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Final report

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prepared by	Chris Beadle (Project Leader) Maria Ottenschlaeger (CSIRO) Pham The Dung (FSSIV and In-country Project Co-ordinator) Caroline Mohammed (University of Tasmania)
co-authors/ contributors/ collaborators	Vu Dinh Huong (FSSIV) Kieu Tuan Dat (FSSIV) Daniel Mendham (CSIRO) Chris Harwood (CSIRO) Morag Glen (University of Tasmania)
approved by	Mr Tony Bartlett, Research Program Manager for Forestry, ACIAR
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Contents

1 Acknowledgments

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Abbreviations

CSIRO	Commonwealth Scientific and Industrial Research Organisation
FSIV	Forest Science Institute of Vietnam
FSSIV	Forest Science Sub-Institute of Vietnam
JAF	John Allwright (Postgraduate Fellow) Fellow
RCFTI	Research Centre for Forest Tree Improvement
DSS	Decision Support System

2 Executive summary

Vietnam imports 80% of its wood supply to service a growing export-focused furniture industry. The small-holder sector manages approximately half the total area of its plantation forests. A pre-project financial analysis had shown that there may be significant economic advantages for typical small-holders of sawlog over pulpwood production. We investigated the suitability of silvicultural systems that optimise the production of sawlogs from the most commonly planted species, *Acacia* hybrid, by exploiting its very high early growth rates and minimizing the length of rotation required to attain a commercial log size. Short rotations are an economic imperative for farmers who need the cash flow and income sooner rather than later. A key objective was to develop tools to support improved management of these plantations in the context of site, silvicultural inputs and sustainable management.

A series of trials that incorporated a common silvicultural approach to site preparation, planting, weed control, pruning and fertiliser application at planting showed that growth rates were consistently higher in southern than central and northern Vietnam which have a longer dry season and a colder winter, respectively. An important finding was that 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 years; in Central Vietnam it was 7.3 cm, and in the north 6.3-6.5 m to age 2 years.

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 fast-growing *Acacia* hybrid stands established at conventional stockings between 1111 and 1667 trees per hectare such that individual tree growth rates and therefore saw-log values can be compromised as early as age two years; delayed thinning and low thinning intensities may also compromise individual tree growth. This rapid response to thinning was not related to the application of fertiliser at thinning at the southern sites but was at the northern sites. However there was no simple relationship between a measure of potential phosphorus supply and diameter growth at age two years across sites; the highest productivity sites were on soils that combined a high total nitrogen and organic carbon content. In the absence of factors that downgrade wood quality, the research found that with improved silviculture, including thinning, management for saw logs is financially more attractive than for pulpwood over a six-year rotation, a length commonly adopted for pulpwood.

Poor planting stock and high rates of fertiliser application can lead to the formation of poor form and lack of stem straightness and large branches. Pruning large branches led to the development of heart rot at southern sites which makes logs unacceptable for sawn timber. The very high growth rates which led to the formation of large crowns were associated with branch and on occasions stem breakage during severe storm events. Better choice of planting stock, timely and correct pruning techniques, and management of canopy size are therefore essential if these problems are to be minimised. Surveys and the experimental data suggest that in addition to heart-rot fungi there are other significant biotic agents that may impact on wood quality.

A package of extension materials was delivered to the National Agricultural and Forestry Extension Centre: (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 saw logs; and (iii) seven Technical Information Sheets giving advice on soils and the management of silvicultural inputs for saw-log production. The key audience for these materials is Extension Officers who service the small-holder sector at provincial and district levels.

Successful communication of the information gained from this project through the extension services should enable the transformation of a plantation resource from one that is primarily focused on low-value pulpwood to a high-value resource that can markedly reduce Vietnam's reliance on imported timber. Extension personnel report that changing the silvicultural practices of growers in Vietnam is a challenge, particularly if improved outcomes depend on timely interventions of inputs like fertiliser, pruning and thinning. Producing trees of good form, an essential requirement for saw logs, also requires high quality seedlings or clones. The establishment of demonstration plantations that incorporate best practice at district level should be tested as a means of encouraging the adoption of the silvicultural approaches developed by this project for saw-log production in the small-holder sector.

3 Background

3.1 Key issues addressed

At the inception of this project, The Government of Vietnam was promoting an ambitious 5 Million Hectare Reforestation Program (5MHRP) that required the establishment of about 3M ha of tree plantations by 2010. The commercial sector of this estate then included 300-400k ha of *Acacia* species and the focus of this project, the natural hybrid between *Acacia auriculiformis* and *A. mangium*, was the most planted acacia species. The other major development was that Vietnam was building an export wood-products industry focused primarily on wooden furniture which consumes approximately 6M m^3 of timber in roundwood equivalents each year, was already worth US$2.2 B in 2006 and had become the world's fourth largest of its type. However this industry was reliant on imported logs and lumber for 80% of its resource (worth US$600M); the remaining 20% was from their own emerging resource, which included acacia wood. This domestic supply was primarily from small-scale plantations that form a significant part of the rural economy and which are ideally suited to the more intensive management required for high-value wood products. Continuity of imported raw material supplies for furniture-making was a major concern for the industry.

The intention of this project was to investigate the suitability of silvicultural systems that optimise the production of sawlogs in short rotations from trees that have been managed in such a way that wood recovery is maximised. A key focus was to exploit the very high early growth rates of *Acacia* hybrid so that rotation length to a commercial log size was minimised. This is a crucial requirement in Vietnam where growers seek to generate income from their investments in just a few years, and where pulpwood production can appear to be competitively advantageous *v.* sawlog production. A key hypothesis underpinning the study was whether timing of thinning affected the thinning response. An integrated approach was adopted that embraced expertise in silviculture, soils, forest health, genetic improvement and modelling.

Although tropical acacias have the potential to grow across a range of soil types, including degraded soils in Vietnam, harvesting their potential wood yields is still dependent on site selection and then good planting stock and stand management. Vietnam has a long record of germplasm improvement of tropical acacia species that has come about in part through ACIAR-funded projects, and also the development by Vietnamese scientists of *Acacia* hybrid. *Acacia* hybrid occupies at least 230,000 ha in Vietnam, the major product being pulpwood in a cutting rotation of about five years (Griffin et al., 2011). Although some improved planting stock was being deployed, its benefit was not being realised because of a lack of understanding of how best to capture value through timely silvicultural inputs that sustain tree vigour and stand health. As rotations can be as short as six years and as growers were already establishing second rotations, there was a pressing need to improve stand management practices.

The ideas behind this project were formed through the networks that had been developed between CSIRO and the Forest Science Institute of Vietnam (now the Vietnam Academy of Forest Science) in a CARD project (2006-2008) funded by AusAID and in previous and current projects funded by ACIAR in Vietnam and Indonesia. The CARD project (VIE 032) used demonstration trials in Central Vietnam to teach growers in the public and small-holder sectors how to prune and thin small woodlots of acacias that form the major part of the domestic supply of sawn wood for the local furniture industry. The current project would put these practices on a more soundly-based footing. The decision tools and related material would enable Extension Officers to provide advice to growers on how to maximise the benefits that can accrue from their acacia plantings. Greater certainty in predicting plantation productivity on different sites will provide growers with an objective compare potential returns from plantations with other land-uses.

In summary, the research and development strategy would:

- Develop pruning, thinning, and nutrition practices that maximise value recovery from improved and identified genetic material of *Acacia* hybrid and/or *Acacia auriculiformis*.
- Foster and enhance knowledge of sustainable management of soil resources and biological risk factors to ensure maintenance of yield.
- Incorporate these into a process-based framework for understanding the biological impacts of site selection and management.
- Adapt the *A. mangium* decision support system (DSS) under development for Indonesia to accommodate *Acacia* hybrid and/or *A. auriculiformis* in Vietnam.

