**).

Table 9.1.7: Profit growth as a ratio of plantation revenue for the 600-3y treatment from age 5.9 to 6.9 y under baseline real interest rate and log price assumptions

Indices	
Non-discounted profit at age 5.9 y (USD/ha)	3680
Non-discounted profit at age 6.9 y (USD/ha)	5687
Marginal increase in non-discounted profit from 5.9 to 6.9 y (USD/ha)	2007
Non-discounted value of standing timber at 5.9 y (USD/ha)	6270
Incremental growth in stand value, from 5.9 to 6.9 y (%)	32

Although the growth and value trajectories to age 6.9 y remain uncertain, marginal profit analysis suggests that the percentage growth of profit at age 6.9 y of the 600-3y treatment based on revenue that would be obtained by harvesting at age 5.9 y is 32% (**Table 9.1.7**). This rate is much higher than the current nominal interest rate (12-13%). Thus, forest owners should benefit by extending the rotation length of the plantation to at least 6.9 y.

Discussion

Financial analysis of costs and returns confirmed that acacia plantations having the growth rates achieved in this experiment are a profitable investment under a wide range of assumptions. Profit and other indicators of financial performance (NPV, IRR and BCR) increased from age 3.9 up to 6.9 years. Profitability was sustained across a wide range of interest rates and product price scenarios. At age 5.9 and 6.9 y, the 600/3y silvicultural treatment displayed the best financial performance, although the advantage of this treatment over the unthinned experimental control was not great, and would not be maintained if the price of large sawlogs declined significantly in relative terms. However, if the price of large sawlogs rose relative to small sawlogs and pulpwood, the financial advantage of the 600-3y over the unthinned regime would increase.

For all experimental treatments, the increase in NPV obtained by growing on the stand from 5.9 to 6.9 y was high. Under the baseline product price scenario, the marginal profit from extending the rotation to harvest-age 6.9 y was 32%, much higher than the current interest rate. Thus, it should be profitable for growers to extend the rotation to at least seven years. A major cause of this increasing profitability was that a substantial volume of high-value large sawlog was projected to develop in the seventh year of stand growth. Growers who require early cash returns by an age of around 5 years could manage part of their plantation on a no-thinning regime and harvesting this at age 5 y for early cash flow, while leaving the balance of their plantation area to grow on to age 7 y, to achieve greater return on investment.

Thinning to 450 trees/ha resulted in poorer financial performance than thinning to 600 stems/ha. From a previous thinning trial involving *Acacia* hybrid in central Vietnam, Beadle et al (2013) similarly concluded that thinning to 600 trees/ha gave a better financial outcome than heavier thinning to 300 or 450 trees/ha. *Acacia* hybrid plantations in Vietnam typically display ongoing mortality as the stand develops, so that effective stocking falls below the nominal post-stocking target. Thus, for example, stocking in the unthinned experimental treatment had dropped from 1143 trees/ha at establishment to only 830 trees/ha at age 5.9 y, while stocking in the 450-2y treatment had dropped from 450 trees/ha after thinning to only 395 trees/ha at 5.9 y. These patterns of ongoing mortality need to be kept in mind when recommending initial stocking and subsequent thinning regimes for *Acacia* hybrid. It may be that a lighter thinning at age 3 y to a residual stocking of about 800 trees/ha would result in the best financial performance for the sawlog price scenarios reported here.

Provided high rates of volume growth are achieved, a high proportion of the wood yield from unthinned *Acacia* hybrid plantations established at an initial stocking of about 1100 trees/ha can be accepted by local solid wood processors. Even at age 4.9 y, 75% of the commercial wood volume in the unthinned experimental treatment was marketable as small sawlog (10-18 cm diameter). By age 5.9 y, over 71% of the commercial wood volume in the unthinned experimental treatment was marketable as small sawlog, and 11% as large sawlog, with only 18% remaining as pulpwood. It is therefore misleading to describe productive plantations managed without thinning as “pulpwood regimes”.

Treatment differences that may have contributed to the faster growth in the ACIAR experiment compared with the commercial plantation include the higher rate of fertilizer application and the different weed control methods (more effective removal of bamboo, and general weed control by herbicide rather than ploughing in the first two years, in the ACIAR experiment). It is not possible to determine the relative contributions of fertilizer and weed control as these are confounded in this treatment comparison. The ACIAR experiment used a very high rate of fertilizer application, equivalent to 50 kg of elemental P per hectare at planting. A lower rate of 10-20 kg elemental P per hectare, applied as superphosphate, may be more appropriate (Bon and Harwood 2014, Harwood *et al.* 2014) and deliver similar volume production at lower growing cost and increased financial efficiency; this remains to be investigated.

The growth rate to age 5.9 years achieved in the unthinned treatment of this experiment, an MAI of 23.6 m^3/ha, was very similar to the average of 23 m^3/ha reported for 19 commercial, second-rotation plantation blocks of *Acacia* hybrid in South-east Vietnam, estimated from inventory data (Harwood and Nambiar (2014). This makes the current findings on product volumes representative for the region. The product volumes at age 6.9 years are projections only, and the volumes actually obtained at this age should be checked when the experiment is re-measured. Damage or mortality arising from strong winds or disease attack could impact on volumes achieved. Pink disease, *Erythricium salmonicolor*, is already present in the stand and causing damage to some trees.

A number of uncertainties need to be emphasised in the wider context of acacia plantation management in Vietnam. The annual land rental cost of $54.25/ha used in the financial analysis is determined by local regulations, and is well below the true opportunity cost of good-quality land in South-east Vietnam. This means that the true economic returns at the national level would be somewhat lower than the financial returns presented here. The allometric relationships used to estimate product volumes are approximate only. The linear regression between Dbh and % volume of large sawlog accounts for only 76% of variance in the sample set of 19 large trees. The yield of high-value large sawlog, which in turn influences whether thinning treatments are financially attractive, is therefore estimated with relatively low precision. The price premiums paid for large and small sawlogs over pulpwood depend on the sawlogs being sound, with no heart rot. If heart rot or other log defects such as rotten knots significantly reduced the volume marketable as high-value large sawlogs, this would favour the unthinned regime, which has the highest total wood volume, over the thinning regimes with lower total wood volume but greater volumes of large-diameter logs. There is therefore a need to improve the allometric relationship for estimating the proportion of large sawlog and to evaluate the levels of value-limiting wood defects in this and other *Acacia* thinning trials, at final harvest.