3.2 Justification for project

Immediately before the commencement of this project, ACIAR commissioned a scoping study (Blyth and Hoàng 2013) to determine the economic prospects for acacia sawlog production in Vietnam, and to identify communities involved in acacia planting and their motivation for migrating from pulpwood to sawlog production. Its major conclusions were:

- There were significant economic advantages of sawlog over pulpwood production based on financial analyses conducted for typical smallholders throughout the country.
- Acacias are grown by many smallholders as part of their farming enterprise: these growers are attracted by the greater returns from sawlogs.
- Access to appropriate technical advice and assistance is a critical need to underpin realisation of this opportunity, with research on species-site selection, plantation establishment and silviculture a major priority.
- Research projects should be initiated in regions with good potential for sustaining profitable sawlog production, for example in respect of access to markets.

Based on a number of assumptions, that the area of acacia plantations will continue to grow at 5% a year, that those grown primarily for sawlogs comprise 10% of the total area and those for pulpwood 90%, that sawlogs comprise 30% of the total acacia harvest, and that prices received by growers are AU$23 m^{-3} for pulp logs and AU$67 m^{-3} for sawlogs, the benefits of the project were assessed in terms of improvements in site selection and management, better silviculture, increased proportion of plantations managed for sawlogs and reduced reliance on imported logs. In the three provinces used in the study, sawlog production systems generated higher Net Present Values and Annual Equivalent Values than existing pulpwood production systems for a range of discount rates, sawlog prices and annual yields. The benefit measured as an estimated NPV at a discount rate of 7.5% was AU$16.6M with a benefit/cost ratio of 18.

The establishment of plantation acacias was, and still is, a relatively new practice in Vietnam. However it has attracted numerous small-holders that are new to forestry, as well as public forestry and commercial private interests. In 2010, the small-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 small-holder interests, these officers were not well versed in silvicultural practices like pruning and thinning that are crucial for sawlog production, or in those required for the sustainable management of fast-growing, short-rotation species like acacias. This was not surprising as a review by Dang Thinh Trieu (2007) was able to identify 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. Pruning is often done without an awareness of preferred practice, particularly with respect to timing, the crucial role of the branch collar in the processes of occlusion, and the management of branch size. If not managed, pruning simply becomes the creation of portals for disease entry and ensuing wood decay. Site preparation is often done without an awareness of the need to conserve the nutrient capital on the site. In Vietnam, removal of dead wood for firewood is a common practice, as is ploughing for fire and weed control, a practice that may be associated with repeated damage to the fine root system and reduced efficiency of nutrient turnover. Chemical approaches to weed control may be part of the solution. Thus the increasing numbers of persons actively involved in tree growing and the current paucity of information critical to success of their operations suggested that this project was timely and could deliver a wide range of benefits.

Australia strongly supports practices that maximise the benefits to be gained from the sustainable management of planted forests as part of its policy of reducing pressure on the logging of native forests for wood production in developing countries – Vietnam currently relies in part on wood, and particularly imported wood, harvested from this source. Pursuit of such a policy also contributes to a soundly-based carbon economy as undisturbed native forests on average store more carbon and have greater biodiversity than frequently harvested plantation forests. Australia also supports knowledge transfer for the development of its tropical species in developing countries. An added benefit is the validation of models being developed for tropical acacia and other species being planted in northern Australia.

4 Objectives

Aim: To develop silvicultural practices in rural areas of Vietnam for the *sustained* yield of sawn timber in the *small-holder* and *community* sectors.

Objective 1: Quantify the role of fertiliser, pruning and thinning to optimise tree size, log distribution and economic returns from plantations managed for sawn timber

Sites for new plantings in the small-holder and community sectors will be identified by FSIV staff. Existing silvicultural and genetics trials will also be identified. Robust experimental designs will be imposed on selected sites to support activities in Objectives 1 and 2.

Activity 1.1 Establish experiments to examine the growth responses and wood production of selected clones of *Acacia auriculiformis* and/or *Acacia hybrid* to fertiliser, pruning and thinning across a range of sites.

Activity 1.2 Determine the susceptibility of genetically improved lines to pest and diseases especially those that cause stem defects.

Activity 1.3 Establish the influence of site on pruning and thinning responses and of pruning and thinning on heart-rot incidence and severity. Quantify yields by piece size, wood value and financial benefit.

Objective 2: Examine the roles of site and soil management in the sustainable production of forests grown for sawlog (and pulpwood) production

One (or two) trial(s) containing improved and identified clonal planting stock of *Acacia* hybrid and/or *Acacia auriculiformis* will be used to examine factors that contribute to sustainable wood production. Small satellite trials, primarily those established under Objective 1 where feasible will be used to validate the findings from these large experiments across a wider range of site types (in conjunction with Objective 3).

Activity 2.1 Establish experiments that measure the capacity of sites/soils to meet the demand for, and supply of nutrients, during thinning for sawlog production. Describe soil physical and chemical properties and quantify responses to phosphorus fertiliser.

Activity 2.2 Upgrade procedures in an existing analytical laboratory facility by developing protocols that include reference samples so that secure and repeatable procedures are available to support the project. Test a semi-portable nutrient-analysis system suitable for assessing soils and plant material in a rural environment.

Activity 2.3 Develop simple indices that describe nutrient requirements based on soil type, land-use history and diagnostic tests in Activity 2.2.

Objective 3: Relate potential productivity of *Acacia* hybrid and *Acacia auriculiformis* to site parameters in resource-limited environments in Vietnam

The model CABALA™ will be further developed for use with tropical acacias in the context of sawlog production.

Activity 3.1 Model parameterisation of CABALA™ based on experimental results collected in the project and existing relevant physiological information and validation of the new CABALA™ parameters using small-holder and community forests identified in Activity 1.1.

Activity 3.2 Develop a simple decision-support system for small-holder and community growers based on tables that quantify productivity against climatic and soils information, potential to respond to fertiliser addition and options for pruning and thinning.

Objective 4: To develop tools to support improved management, train Extension Officers to effectively disseminate information to foresters and provide targeted training to FSIV staff

This segment develops a range of activities that deliver the information from the project to users and policy-makers

Activity 4.1 Integrate modelling and experimental results into “forester-friendly” Technical Information Sheets (TIS) written in Vietnamese and a software package for use by the provincial extension service working with community foresters/small growers.

Activity 4.2 Conduct a two training workshops that provides Extension Officers with a template for the effective technology transfer of tools (pruning/thinning strategies, nutrient management, software) developed by the project; field days that allow dissemination of project outcomes to small-holder and community foresters, and three individual training visits to Australia for FSIV staff.

Activity 4.3 Conduct an Inception Workshop for research providers (CSIRO, FSIV and University of Tasmania) and a Final Project Workshop for project staff and the broader scientific community and key players involved in growing tropical acacias for sawn timber in Vietnam.

5 Methodology

5.1 Location of sites and other activity

Thirteen experimental trials were established at seven locations during the project period. Four locations were in southern, one in Central and two in northern Vietnam (Figure 5.1).

Figure 5.1: Map of Vietnam showing the seven locations where experimental sites were established for ACIAR Project FST/2006/087

The sites by type, year of establishment of the experimental treatments, longitude and latitude and province were as in the list below. BP, BD, DN, QT, HN and TQ refer to Binh Phuoc, Binh Duong, Dong Nai, Quang Tri, Ha Noi and Tuyen Quang provinces respectively. There were two main types of experimental trials, Core and Satellite (see Section 5.2). The last experimental trial established at Nghia Trung in 2011 investigated issues that had arisen in the project and related to the effects of stock type and fertiliser application on the expression of form and branch size.

Southern

Core A (2008)	$11^0$34'25.7"N	$109^0$00'51.9"E	Phan Truong 2	BP
Satellite 1 (2009)			Nghia Trung	BP
Satellite 2 (2009)			Phu Thanh	BP
Satellite 3 (2010)	$11^0$18'87"N	$106^0$52'68"E	Phu Binh	BD

Satellite 4 (2010)			Xuan Loc	DN
StockType (2011)			Nghia Trung	BP
Central				
Satellite 5 (2009)			Dong Ha	QT
Northern				
Core B, C (2009)	$21^0$09'00.6"	$105^0$20'33.7"E	Ba Vi	HN
Satellite 6, 7 (2009)	$21^0$08'49.5"	105^0 20'03.0"E	Ba Vi	HN
Satellite 8, 9 (2009)	105^0 20'03.0"	105^0 16'58.0"E	Son Duong	TQ

The sites at Nghia Trung, Phu Binh, Dong Ha and Ba Vi were at experimental field stations managed by FSIV. The sites at Phan Truong Hai and Phu Thanh, and at Xuan Loc and Tuyen Quang were on land owned by private plantation companies viz Hai Vuong Company, Xuan Loc Forest Management Board and An Hoa Company, respectively.

All sites were planted to *Acacia* hybrid except Satellites 7 and 9 which were planted to *Acacia auriculiformis* and *Acacia mangium*, respectively. Satellite 7 was abandoned because low temperature events compromised seedling establishment. This trial had been established on a site that had supported an earlier clonal trial of *A. auriculiformis*. All clones except BV84 had been killed by a low temperature event in winter 2007/8. The death of seedlings in this new trial confirmed that this environment may not be suitable for the growing *A. auriculiformis*.

It had been the intention of the project at inception to use existing plantations. However it was not possible to find suitable one- or two-year-old stands in Southern and Central Vietnam to meet the demands of the project. In the south, the main reason was that slash pruning with a machete at age one year and ploughing for fire and weed control during the first two years of the rotation had been routinely carried out. Other potential stands had not been singled. These practices had reduced the potential for tree growth and the recovery of sawlogs. Core trials B and C at Ba Vi were able to take advantage of two well-managed though slow-growing stands planted by the FSIV's Research Centre for Forest Tree Improvement in September 2006. Otherwise the dates above are also the dates when the stands were planted.

The locations were chosen to reflect the range of environments that are used for much of the acacia plantation-based forestry in Vietnam. The sites in the south experience a tropical climate with a short dry season, in central Vietnam the climate is monsoonal with an extended dry season; in the north, a continental influence results in cold winters for these latitudes and very hot summers.

5.2 Experimental protocols

The acacia species used in tropical plantation forestry include *Acacia mangium*, *Acacia auriciliformis*, *Acacia* hybrid, the natural hybrid *Acacia mangium* × *Acacia auriciliformis* between these two species, and *Acacia crassicarpa*. After some discussion, *Acacia* hybrid was finally selected for this study because it appears to be the best adapted to the range of growing environments used for plantation-based acacia forestry in Vietnam. It is also the most widely planted of the above acacia species in Vietnam.

These acacia species have a potential for 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 *Acacia mangium* responds strongly to increasing levels of P application at planting was established in an experiment undertaken in South Sumatra as part of ACIAR Project FST/2004/058 (Figure 5.2) which showed that significant growth responses can be experienced at one year even on sites that are inherently productive.

The results from this experiment led to the decision to apply 50 kgP/ha routinely to all experiments except Core B at Ba Vi and the Stock Type × Fertiliser trial at Nghia Trung. This decision to apply P at planting was to ensure that growth rates were not compromised ahead of thinning and that growth responses to thinning were maximised; without this application thinning would have been delayed and the thinning response less than the maximum achievable because of lower than potential growth rates at thinning. In the context of a four-year project this application of P at planting was also essential if useful information about responses to thinning rate and thinning time was to be obtained by the end of the project. This became even more pressing when it became necessary to establish the Core A trial, the trial at Phan Truong 2 which was the flagship experiment in this project, in a three-month-old stand rather than in a suitable older stand where thinning treatments could have been applied earlier and responses to thinning measured over a longer period during the project. Application of P at thinning with or without basal fertiliser was then used to establish whether additional responses to P can occur, most likely associated with more rapid recovery of canopy cover in the first instance. The basal fertiliser applied at thinning was used to ensure that responses to P were not compromised by any deficiency of other nutrients, a possibility that was also established in ACIAR Project FST/2004/058.

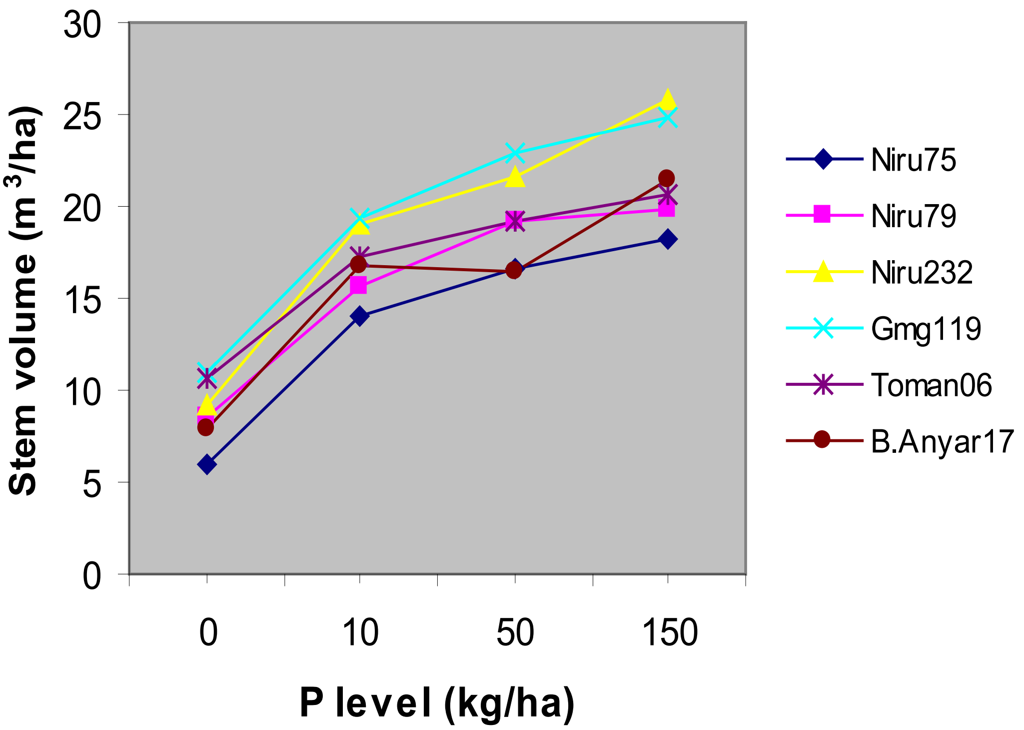

Figure 2: The response of stem volume (m^3/ha) of six families of Acacia mangium at age one year to four levels of P (0, 10, 50 and 150 kg P/ha) applied at planting.

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The Core and Satellite trials were established to answer the following questions:

- Does time of thinning affect the thinning response?
- Does time of thinning affect recovery of sawlogs (Figure 5.3)?

Does P addition at thinning increase the growth response to thinning?

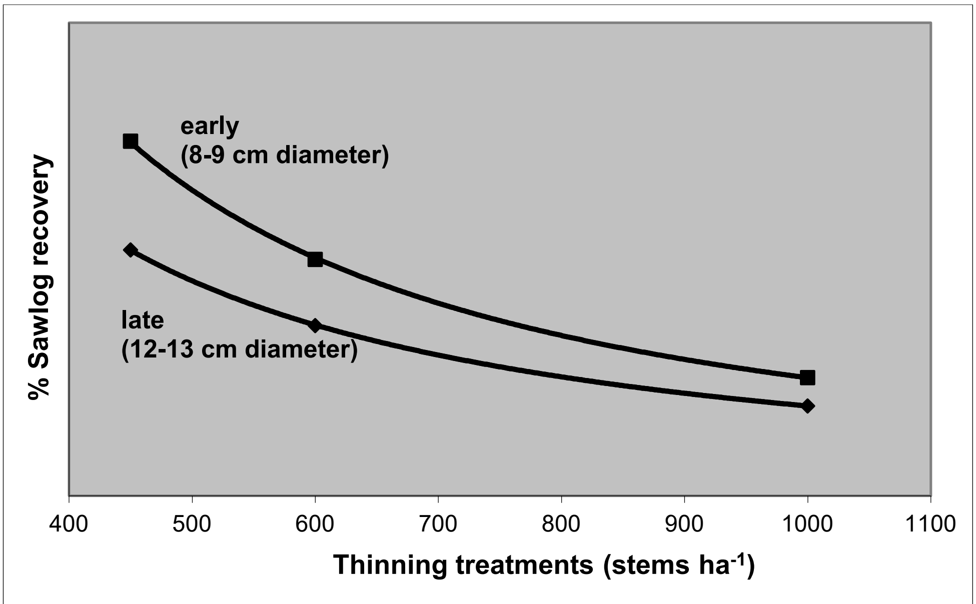


Figure 5.3: A representation of the relationship between sawlog recovery and thinning intensity for two times of thinning as used in the Core A trial. The diameters represent the mean diameters at breast height (1.3 m, DBH) at the early and late thinning times, at approximately age 2 and 3 years respectively. It is hypothesised that the growth response and % recovery of sawlogs to thinning will be greater at the earlier than later thinning. Per cent sawlog recovery will also increase with thinning intensity.