Conclusions

- The unthinned treatment produced the highest commercial volume growth throughout the experiment, with a mean annual increment of 23.6 m^3/ha at age 5.9 y, which is typical for *Acacia* hybrid in SE Vietnam.
- By age 4.9 y, volumes of higher-value large sawlog (>18 cm diameter) were greater in the thinned treatments. At age 5.9 y, 17% of the total commercial volume of the 600-3y treatment was large sawlog, the corresponding figure for the unthinned treatment being 11%.
- At age 5.9 y, the 600/3y regime delivered the highest financial return (NPV 2176 USD/ha) under base case assumptions of interest rate and product prices), although this NPV was only USD160 higher than the unthinned experimental regime. Heavier thinning to 450 trees/ha gave a poorer financial return, while the adjacent commercial plantation had the lowest NPV at 1361 USD/ha.
- The profitability of acacia growing for both 600/3y and unthinned regimes increased with age to 6.9 y and was maintained across a range of real interest rates (6-16% and product price scenarios.

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9.2 Three Trials at Phu Binh

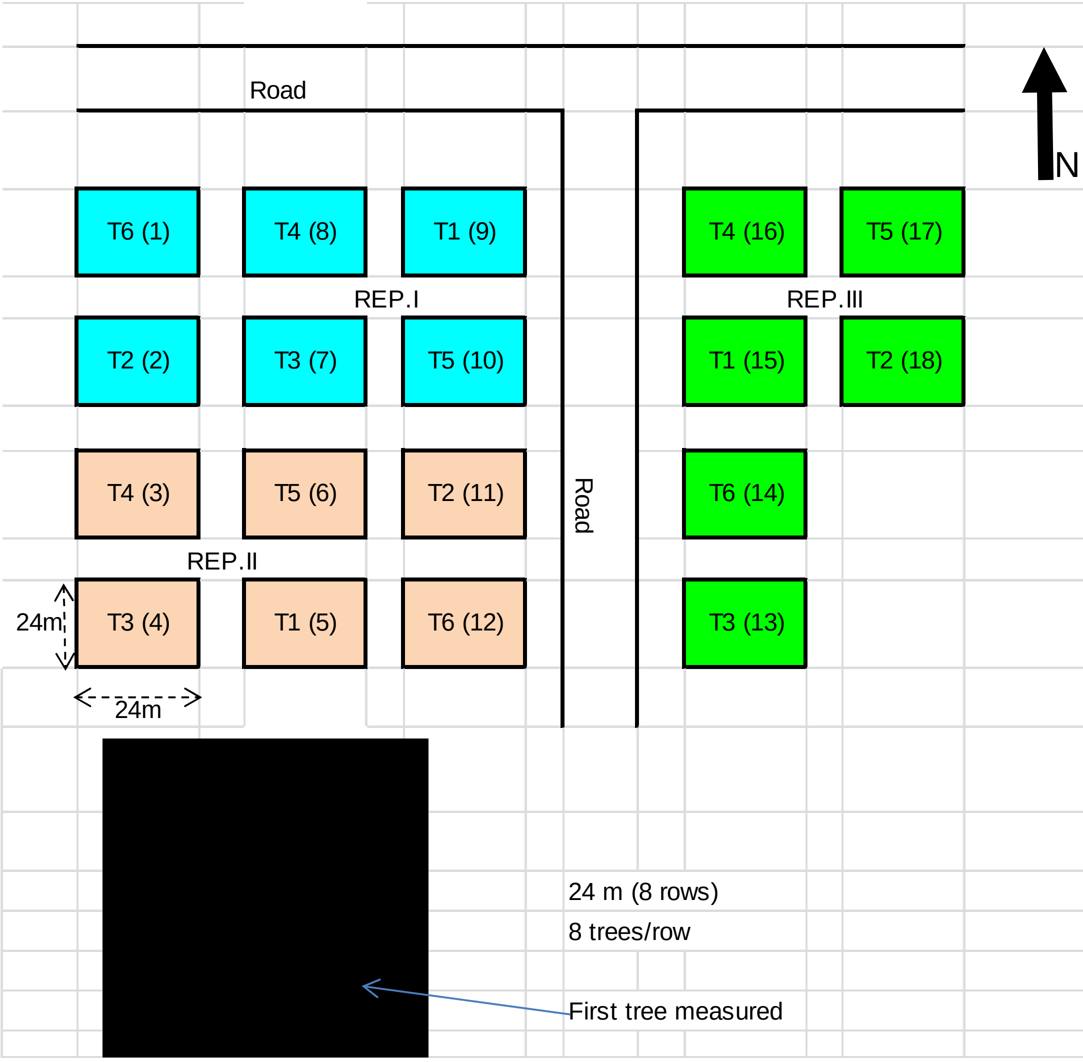
TRIAL #1: *ACACIA* HYBRID THINNING TRIAL PB01Ah

Location:	Phu Binh Station
Species:	*Acacia* hybrid; Clone AH7
Planting time:	27 – 31 July 2010
Stocking rate:	1111 trees ha^{-1}
Gross plot size:	576 m^2 (64 trees)
Net (measured) plot size:	324 m^2 (36 trees)
Experimental design:	Randomised complete block with three replications

Treatments:

Measured control plot T1:	324 m^2 (36 trees)
First thinning T2, T3 &T4:	22nd July 2012
Second thinning T4, T5 & T6:	12 – 13th June 2013
Stems $plot^{-1}$ remaining at T2 & T5:	Gross (48 trees); Net (27 trees); Buffer (21 trees)
Stems $plot^{-1}$ remaining at T3, T4 & T6:	Gross (35 trees); Net (19 trees); Buffer (16 trees)

Layout of experiment



Results (August 2014)

Table 9.2.1: Effects of time and intensity of thinning on diameter of *Acacia* hybrid