Experimental design

At the Core A trial, the treatment matrix consisted of three thinning treatments, two thinning times and three fertiliser treatments (Table 5.1). The early and late thinning times were anticipated to coincide with mean stem diameters of approximately 8-9 cm and 12-13 cm at breast height (1.3 m, DBH), respectively. On productive sites receiving 50 kg P/ha at planting, the first thinning time was anticipated to coincide with canopy closure at approximately age 2+ years and one year after canopy closure at age 3+ years at the planting densities used for trials established during this project viz 1111 (3 m × 3 m spacing) or 1143 (3.5 m × 2.5 m) stems/ha. At the Core B and C trials planted before the project started, the spacing was 3 m × 2 m (1667 stems/ha).

Table 5.1: Treatment matrix at the Phan Truong 2 Core A trial (P, phosphorus in kg/ha; T is thinning treatment in stems/ha). The thinning treatments are control (nominally 1143 stems/ha), 600 and 450 stems ha^{-1}. The fertiliser treatments were applied at thinning; the

level of P applied is 50 kg P/ha. At-planting fertiliser, including 50 kgP/ha, was applied three months after planting.

Treatments	No fertiliser	P50 + basal	P50 - basal
Control	T1143	T1143	T1143
Thinning #1	T600	T600	T600
Thinning # 2	T450	T450	T450

The Core A experiment used a replicated complete block design (RCBD) and had the following structure:

- Three replications (blocks)
- Three thinning treaments
- Two times of thinning
- Three fertilser treatments

leading to the following statistical model:

	Degrees of freedom
Blocks	2
Thinning	2
Time	1
Fertiliser	2
Thinning × Time	2
Thinning × Fertiliser	4
Time × Fertiliser	2
Fertiliser × Thinning × Time	4
Residual	34 (53-19)

This design of the Core A trial enabled investigation of the effects of thinning rate and thinning time on diameter, height and stem volume growth, and when the trees reached a merchantable size, sawlog recovery. Parallel measurements of changes in leaf area index following thinning were also taken; leaf area index is an indicator of potential growth rate.

Five Satellite trials (Phu Thanh, Nghia Trung, Ba Vi, Son Duong [2 trials]) also used an RCBD but had a subset of the Core A trial treatments (Table 5.2).

Table 5.2: Treatment matrix at five Satellite trials (P, phosphorus in kg/ha; T is thinning treatment in stems/ha). The thinning treatments are control (1100 stems/ha) and 600 stems/ ha. The fertiliser treatments were applied at thinning; the level of P applied is 50 kg P/ha. At-planting fertiliser, including 50 kgP/ha, was applied at planting.

Treatments	No fertiliser	P50 + basal	P50 - basal
Control	T1111	T1111	T1111
Thinning #1	T600	T600	T600

The treatments were modified from the above at the remaining Satellite trials. At Dong Ha (Table 5.3), an alternative design enabled thinning rates to be increased from two to three, and thinning time from one to two (as in the Core A experiment), whilst retaining one test of whether responses to P fertiliser occur at thinning.

Table 5.3: Treatment matrix at Dong Ha FSIV Station Satellite Trial (P, phosphorus in kg/ha; T is thinning treatment in stems/ha). The thinning treatments are control (1100 stems/ha) and 600 or 450 stems/ ha. The fertiliser treatment (No. 6) was applied at thinning; the level of P applied was 50 kg P/ha. Note the year when treatments were applied. At-planting fertiliser, including 50 kg P/ha, was applied at planting.

Treatments	Year	Thinning	Fertilizer
1. Control	2	T1111	n/a
2. Thinning #1	2	T600	n/a
3. Thinning #2	2/3	T600/450	n/a
4. Thinning #3	3	T600	n/a
5. Thinning #4	3	T450	n/a
6. Thinning #5	2	T600	P50+basal

The Satellite trials at Phu Binh and Xuan Loc were managed as intended until age 2 years but then not used for their intended purpose. These trials now form part of a different investigation by Mr Vu Dinh Huong, one of the four John Allwright fellows attached to the project who commenced his PhD studies in February 2012.

The Core B trial was used to investigate the response of a slow-growing four-year-old stand at Ba Vi to thinning and fertiliser application. When the trees were planted, the planting hole received 2 kg manure and 100 g of 5:10:3 N:P:K. As the planting density is 1667 stems ha^{-1} (3 m $\times$ 2 m), this is equivalent to 8.3 kg N, 16.7 kg P and 5.0 kg K ha^{-1}. The trees had therefore received about one-third of the level of P application at planting *v.* that received in the Core A and Satellite trials.; There had been no further silvicultural interventions since planting until the ACIAR experimental treatments were applied. The clonal planting stock was BV 33. The treatment matrix was as follows (Table 5.4).

Table 5.4: Treatment matrix at Ba Vi Core B Fertiliser Trial (P, phosphorus in kg/ha; T is thinning treatment in stems/ha). The thinning treatments are control (nominally 1667 stems/ha) and 600 stems/ha. The fertiliser treatments were applied at thinning; the level of P applied is 50 kg P/ha. At-planting fertiliser, including 16.7 kgP/ha, was applied at planting.

Treatments	No fertiliser	P50 + basal	P50 - basal
Control	T1667	T1667	T1667
Thinning	T600	T600	T600

The Core C trial was used to investigate the response of a slow-growing four-year-old stand at Ba Vi to thinning rate and thinning time only. When the trees were planted, the planting hole received 2 kg manure and 200 g of 5:10:3 N:P:K. As the planting density was 1667 stems ha^{-1} (3 m $\times$ 2 m), this is equivalent to 16.7 kg N, 33.3 kg P and 10 kg K ha^{-1}. Until age three years, there were no further silvicultural interventions. The clonal planting stock was a mixture of BV 10, 16, 32, 33, 71, 73 and 75.

At age three years in July 2009, an experimental area was created that contained 60 plots with 72 trees $plot^{-1}$. Two treatments were applied:

- Total weed control using 4.0 L ha-1 glyphosate
- The standard at-planting application of fertiliser for ACIAR trials. For this stand:
    - 100 g/tree 16:16:8 N:P:K. This is equivalent to 26.7 kg N, 26.7 kg P and 13.3 kg K
    - 195 g/tree superphosphate equivalent to 23.4 kg P ha^{-1} (superphosphate contains 7.2% P) to give a total of 50 kg ha^{-1} P.

The fertiliser was applied in a 5-10 cm-depth circular trench 30-40 cm from the tree. The purpose of this application was to increase crown size and tree vigour ahead of the first thinning at age four years.
There were four thinning rates; three times of thinning were anticipated (Table 5.5):

- Trees 8-9 cm diameter (in late April/early May 2010)
- Trees 10-11 cm diameter (in late April/early May 2011)
- Trees 12-13 cm diameter (in late April/early May 2012)

This assumed growth rates of ca. 2 cm per annum.

Table 5.5: Treatment matrix at Ba Vi Thinning Core C trial (T is thinning rate). The thinning rates are control (nominally 1667 stems ha^{-1}), 900, 600 and 450 stems/ha. The thinning times are age 3.6 (#1), 4.6 (#2) and 5.6 (#3) years.

Thinning	Time #1	Time #2	Time #3
Control	T1667	T1667	T1667
Rate #1	T900	T900	T900
Rate # 2	T600	T600	T600
Rate # 3	T450	T450	T450

The Stock Type × Fertiliser (or nutrient supply) trial at Nghia Trung differed from the other trials. The experiment was designed to address the following questions:

1. Does stock type as defined by “age of cutting” influence the expression of form?
2. Do high levels of P fertiliser applied at planting influence the expression of form?
3. Are the effects of stock type and nutrient supply on the expression of form additive?