Treatments	Stocking (trees ha^{-1})	Diameter at stand age and increment after thinning (cm)			
		year 2	year 4	# 1st	#2nd
T1_control	1111	9.7	13.2	1.8	1.7
T2_early thinning	833	10.2	14.1	2.0	1.8
T3_early thinning	600	10.0	15.0	2.3	2.7
T4_early&late thinning	833/600	10.0	15.0	2.1	2.8
T5_late thinning	833	10.2	14.1	1.8	2.0
T6_late thinning	600	9.9	14.8	1.8	2.6
F pr (α=0.05)		*0.3*	<0.001	<0.001	<0.001
LSD		*0.6*	0.3	0.2	0.3

Table 9.2.2: Effects of time and intensity thinning on volume of *Acacia* hybrid

Treatments	Stocking (trees ha^{-1})	Volume (m^3 ha^{-1}) before thinning		volume (m^3 ha^{-1}) after thinning		
		year 2	year 3	year 2	year 3	year 4
T1_control	1111	53.4	95.7	53.4	95.7	117.4
T2_early thinning	833	51.1	82.2	47.2	82.2	102.6
T3_early thinning	600	47.0	59.3	31.7	59.3	90.0
T4_early&late thinning	833/600	52.8	81.5	44.7	58.0	80.8
T5_late thinning	833	54.9	92.9	54.8	82.3	104.5
T6_late thinning	600	55.3	94.8	55.3	58.8	77.8
F pr (α=0.05)		0.5	<0.001	<0.001	<0.001	<0.001
LSD		9.5	8.1	8.1	7.4	7.0

Note: Survival rates (%) were 93.5, 98.8, 100, 100, 100 and 98.3 for T1, T2, T3, T4, T5 and T6, respectively and no significant difference between treatments ($p < 0.05$).

Conclusions from Phu Binh trial

The growth response to thinning occurs because:

- The leaves of individual trees, particularly in the lower canopy, have greater exposure to light;
- The roots have greater access to water and nutrients (because of less competition between trees)

In this trial, greater exposure to light was probably the most important, except at the end of the dry season when available soil water is limiting growth. A problem that occurs when stands are thinned is that the retained trees lose some of their stability. Treatment T4 examines whether two-stage thinning leads to greater stability (higher survival). In this case there was no effect.

For the early thinning at age two years:

- There was a diameter growth response in the 1st year after thinning in the 833 (2.0 cm) and 600 (2.3 cm) trees ha^{-1} treatments. In the unthinned (1111 trees ha^{-1} treatment, diameter growth was 1.8 cm. The results clearly illustrate how diameter increment increases with the growing space available.
- In the second year after thinning, the diameter responses in the unthinned (1.7 cm) and 833 (1.8 cm) treatments were similar; in the 600 treament the diameter increment was 2.7 cm. This is probably because one year after thinning the 833 treatment, the canopy has closed and competition for light is similar to that in the unthinned treatment. In the 600 treatment, trees are still able to take advantage of better access to light because the tree canopies remain more open.

For the late thinning at age three years:

- A similar pattern is emerging in the late thinning
- The second thinning from 833 to 600 has sustained the thinning response by reopening the canopies.

TRIAL #2: ACACIA AURICULIFORMIS SLASH MANAGEMENT STUDY (3^{rd} rotation)

Location:	Phu Binh Station
Area :	4 ha
Species:	*Acacia auriculiformis*
Clone:	AA1, AA 9 (mixture)
Stocking rate:	1666 trees ha^{-1}
Planting time:	August, 2008
Experimental design:	Randomised complete block with five replications

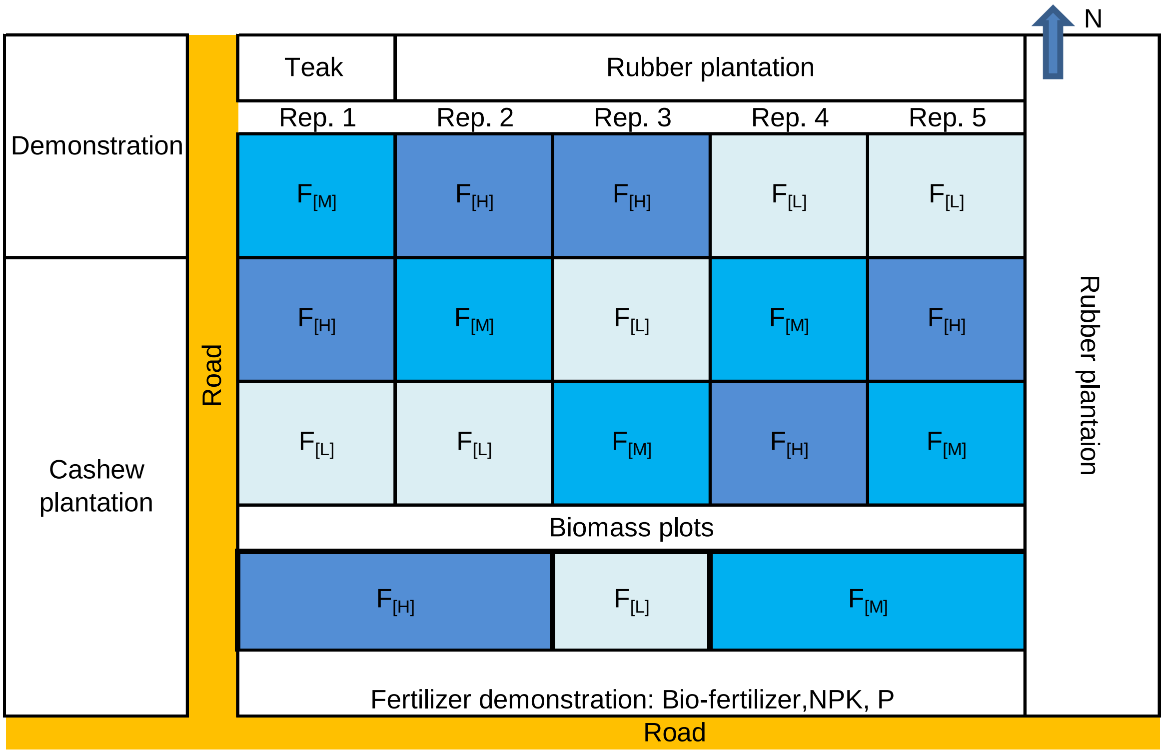
Treatments:

F $_{(L)}$: All above-ground biomass including the crop trees, understorey and litter removed (no slash).