The treatment matrix consists of two stock-type treatments and two at-planting fertiliser treatments in a split-plot factorial design (Table 5.6). The stock-types were three commonly planted clones (BV10, 32 and 33) supplied by the FSIV centre at Trang Bom from new (1st year) and old (4th year) hedges. The at-planting fertiliser treaments were either no fertiliser or 100 g N:P:K at 16:16:8 plus 403 g tree^{-1} superphosphate (= 50 kg P ha^{-1}). The whole plots represented the fertiliser treatments and the sub-plots the stock-type treatments.

Table 5.6: Treatment matrix at the Nghia Trung Stock Type × Nutrient Supply Experiment (P, phosphorus in kg ha^{-1}; S is stock-type treatment). The fertiliser treatments were applied at planting; the level of P was either 0 kg/ha or the equivalent of 50 kg P/ha.

Treatments	P1 (0 kgP/ha)	P2 (50 kgP/ha)
S1 (new hedge)	S1P1	S1P2
S2 (old hedge)	S2P1	S2P2

Plots

All experimental plots 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. Treatments were applied uniformly to trees in both the net and gross plots. As three at-planting spacings were present in the trials, there were small differences in the sizes of the net and gross plots. However, in all trials as close as possible to square net plots were used.

For example, in the Satellite trials the spacing (3.0 m × 3.0 m) meant that the net plots were 6 rows wide (18.0 m) with 6 trees in each row (18.0 m); the gross plot size was 24.0 m × 24.0 m (Table 5.7 and Figure 5.4). Thus the gross plot size is 0.058 ha and the full size of these trials of three replications was 18 × 0.058 = 1.04 ha.

Table 5.7: Thinning treatments and plot sizes.

Treatments	#Tree numbers/plot	
(stems/ ha)	Gross	Net
1111 (unthinned control)	64	36
600	35	19
Plot size (ha)	0.058	0.032
Dimensions (m × m)	24.0 × 24.0	18.0 × 18.0

#Tree numbers per plot refer to the number of trees within each plot after thinning.

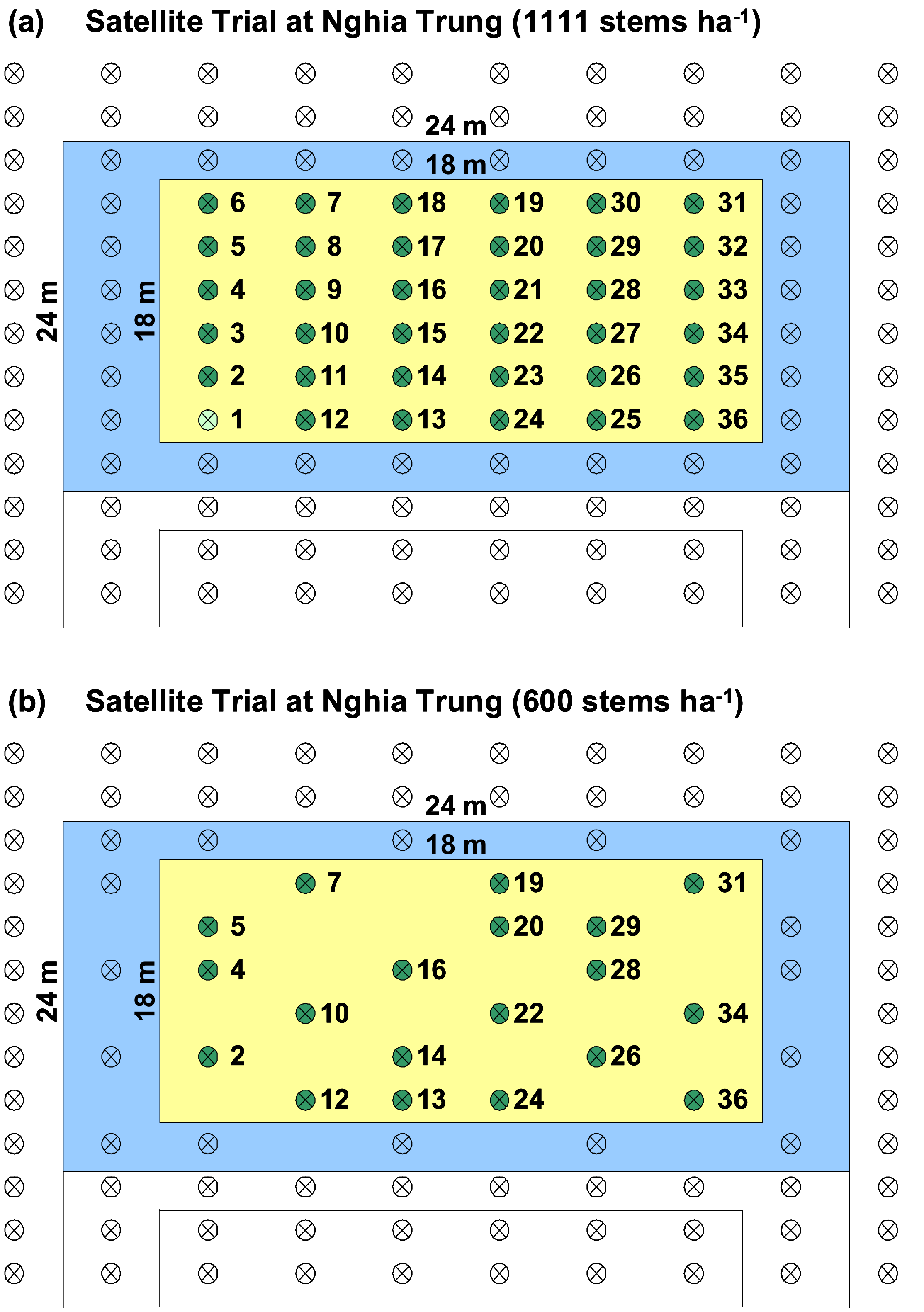


Figure 5.4. The layout of the plots in the Satellite trials e.g. Nghia Trung before (a) and after (b) thinning to 600 stems/ha. Note the net plot is yellow and the buffer area is blue. The trees removed in the thinned plot are nominal only. The diagram illustrates the importance of distributing the final- crop trees as evenly as possible throughout the plot.

Weed control

- Round-up (glyphosate) was applied as necessary at 4.0 L ha^{-1} (equivalent to 1.92 kg/ha active ingredient) while the weed foliage was green (that is before the dry season). The planting stock was protected during spraying by using shrouded spraying equipment applying herbicide only when the conditions were still. Weed control was used as necessary until canopy closure, and again if necessary, just ahead of the at-thinning fertiliser treatments. A modified form of this weed control was used to deal with persistent bamboo at the Phan Truong Hai and Phu Thanh sites (Technical Information Sheet No. 1, Appendix 11.3).

Singling and form pruning

- The first singling was undertaken between ages four and six months using the tip-pruning technique (Technical Information Sheet No. 3, Appendix 11.3). Tip pruning removed approximately one-half of the length of competing leaders and branches. This technique captures dominance in the retained leader without prejudicing the capacity of the leaders that are tip pruned to contribute to the recovery of growth. It also allows form pruning to occur throughout the year without potentially increasing the risk of heart-rot entry. Lift pruning is undertaken only in the dry season to minimise the risk of disease entry through pruning wounds adjacent to the stem (Technical Information Sheet No. 4, Appendix 11.3).

Thinning strategy (e.g. Satellite trials; (Technical Information Sheet No. 5, Appendix 11.3)

An important criterion was that the mean diameter after thinning should be roughly the same in all thinning treatments so pre-measurement of all trees ahead of thinning was essential and before thinning was undertaken, the consequences of removal of the trees selected for thinning was checked.