F $_{(M)}$: Stem wood with bark harvested, all other slash residue left in plots with minimum disturbance (single slash).

F $_{(H)}$: Single slash plus superphosphate fertilizer. The same as BL_2 treatment but addition of 300 g superphosphate per tree (20 g P/tree) at planting (= 30 kg P per ha.

Layout of the experiment



Results

Table 9.2.3: Effects of slash and litter retention and phosphorus fertilizer application on stand growth of the third rotation at age six years

Treatments	Height (m)	DBH (cm)	Volume ($m^3 ha^{-1}$)	MAI ($m^3 ha^{-1} y^{-1}$)
$F_{(L)}$	18.9	12.4	182.9	30.5
$F_{(M)}$	19.4	12.9	195.4	32.6
$F_{(H)}$	19.7	13.4	216.9	36.2
p-value	<0.01	0.003	<0.001	
LSD (p=0.05)	0.4	0.5	12.5	

Conclusions from trial

Slash and litter retention have the positive effects of:

- Retaining nutrients on site which can be recycled to support tree growth in the next rotation;
- Protecting soil from erosion during the inter-rotation period and pre-canopy closure in the next growth cycle.

Slash retention and slash retention + application of P fertiliser were associated with statistically significant increases in tree diameter growth and stand volume at age six years.

Standing volume of the $F_{(H)}$ treatment (216.9 $m^3 ha^{-1}$) is currently 18% greater than that of the $F_{(L)}$ treatment (182.9 $m^3 ha^{-1}$)

Trial #3: *ACACIA* AURICULIFORMIS THINNING TRIAL WITH AND WITHOUT SLASH RETENTION AND PHOSPHORUS FERTILISER PB01Ah

Location: Phu Binh Station

Species: *A. auriculiformis*; Clone: AA1, AA 9

Stocking rate: 1666 trees ha^{-1}

Planting time: August, 2008

Thinning time: July, 2012

Gross plot size: 504 m^2 (64 trees)

Measured control plots (T1) and T2, T3: 300 m^2 (50 trees)

Measured thinned plots (T4, T5, T6): 300 m^2 (25 trees)

Treatments:

T1: No thinning, 1666 trees ha^{-1}; no fertiliser; retained slash and litter (control)

T2: No thinning, 1666 trees ha^{-1}; no fertiliser; removed slash and litter

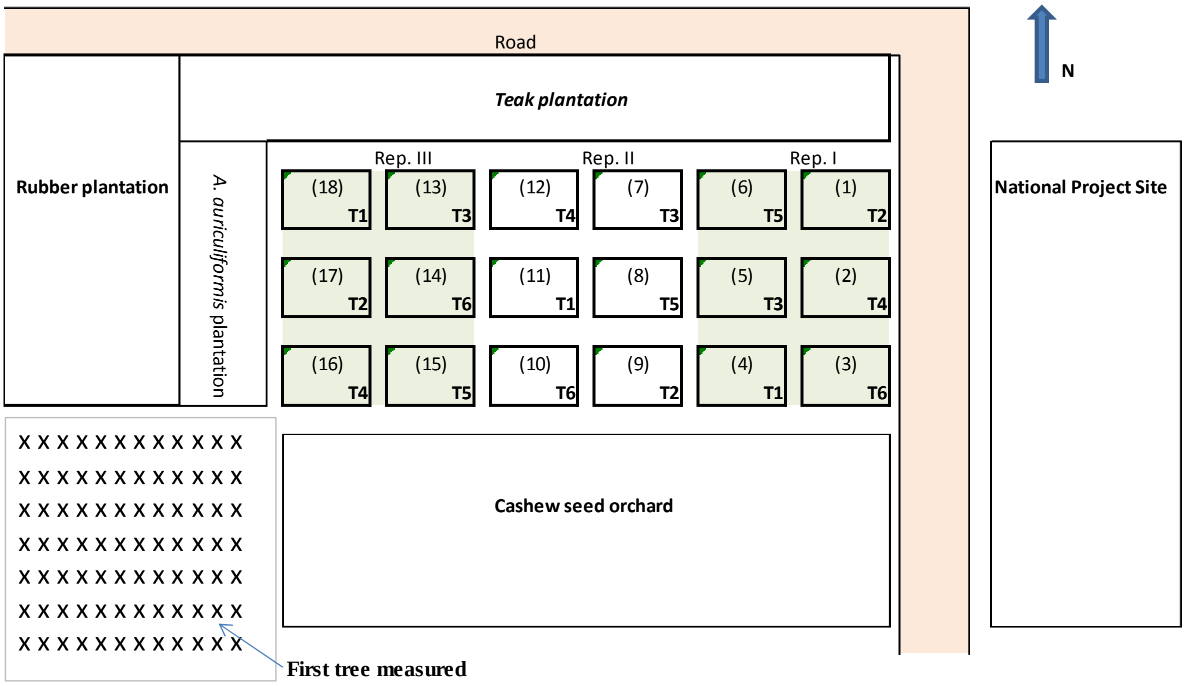
T3: No thinning, 1666 trees ha^{-1}; supplied 50 kg P ha^{-1}; retained slash and litter

T4: Thinning, 833 trees ha^{-1}; no fertiliser; retained slash, litter and thinning residues

T5: Thinning, 833 trees ha^{-1}; no fertiliser; removed slash, litter and thinning residues

T6: Thinning, 833 trees ha^{-1}; supplied 50 kg P ha^{-1}; retained, litter and thinning residues

Experimental layout



Gross plot: 7 rows x 12 trees/rows = 84 trees
Net plot: 5 rows x 10 trees/row = 50 trees
Buffer area: 34 trees

Results

Table 9.2.4: Effects of thinning and fertiliser application on diameter of the *Acacia auriculiformis* plantation

Treatments	Stocking (trees ha^{-1})	Height* (m)	DBH* (cm)	Diameter increment (cm) after thinning	
				1st year	2nd year
T1	1666	15.6	11.6	0.8	1.1
T2	1666	16.1	11.8	0.7	1.2
T3	1666	16.0	12.0	1.1	1.0
T4	833	16.3	12.5	1.7	1.6
T5	833	16.5	12.4	1.5	1.6
T6	833	16.4	12.0	1.8	1.8
F pr (α=0.05)		*0.2*	*0.08*	<0.001	<0.001
LSD		*0.4*	*0.8*	0.3	0.2

Note: * Height and diameter measured immediately in July 2012 after thinning

Table 9.2.5: Effects of time and intensity thinning on the standing volume of the *Acacia auriculiformis* plantation

Treatments	Stocking (trees ha^{-1})	Volume (m^3 ha^{-1}) at stand age	
		year 4	year 6
T1	1666	117.2	206.4
T2	1666	116.4	207.8
T3	1666	111.2	199.4
T4	833	80.2	167.7
T5	833	80.9	157.8
T6	833	75.3	164.4
F pr (α=0.05)		0.002	0.04
LSD		20.9	17.3

Conclusions from trial

- There have been strong responses to thinning in all treatments. As half the trees were removed at thinning at age four years, the thinning response should be sustained for at least another year;

- There have been no apparent responses to retention of slash and litter, or application of P fertiliser at thinning, but this needs further investigation;

- The ratios of the average stand volume and mean annual increments (MAIs) in the unthinned treatments (T1 + T2 +T3) to that in the thinned treatments (T4 +T5 + T6) at thinning was 1.46. Two years after thinning this ratio was 1.25.

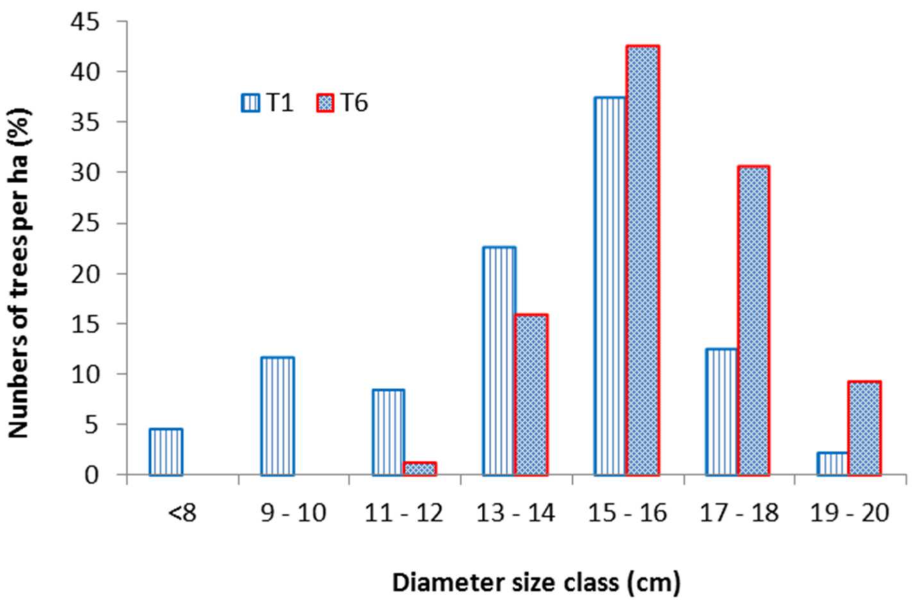


Figure 9.2.1: The percentage number of trees per ha in each diameter (DBH) class 2 years after thinning and fertiliser application for T1 (control) and T6 (thinning to 833 trees ha^{-1}application of 50 kg P ha^{-1}; retained, litter and thinning residues)

9.3 Growth of *Acacia* hybrid under Intensive Management at age two years at seven sites located throughout Vietnam

Introduction

Acacia hybrid is planted throughout Vietnam and currently occupies at least 0.23 Mha (Griffin et al., 2011). This means that it has been established on a wide range of soil types and across a wide range of climates. Its fast growth rates and short-rotation cycle across these landscapes suggests that *A.* hybrid is reasonably well-adapted to these varied growing conditions. These plantations are currently harvested for a wide suite of end-uses: paper, particle- and fibre-board, construction, and furniture. However, as the majority of timber used for furniture industries is imported and the continuity of these supplies is a major concern, Vietnam is encouraging the management of a greater proportion of it acacia plantation estate for sawlogs. Blyth and Hoàng (2013) have shown that there can be significant economic advantages of sawlog over pulpwood production based on a financial analyses conducted for typical smallholders throughout the country. Such plantations are likely to require fertiliser addition as well as pruning and thinning to maximize their productivity and value.

Substantial areas that have been allocated to acacia-based plantation forestry in Vietnam were degraded because of the impacts of war and a history of unsustainable logging practices (Sunderlin and Ba 2005). There is also evidence of declining forest productivity after successive rotations which are probably related to the use of inter-rotational collecting of firewood and burning of residues, and inter-row ploughing for weed and fire control. Thus in spite of the application of fertiliser at planting, soil erosion and lost capacity for the recycling of nutrients have led to a reduction in productive potential. There appears to be no good record of this lost capacity; it is probably related to soil type and climate which both vary along the 2000 km length of Vietnam.

Acacia hybrid and its parent species, *A. mangium* and *A. auriculiformis* have very high early growth rates and this is one of the reasons that they have been exploited in short-rotation tropical plantation forestry. All acacias belong to the Fabaceae and are legumes which are generally considered to have a reduced requirement for N and an increased requirement for P compared to non-leguminous tree species (Ingestad 1980). This appears to be the case for tropical acacia trees (Waki 1984), although it remains unclear whether this is related to the direct requirements for N-fixation or to processes determining plant nutrition and nutrient supply more generally (Binkley and Giardina 1997). That *A. mangium* responds strongly to increasing levels of P application up to 150 kg ha^{-1} at planting was established in an experiment undertaken in South Sumatra which showed that significant growth responses can be experienced at age one year even on sites that are inherently productive, though differences between P-fertiliser treatments were no longer significant at age five years (Mendham & Hardyanto 2011). Nevertheless, the early response to P suggests that its application is essential if responses to early thinning are to be maximised. Whether responses to P or other nutrients occur if applied later in the rotation, for example at thinning, remain to be tested.