The following criteria were used when thinning to 600 stems ha^{-1}. The final-crop stocking in the net plot was 19 stems/plot (Table 5.7). If this plot was fully stocked it had 36 stems so 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. This was done by first going to the row with trees 1-6 and selecting two trees for thinning. This was repeated for trees 7-12, 13-18, 19-24, 25-30 and 31-36. Then one more tree was selected for thinning from five of the six rows (Figure 5.4). The trees selected for thinning were based on the following criteria:

Poor form

- Trees that were of poor form in the first 4.5 m of the stem. The main reason for this was large forks where the stem had split into at least two leaders. Trees of poor form were always removed.
- For trees that were still multi-stemmed from the ground in spite of singling, if necessary it was sometimes possible to retain one of the stems that was of good form in the first 4.5 m, particularly if it had a large diameter.

Small diameter

- Trees of the smallest diameter were removed, particularly if they were likely to become suppressed. As clonal material was used, this was not a serious issue.

As it is important to maximise the spacing around each retained tree, removal of three trees that were adjacent to each other in a row was avoided, even if these were smaller trees. The aim was to have the retained trees as evenly spaced as possible in the plot (Figure 4b).

The same criteria were used to select trees for thinning in the buffer rows. For example, in the 600 stems ha^{-1} treatment there are 64–36 = 28 trees in the buffer area if it was fully stocked (Table 5.7). After thinning, there were 35–19 = 16 trees in the buffer area. Thus 28–16 = 12 trees were removed in this treatment from the buffer rows. The same principles was used to thin plots to 450 stems/ha.

Fertiliser strategy

Fertiliser at planting

There has been some history of applying P fertiliser at planting to *Acacia* species in Vietnam and significant responses to P fertiliser applied in the first two years after establishment have been observed in research trials undertaken by FSIV (Dang Thinh Trieu, 2007). The decision was made to apply the equivalent of 50 kg P/ha in this project excepting those trials referred to above (Technical Information Sheet No. 2, Appendix 11.3).

The standard practice was to first apply 100g/tree of N:P:K at 16:16:8. This was equivalent to 17.8 kg P ha^{-1}. For the Satellite trials established at 1111 stems/ha, in order to apply a total of 50 kg P ha^{-1}, 403 g superphosphate/tree (= 32.2 kgP/ha) was then applied. The application procedure was as follows:

- Make a planting hole with size 40 x 40 x 40 cm;
- Apply each fertiliser (NPK and superphosphate separately) at bottom of the pit;
- Cover with soil.

It was important not mix the fertilisers before application as it is very difficult to accurately control the ratios.

For other planting densities the necessary adjustments to the amount of P applied per tree were made so that the total applied per hectare remained at 50 kg.

As the trees had already been planted in the Core A trial, as in the Core B trial, it was necessary to apply 100 g/tree N:P:K at 16:16:8 (= 18.3 kgP/ ha) plus 385 g/tree superphosphate (= 31.7 kg P ha^{-1}) in a 5-10 cm-depth circular trench 40 cm from tree.

Fertiliser at thinning (e.g. Satellite trials)

Phosphorus

Rate: The equivalent of 50 kgP/ha was applied to treatments (P50 + basal and P50 – basal) allocated to the P-fertiliser treatment. In the Satellite trials, this was equal to 12 of the 18 plots.

Method of application: The P fertiliser was applied in a 50-cm band in the centre of the inter-row area. This method of application combined the need to concentrate P fertiliser over a small area to maximise its efficiency of uptake, and ease of application. The idea for applying fertiliser at thinning in this way was developed by Mr Hung Thai Trieu.

Amount required: As the gross plot size was 0.058 ha:

- The equivalent of 2.90 kg P per plot was required
- As superphosphate is 7.2% P, 40.28 kg superphosphate per plot was required. As four (4) treatment combinations in each block received P fertiliser at thinning, 12 plots (4 × 3 replicates) received P fertiliser (12 plots required about 500 kg (483.36 kg) of superphosphate.

The superphosphate was applied (see detailed notes on “Application below”) along 7 rows of 24.0 m in length (168 m total length). No fertiliser was applied in the inter-row area between buffer rows of two adjacent plots. This meant that the application rate per metre length across a 50 cm-wide band was 0.240 kg superphosphate (40.28/168).

The fertiliser was applied along a reference line marked at 1.0 m intervals. Cups made from the plastic chemical containers which had been cut and calibrated to contain 0.240 kg superphosphate were used to apply the fertiliser (Plate 5.1).

Basal fertiliser

The make-up of the basal fertiliser treatment (Table 5.8) was based on one used in Indonesia in Project FST/2004/058 in an experiment with *Acacia mangium*.

Plate 5.1: Applying superphosphate fertiliser from calibrated plastic cups to a 50-cm band in the inter-row at the Ba Vi Core B Fertiliser trial in May 2010. Mr Hung who developed this idea is in the centre of the photograph.

For this experiment, urea was omitted from the basal fertiliser mix; in Indonesia, basal fertiliser was applied at planting whereas the plantations in Vietnam are well established and should already be fixing large quantities of atmospheric N. The hydrated lime was also omitted because superphosphate includes Ca. Basal fertiliser was applied only in the P + basal treatments.

The basal fertiliser was first evenly mixed with its eight components.

Rate: The equivalent of 168.06 kg basal fertiliser/ha (Table 5.7, column 2) was applied to the P50 + basal fertiliser treatment only (2 plots per block or 6 plots for each Satellite trial)

Method of application: The basal fertiliser was applied in a 50-cm band in the centre of the inter-row area. This method of application was adopted to coincide with that used to apply P fertiliser.

Amount required: As the gross plot size was 0.058 ha:

- The equivalent of 9.75 kg basal fertiliser per plot was required (Table 5.7, column 3). As two treatment combinations received basal fertiliser, 6 plots (2 × 3 replicates) received basal fertiliser (6 plots required 58.50 kg basal fertiliser).

Table 5.8: Basal fertiliser mix for the Satellite trials. The calculations in columns 2 and 3 are based on gross plot size of 0.058 ha and row length of 24 m.

	Rate (kg fertilizer/ha)	Rate (kg fertilizer/plot)	Rate (kg fertilizer/m length)	Rate equivalent to 100 kg basal fertiliser (kg)
KCl	80	4.640	0.0276	47.60
MnSO4.H2O	6.00	0.348	0.0021	3.57
FeSO4.7H2O	64.00	3.712	0.0221	38.08
ZnSO4.7H2O	3.50	0.203	0.0012	2.083
CuSO4.xH2O, FW=159.6	2.00	0.116	0.0007	1.190
Boric acid (H3BO3)	0.45	0.0261	0.0002	0.268
Na2MoO4.2H2O	0.11	0.0064	0.00004	0.066
MgSO4	12.00	0.696	0.0041	7.14
Totals	168.06	9.75	0.0584	100.00

The basal fertiliser was applied along 7 rows of 24.0 m in length (168 m total length). The application rate per metre length across a 50 cm-wide band was 0.0584 kg basal fertiliser (Table 5.7, column 4).

The fertiliser was applied along a reference line marked at 8.0 m intervals. The mixed fertiliser was weighed out in 0.467 kg lots (8.0 × 0.0584 kg) and spread evenly along the 50-cm band. Three lots were required per 24.0-m row length.

Mixing the basal fertiliser: The basal fertiliser was mixed on a plot basis (Table 5.7, column 3). This facilitated accurate weighing of small quantities and ease of mixing. The procedure was as follows (Plate 5.2):

- Spread the KCl (4.64 kg) out evenly on a large plastic sheet (approximate 1.5 m × 1.5 m) and across half its area (about 0.8 × 0.8 m);
- Spread the remaining seven fertilisers sequentially in decreasing order of quantity (FeSO4.7H2O next; Na2MoO4.2H2O last). Those required in very small quantity will need to be carefully sprinkled across the area);
- Mix the fertiliser by folding and unfolding the sheet in two directions three or four times. This is done to prevent particle sorting;
- Divide the mixed fertiliser into 21 × 0.467 kg lots per plot and place in bags for storage until use.

The above procedures were modified as necessary to accommodate different plot sizes and layouts.

Application

To be effective, significant rain had fallen before moving on to the second numbered point below. To maximise the chances that this would be the case, thinning was carried out and fertiliser was only applied after the wet season had commenced.

Plate 5.2: Mr Hung adding spreading the layer of copper sulphate evenly across layers of other chemical ingredients used in the basal fertiliser ahead of mixing.