The establishment of plantation acacias is a relatively new practice in Vietnam. However it has attracted numerous smallholders that are new to forestry, as well as public forestry and commercial private interests. In 2010, the smal-holder sector was responsible for the management of 46% of the total area of plantation forests in Vietnam (Blyth and Hoàng, 2013). While elaborate networks of Extension Officers service smallholder interests, these officers are not well-versed in silvicultural practices like pruning and thinning that are crucial for sawlog production. This is not surprising as a review by Dang Thinh Trieu (2007) showed that at that time there had been only one thinning trial of an acacia species in the whole of Vietnam; the results had been inconclusive as some of the major principles of thinning had not been adhered to when the treatments were imposed. Thinning is used so that tree size at harvest is optimised; the final stocking will determine that size (Beadle et al. 2013). However, the only moderate apical dominance of *A.* hybrid means that plantations will usually have to be planted at higher stockings so that between-tree competition, assisted by singling and form pruning, encourages the development of good form. The high growth rates and early development of this competition mean that early thinning is preferable if growth rates of retained trees are not to be compromised.

In this study, seven trials of *A.* hybrid spread through southern, central and northern Vietnam were established that incorporated a common silvicultural approach to site preparation, planting, weed control, and fertiliser application at planting. Growth responses to around age two years, and subsequently to fertiliser and thinning to age three years across were measured. The results are discussed in the context of soil type, soil properties and climate.

Materials and methods

Sites, experimental design and plantation establishment

The seven sites used in this experiment were located in southern (four sites), central (one site) and northern (two sites) Vietnam (**Table 9.3.1**). At all except Son Duong in Tuyen Quang province, the previous vegetation had been planted *Acacia auriculiformis* (Phu Binh, Ba Vi), *Acacia* hybrid (Phu Thanh, Xuan Loc, Dong Ha) or *Acacia mangium* (Nghia Trung); at these sites all slash/residue was retained and cut after harvesting. At Son Duong, the land had previously been used for agriculture.

A randomised complete block design was used to accommodate a treatment matrix that allowed for two thinning and three fertiliser treatments at thinning, with three replications. The density at planting was 1111 stems ha^{-1} (3 m × 3 m). All 18 experimental plots in each trial consisted of a net plot surrounded by one line of trees which acted as a buffer row, and which together with the net plot defined the gross plot. The net plots were six rows wide (18.0 m) with six trees in each row (18.0 m); the gross plot size was 24.0 m × 24.0 m or 0.058 ha and the full size of each trial was 1.04 ha. Treatments were applied uniformly to trees in both the net and gross plots.

Planting was into 40 cm × 40 cm × 40 cm pits. At all trials, 100 g tree^{-1} of 16:16:8 N:P:K plus 403 g tree^{-1} superphosphate was placed at the bottom of the pit. Thus the total amount of N:P:K applied at planting was 17.8, 50 and 8.9 kg ha^{-1}, respectively. A variety of clonal stock was used either in mixture or singly (**Table 9.3.1**). The ramets were planted manually using spades. Total weed control using Round-up at 4 L ha^{-1} (0.48 g L^{-1} and 1.92 kg ha^{-1} *Glyphosate isopropylamine* salt) was applied as necessary and supported on occasion with slash cutting. As the plantations were being managed for sawlogs, tip (form) pruning to 4.5 m to maximize tree straightness and lift pruning to up to 2.5 m so that the bottom log of 2.2 m was clear (knot-free) wood, were undertaken. During the first three months after planting at Nghia Trung only, a 1.2% solution of the termiticide Lenfos 50EC with Chlorpyrifor Ethyl at 500 g L^{-1} was applied around each tree as required.

Table 9.3.1: Sites (southern S, central C or northern N Vietnam), location, planting dates and clonal stock used in this study. Where clonal mixtures were used, these were planted randomly

Site (S, C or N)	Latitude Longitude	Planting date	Clonal stock#
Nghia Trung (S)		July 2009	TB01, TB06, TB11; TB12
Phu Binh (S)	11°18'87''N 106°52'68''E	July 2010	AH7
Phu Thanh (S)		August 2009	TB06, TB12
Xuan Loc (S)		July 2012	AH7
Dong Ha (C)		November 2009	BV10, BV16, BV32
Ba Vi (N)	21°08'50''N 105°20' 03''E	July 2009	BV10, BV16, BV32
Son Duong (N)	105°16'58''E	June 2009	BV10

#All clones have been approved for planting in Vietnam

Soil description, sampling, preparation and chemical analysis

Following Isbell et al. (1997), three soil pits were dug at each site to expose soil horizons A, top soil, B, sub-soil and C, parent material. Soil colour, texture and strength were then used to classify the soil type and productivity potential.

At each study site and using an auger, 3-cm diameter soil cores were taken from at least five and up to nine randomly-selected points from each plot at two soil depths, 0-10 and 10-20 cm. Prior to sampling, surface litter was removed to expose the mineral soil boundary. Samples from each depth were combined into two composite samples and thoroughly mixed. A minimum of 200 g of the <5 mm fraction was retained for transport to the laboratory.

Using a 5-mm sieve, the <5 mm fraction was separated and air-dried at 40-60°C; the >5 mm fraction was discarded. A 2-mm sieve was then used to provide a 50-100 g subsample, sufficient for the desired analyses, which was dried for 24 h at 105°C to constant weight.

The instructions for soil analysis in van Reeuwijk (2002) were used to determine the total organic carbon (%) content using the Walkley-Black method, total nitrogen content (%) by digestion in a mixture of sulphuric acid and hydrogen peroxide-selenium using the micro-Kjeldahl method, and available P (mg/kg) following extraction by Bray-I solution containing 0.03M NH_4F and 0.025M HCl. pH_{H2O} was determined in a 1:2.5 mixture of soil:water and particle size following the method of Robinson (see van Reeuwijk 2002); bulk density (g cm^{-3}) was based on the oven-dry weight.

Thinning and at-thinning fertiliser treatments

At Nghia Trung, Phu Thanh, Dong Ha and Ba Vi, thinning of half the plots to 600 stems ha^{-1} was undertaken when the mean diameter at breast height, 1.3 m ($d_{1.3}$) was 7-8 cm. The following criteria were used. As the final-crop stocking in the net plot was 19 stems per plot, a maximum of 17 trees had to be removed. To meet this requirement, five of the 6-tree rows had three trees removed, and 1 row had two removed. If there were fewer than 36 stems, then fewer trees were removed. The net plot was thinned first and thinning undertaken on a row-by-row basis. The selection of trees for thinning was based on the following criteria; trees that were of poor form in the first 4.5 m or with large forks; trees that were still multi-stemmed in spite of singling; trees of small diameter that were suppressed though as clonal stock was used, this was not a serious issue.

As it was important to maximise the spacing around each retained tree and to obtain even spacing, removal of three trees that were adjacent to each other in a row was avoided, even if all three were smaller trees. The same criteria were used to select trees for thinning in the buffer rows.

There were three fertiliser treatment at thinning, no fertiliser, and the equivalent of 50 kg P ha^{-1} – or + basal fertiliser. The inclusion of basal fertiliser in the last treatment was to ensure that responses to P were not compromised by any deficiency of other nutrients (Mendham & Hardyanto 2011). The P-fertiliser was applied as superphosphate in a 50-cm band in the centre of the inter-row area. This method of application was used to combine the need to concentrate P-fertiliser over a small area to maximise its efficiency of uptake, and ease of application. On a per hectare basis, the basal fertiliser consisted of the equivalent of 80.0 kg KCl, 12.0 kg $MgSO_4$, 64.0 kg $FeSO_4.7H_2O$, 6.0 kg $MnSO_4.H_2O$, 3.5 kg $ZnSO_4.7H_2O$, 2.0 kg $CuSO_4$.xH2O and 0.11 kg $Na_2MoO_4.2H_2O$. Urea was omitted because the plantations were well established and should have already been fixing large quantities of atmospheric N. Hydrated lime was also omitted because superphosphate includes Ca.

Growth

From age one year, top height (*H*) was measured with a height pole and diameter at breast height (1.3 m), $D_{1.3}$ with a diameter tape were measured on a regular basis for at least two years at all sites, and for those sites that were thinned and fertilized at thinning, for approximately three years

Analysis of results

Analysis of variance was used to examine responses to thinning and fertiliser application at thinning. As there were no responses to either fertiliser treatments (basal + or – 50 kg P ha^{-1}) at thinning, the fertiliser treatments were combined before examining responses to thinning.

Results

Soil type and chemistry

Three major soil types were represented, basalt soils at Nghia Trung and Phu Thanh, gleyic acrisols at Phu Binh and Xuan Loc, and red-yellow ferric soils at Dong Ha, Ba Vi and Son Duong (**Table 9.3.2**). Organic carbon (C) and total nitrogen (N) were greatest at the basalt sites; conversely available P was amongst the lowest levels across sites. The gleyic acrisol sites were associated with higher levels of available P; the greatest, 11.1 mg kg^{-1}, was at Phu Binh. Differences between sites were by a factor of 3 for organic C and total N, and 6 for available P.

Table 9.3.2: Soil type and levels of organic carbon, total nitrogen and available P at 0-10 cm depth at the seven sites

Site (S, C or N)	Soil type	Organic C (%)	Total N (%)	Available P (mg kg^{-1})
Nghia Trung (S)	Basalt	4.0	0.22	2.3
Phu Binh (S)	Gleyic acrisol	2.0	0.14	11.1
Phu Thanh (S)	Basalt - Ferralsol	3.4	0.18	3.2
Xuan Loc (S)	Gleyic Acrisol	1.2	0.07	5.8
Dong Ha (C)	Red-yellow ferric - Rhodic ferralsol	1.8	0.12	5.8
Ba Vi (N)	Red-yellow ferric	2.6	0.16	1.8
Son Duong (N)	Red-yellow ferric	1.2	0.11	4.9

Growth in unthinned treatment

Around age two years, growth rates were highest in southern, between 7.6 – 10.4 cm, intermediate in central (7.3 cm) and lowest, between 6.3 – 6.5 cm, in northern Vietnam (**Table 9.3.3**). The best performing sites at age 2 y were Nghia Trung, Phu Binh and Phu Thanh which had $D_{1.3}$ of around 10 cm; at age 3 y at Nghia Trung and Phu Thanh, $D_{1.3}$ was around 12 cm.

Response to thinning

There were significant responses of $D_{1.3}$ to thinning at Nghia Trung, Phu Thanh and Ba Vi within the first year following thinning (**Table 9.3.4**). At Dong Ha, the response to thinning was nearly significant five months after thinning. Height growth at all sites was unaffected by thinning. The most rapid responses to thinning were at Nghia Trung and Phu Thanh.

Table 9.3.3: Growth ($D_{1.3}$) of the unthinned treatment (1111 stems ha^{-1}). S, C and N refer to northern, central and southern Vietnam, respectively.

Nghia Trung (S)		Phu Binh (S)		Phu Thanh (S)		Xuan Loc (S)	
y	$D_{1.3}$	y	$D_{1.3}$	y	$D_{1.3}$	y	$D_{1.3}$
1.1	5.6	1.0	4.9	1.0	6.0	1.1	3.6
1.4	7.6	2.0	9.9	1.7	8.1	2.0	7.3
1.7	8.7			2.2	10.4		
1.9	9.7			2.4	11.0		
2.4	11.3			2.8	12.0		
2.9	12.1						

Dong Ha (C)		Ba Vi (N)		Son Duong (N)	
y	$D_{1.3}$	y	$D_{1.3}$	y	$D_{1.3}$
1.1	3.3	1.1	4.8	1.8	6.5
1.8	6.4	1.8	6.3	2.4	8.5
2.0	7.3	2.4	7.8	2.9	9.2
2.4	8.4	2.9	8.4		

Growth and available P

There was no relationship between diameter growth and available P across the seven sites (**Figure 9.3.1**). High rates of growth were associated with low levels of available P at Nghia Trung and Phu Thanh, and a high level of available P at Phu Binh.

Discussion

Seven trials were used to examine the growth responses of *Acacia hybrid* to a consistent and systematic application of site preparation and establishment across a range of sites which differed in their potential to support tree growth, and subsequently at four of these sites to two thinning and three fertiliser treatments. Application of 50 kg P ha^{-1} at planting was associated with high growth rates but there were no responses to application of P or other fertilisers at thinning. There was a strong response to thinning at all sites at least by one year after thinning. These observations are now discussed in the context of edaphic and climatic factors that can potentially limit the growth of *A.* hybrid.