1. Rake litter off 50-cm inter-row strip, then break up soil with mattocks to approximately 5-cm depth.
2. Just ahead of fertiliser application, use a rake or mattock (more commonly the tool of choice) to take off the top layer of cultivated soil (this is easy once the soil is wet and friable).
3. Lay a 24.0-m line (gross-plot row length) marked at 1-m and 8.0-m intervals along the length of the gross plot.
4. In plots receiving basal fertiliser and phosphate, each bag's worth is sprinkled in an 8.0 m × 50 cm band; superphosphate is then sprinkled in a 1 m × 50 cm band from cups calibrated to hold roughly 0.240 kg of superphosphate.
5. Use rake or mattock to bring back soil to cover the fertiliser, followed by the litter.

Preparation of the rows for fertiliser application and returning the soil and litter after the fertiliser had been applied was undertaken by local (at Ba Vi) and itinerant (at Phan Truong 2) workers.

Soil sampling and analysis

- Using a corer, take nine cores from random points in the inter-row areas of the first plot. Collect separate samples for 0-10 cm and 10-20 cm. Bulk samples from each depth;
- Repeat for each plot;
- Air dry and store in bags at the laboratory. For more detailed information, see Technical Information Sheet No. 6 "How to sample soil for analysis" in Appendix 11.3.

All soil samples were analysed for pH, organic carbon, total N, extractable P, exchangeable cations (K, Mg and Ca). As the techniques used for these analyses were reviewed and modified as part of this project, this is reported as an output.

Soil pits were dug, one per replication at each site and the soil profiles described (Technical Information Sheet No. 7 "How to describe soil" in Appendix 11.3).

Physiological campaigns

Two physiological field campaigns were conducted at the Phu Binh experimental station. The first campaign was undertaken in the wet season (in May 2010) and the second at the end of the dry season in March 2012. For *Acacia* hybrid, the wet season measurements used the Phu Binh Satellite trial at age 10 months; the dry season measurements used an adjacent planting at age 7 months. This was necessary because it was no longer possible to access the crowns of the Satellite trial from the ground. Wildings of *Acacia auriculiformis*, the species previously planted on the site of the Satellite trial, were also used in this study. This enabled comparisons to be made not only between seasons, but also between species. It was necessary to transport the instruments for measuring gas-exchange, water potential and leaf area index from Australia.

Three types of physiological measurements and also foliar analyses were undertaken:

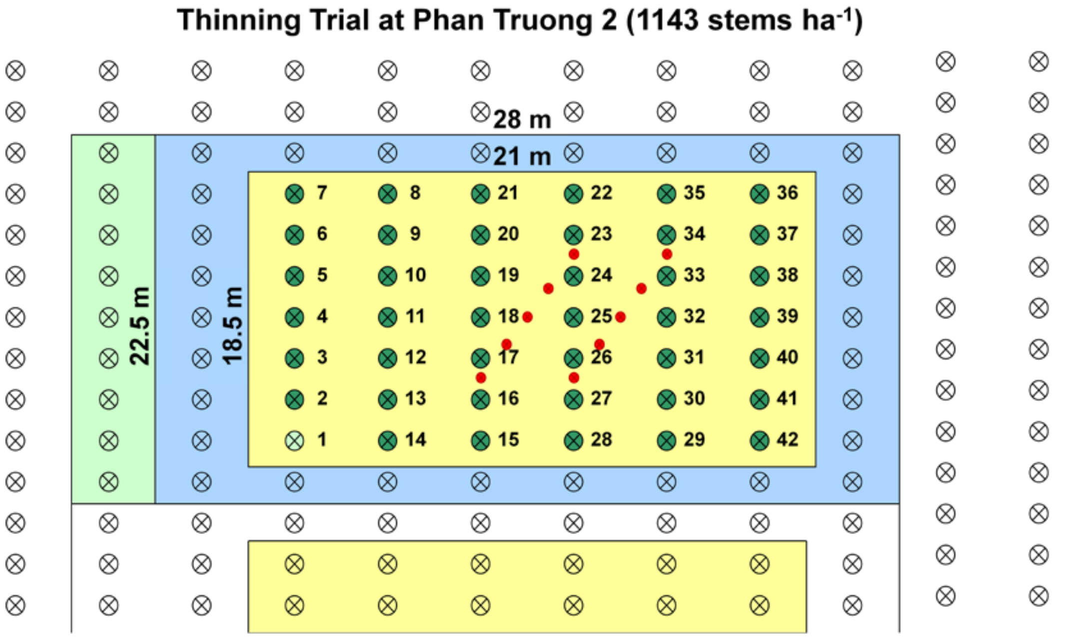
Gas-exchange: Net light-saturated CO_2 uptake and stomatal conductance at saturating photosynthetically active radiation were measured over the natural photoperiod using a Li-Cor LI-6400 Portable Photosynthesis System. CO_2 and light control also enabled the construction and parameterisation of CO_2 and light response curves of photosynthesis which enable a more detailed interpretation of the measurements made.

Water potential: Leaf water potential was measured on separate leaves collected at the same time as gas-exchange measurements. Excised leaves were placed immediately into plastic bags and kept in the dark until measurements were made using a 40-bar pressure chamber (PMS Instruments Co., Corvallis, Oregon, USA). These measurements enable the interpretation of gas-exchange measurements in the context of leaf water stress.

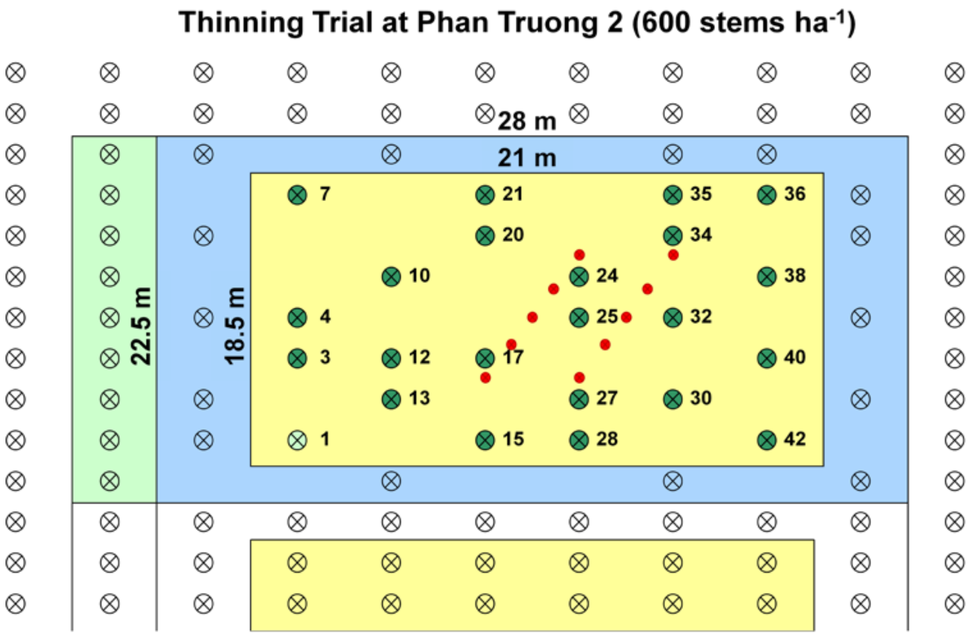
Foliar nutrients: Following completion of all physiological measurements, leaves were collected and processed for specific leaf area, and leaf *N* and *P* concentrations. Leaf *N* and *P* digests followed the sulphuric-acid and hydrogen peroxide method. Digested samples (~0.5 g) were colorimetrically analysed for *N* by the standard MicroKjeldahl method and for *P* concentration by an ANA-720W spectrophotometer (Tokyo Photo-electric Company Limited, Japan). Leaves were scanned and images analysed for leaf area using ImageJ v1.37 (Abramoff et al. 2004). Leaf *N* and *P* were assessed as for Experiment 1. Both leaf *N* and *P* concentrations were calculated on a mass (%) and area ($g\ m^{-2}$) basis.