Table 9.3.4: Growth responses to thinning

Site (S, C or N)	**Treatment Probability**	**Diameter, $d_{1.3}$ (cm)**	**Height, h (m)**
Nghia Trung (S)	1111	12.1	12.6
	600	13.4	12.3
	P-value	0.007	0.213
Phu Thanh (S)	1111	12.0	12.0
	600	13.2	12.0
	P-value	< 0.001	0.898
Dong Ha (C)	1111	8.4	7.4
	600	8.6	7.4
	P-value	0.073	0.326
Ba Vi (N)	1111	8.4	8.2
	600	9.5	8.5
	P-value	<0.001	0.160

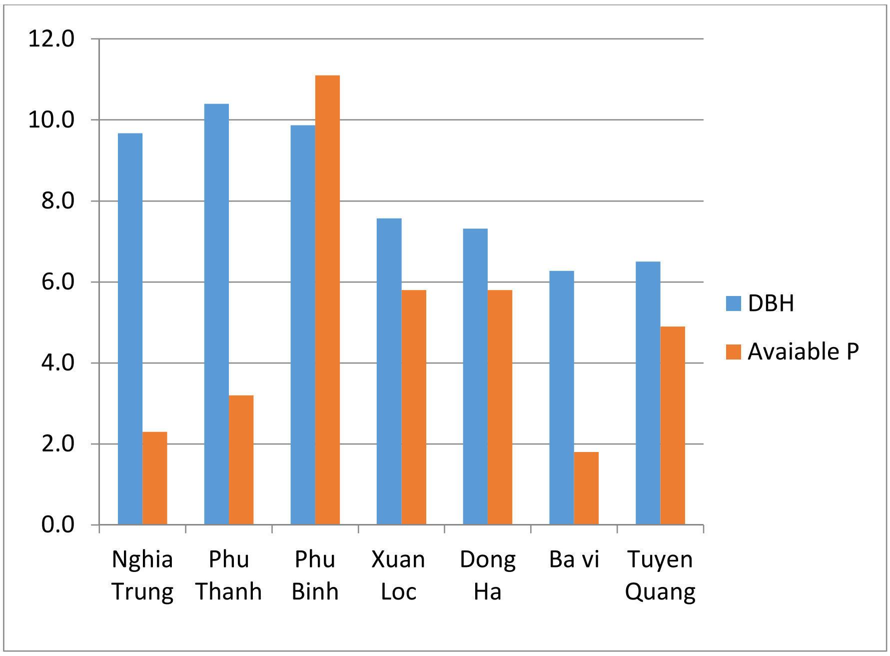


Figure 9.3.1: The relationship between $D_{1.3}$ (cm, DBH) and available P (mg kg^{-1}) at age 2 y in the unthinned stands.

The supply of phosphorus is often considered a constraint on the growth of legumes because of the high concentration of P in nodules associated with nitrogen fixation (Munns & Franco 1982, Sprent 1999). Growth rates were highest at Nghia Trung and Phu Thanh, the sites that had inherently productive basalt soils. That there had been a strong response to application of 50 kg P ha^{-1} at planting is supported by the observation that on an adjacent basalt site at Nghia Trung there were significant differences in growth at age one year between *A.* hybrid receiving the same level of P at planting ($D_{1.3}$ = 9.2 cm) and those receiving no fertiliser ($D_{1.3}$ = 7.9 cm; Pham Van Bon, pers. comm.). Nevertheless there was no relationship between the commonly used Bray-1 measure of available P in soil and diameter growth across sites. Levels of extractable P are related to the P-fixing capacity of soils. This was very high in the basalt-derived soils at Nghia Trung and Phu Thanh. Consequently soil solution P can be more readily replenished in these soils compared to those with higher levels of measured available P, so they are productive. Nghia Trung and Phu Thanh also had the highest levels of total soil N and organic C, suggesting higher inherent fertility. Interestingly, ratios of organic C to total N (C:N) of 10:1 normally represent fertile soils; C:N at Nghia Trung was 17.9; at Phu Thanh was 17.8. This suggests that acacias can grow well in spite of a high C:N.

Thinning extends the period during which lower canopies can contribute to tree growth and early thinning at canopy closure maximises this response because canopy lift is minimised (Medhurst & Beadle, 2005). This was associated with marked growth responses to thinning of *A.* hybrid which were faster and greater at the two southern sites than those in central and northern Vietnam; at the southern sites treatment differences were significant six months after thinning. This response shows that inter-tree competition for resources is very high in fast-growing *Acacia* hybrid stands established at conventional stockings of 1111 stems ha^{-1} and above, suggesting that growth rates and therefore potential sawlog values can be compromised as early as age two years. However it remains unclear whether delayed thinning will compromise individual tree growth or simply extend the time to harvest. In the context of this study, the economic analysis above (**Appendix 9.1**) shows that delaying thinning until age 3 y maximises NPV at age 6 y because the pulpwood value of the thinned trees exceeds that if the thinning is done at age 2 y.

The timing and magnitude of any thinning response will be a function of stand age, site quality and environment (Medhurst et al. 2001). Thus patterns of growth appeared distinct between the south and other parts of Vietnam such that the length of rotation to final harvest will be least in the south where diameter growth rates were 7.6-10.4 cm to age 2 y; in Central Vietnam it was 7.3 cm, and in the north 6.3-6.5 m to age 2 y. The longer dry season in central Vietnam and low winter temperatures in northern Vietnam were probably the main climatic factors contributing to this difference. The extent to which the clonal stock planted may have affected the thinning response remains unknown, although at the Stock Type trial (**Section 6**), there were no significant differences in the growth of three BV clones in unthinned stands at age 2 y (Pham Van Bon, pers. comm.).

In conclusion, this study has shown that with improved silviculture at planting and with careful attention to weed control, management of *A.* hybrid for sawlogs can take advantage of a marked response to early thinning. Thinning rate in this study was to 600 stems/ha which should, on average, result in a first log of 2.2 cm length which exceeds the minimum requirement for large sawlogs (≥ 18 cm, Tran Thanh Cao, pers. comm.). If much larger logs are required (e.g. ≥ 25 cm), a second thinning to a lower stocking will be required.

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