Leaf area index: In May 2011, leaf area index was measured using a Li-Cor LAI-2000 Plant Canopy Analyser. These measurements were undertaken in the 27 plots involved in Thinning #1 at Phan Truong 2. To facilitate these measurements, 10 stakes were placed in two parallel lines through the middle of each plot. This arrangement is designed to capture any heterogeneity in the distribution of the canopy in space, particularly in the thinned plots (Figure 5.5). Parallel estimates at these same 10 points were made using a Visual Guide (Cherry et al., 2002) and digital photography. For the latter, the camera was arranged to capture images to the vertical and directly above the stakes. Calibration curves were used to convert data collected from the LAI-2000 and digital photographs to leaf area index.

The first physiological campaign was also used to teach Vietnamese members of the project team how to use these instruments, and the alternative ways of measuring leaf area index. Mr Kieu Tuan Dat was then able to use the Visual Guide and digital photography for subsequent six-monthly measurements of LAI at Phan Truong 2. A demonstration of the use of these instruments was given to a wider audience from FSSIV at the commencement of the first campaign. The instruments were used again in the second campaign. They are also being used by the John Allwright Fellows (see Section 5.3).



There are five pegs diagonally across the space between two rows of trees. The two end pegs in each diagonal are in the centre of the tree row and equidistant between two trees. The middle peg is equidistant between the two end pegs. There are two more pegs equidistant between the centre and the end pegs. This pattern of five pegs is repeated in the adjacent row giving ten pegs per plot. This pattern is repeated for each plot.



In a thinned plot the ten peg positions are the same as in a non-thinned plot. Use the tree stumps as well as the remaining trees to position the pegs. If the stump is missing determine where it would have been and use that position.

Figure 5.5. The red dots indicate the positioning of 10 stakes arranged diagonally across two rows of trees in the centre of each plot at Phan Truong 2. These positions were used to estimate the leaf area index of each plot using three different techniques (see text).

5.3 Participation

Nine Australian staff participated in the project, eight from CSIRO and two from the University of Tasmania. Twelve FSSIV and FSIV staff contributed to the project. Staff turnover and replacement was necessary because of one resignation, the awarding of two (out of the four) John Allwright Fellowships (JAFs) for postgraduate study and two other training commitments. Dr Ha Huy Thinh, the Director of FSIV's Research Centre for Forest Tree Improvement provided in-kind support to the project in 2009 that allowed the establishment of the Core B and C trials. This might not otherwise have been possible because the 2008 financial crisis reduced funding in real terms to the Vietnamese side of the project. Three private companies, Hai Vuong, An Hoa and Xuan Loc Enterprise Board and their personnel also provided in-kind support to the project.

Personnel from Australia

Chris Beadle (CSIRO): Plant physiologist with 30+ years experience working with forest plantations. Specific responsibility for:

- Project leadership and coordination of activities with PC leader, Dr Dung;
- Design of, and measurement programs for, experiments and application of treatments;
- Negotiation of priorities through several Business and Planning Meetings held in HCMC;
- Oversight of all written communications from project;
- Financial management of Australian budget and allocation of Australian staff;
- Recruitment of John Allwright Fellows and suitable supervisory teams for their postgraduate programs at the University of Tasmania;
- Associate Supervisor of JAF Mr Tran Lam Dong

Daniel Mendham (CSIRO): Soil scientist with 15+ years experience in plantation productivity and sustainability research. His skills are in nutrition, modelling and integration with site-water dynamics for maximising profitability. Specific responsibility for:

- Nutrition and modelling aspects of the project, and leading development of the DSS;
- Upgrading of analytical laboratory at FSSIV in Ho Chi Minh City;
- Associate supervisor of JAF Mr Vu Dinh Huong.

Chris Harwood (CSIRO): Scientist with 25+ years experience in tree breeding and management of forest genetic resources. He has worked on projects in Vietnam for 19 years. Specific responsibility for:

- Genetic material used in the project and species/clone site matching for newly established experiments;
- Data analysis including teaching Vietnamese staff the management of EXCEL spreadsheets and the use of GENSTAT;
- Providing support to Mr Cao on economic analyses.

Philip Smethurst (CSIRO): Soil scientist with 25+ years experience in tree nutrition and nutrient cycling within soils. Specific responsibility for:

- Developing the semi-portable nutrient-analysis system for potential use in Vietnam.

Maria Ottenschlaeger (CSIRO): Senior technician with 20+ years experience working with technologies relating to measurement of leaf area index and biomass, and providing other technical and PA support. Specific responsibility for:

- Assisting Project Leader with all communication activities;
- Providing training to Project staff and JAFs in the measurement of leaf area index and biomass sampling.

Dale Worledge (CSIRO): Senior technician with 20+ years experience working with technologies relating to measurement of light through and below canopies. Specific responsibility for:

- Providing training to JAF Mr Tran Lam Dong in the measurement of incident and transmitted light in three experiments contributing to his PhD program.

Keith Churchill (CSIRO): Senior technician with 2 years experience working with gas-exchange and water potential instrumentation and 20+ years providing support for field experiments relating to forest production. Specific responsibility for:

- Providing support for gas-exchange and water potential measurements in the 2nd physiological field campaign;
- Providing training to John Allwright Fellows Mr Tran Lam Dong and Mr Vu Dinh Huong in the measurement of photosynthesis and stomatal conductance.

Caroline Mohammed (UTas)*:* Forest pathologist with 25+ years experience working with fungal pathogens, their characterisation, and pathogenicity in woody plant hosts. Specific responsibility for:

- Activities that relate to tree health, including experimental design and interpretation;
- Academic supervisor of JAFs Mr Trieu Thai Hung and Mr Tran Thanh Trang.

Morag Glen (UTas): Fungal molecular taxonomist with 10+ years experience working with forest crops. Specific responsibility for:

- Assisting Mr Tran Thanh Trang with the collection and identification of field samples that have suspected heart rot and other decay symptoms.

Sadanandan Nambiar (CSIRO, retd): Soil scientist with 40 years experience. Specific responsibility for:

- Science coordination and mentoring, particularly in relation to the FSSIV's National Project which had overlapping interests with the ACIAR project and the same staffing.

Personnel from Vietnam

Pham The Dung: Director of the FSIV's Sub-Institute of South Vietnam and silviculturalist with 30+ years experience working with plantation forests. Specific responsibility for:

- As In-country PC, liaise with Australian PL and coordinate agreed activities in Vietnam;
- Financial management of Australian budget and allocation of Vietnamese staff;
- Translation of documents and dissemination of outputs to users in Vietnam.

Vu Dinh Huong: Scientist with 10+ years experience working in soils and nutrition; he was the key scientists working on the CIFOR trial in South Vietnam. Specific responsibility for:

- Oversight of the establishment, maintenance, imposition of treatments and measurement of all ACIAR trials (until 31/12/09);
- Providing advice and help as necessary to those responsible for the Core and Satellite sites in southern, central and northern Vietnam (until 31/12/09).

Mr Huong was awarded a JAF in September 2009. His need to study English led to his replacement in this role by Mr Kieu Tuan Dat.

Tran Thanh Cao: Vice-director of the FSIV's Sub-Institute of South Vietnam and forest economist. Specific responsibility for:

- Developing simple economic models based on a financial analysis of solid-wood production that can be applied in southern, central and northern Vietnam.

Le Thanh Quang: FSSIV Analytical chemist based with 15+ years experience. Specific responsibility for:

- Working with an Australian Analytical Chemist on upgrading procedures in his laboratory;
- Collecting, processing and analysing of soil samples from all Core and Satellite trials;
- Training in CSIRO's Perth Laboratory in new techniques, including the semi-portable nutrient-analysis developed by Philip Smethurst.

Kieu Tuan Dat: FSSIV silviculturalist with 10+ years experience. Specific responsibility for:

- All activities at the Flagship Core A trial at Phan Truong 2;
- From 1/1/10, oversight of the establishment, maintenance, imposition of treatments and measurement of all ACIAR trials (except 10/5/12-10/8/12);
- From 1/1/10, providing advice and help as necessary to those responsible for the Core and Satellite sites in southern, central and northern Vietnam (except 10/5/12-10/8/12).

Nguyen Thanh Binh: FSSIV silviculturalist with 10+ years experience. Specific responsibility for:

- Establishment, maintenance and measurement of all Satellite trials in the southern part of the project (until 31/1/11 when Mr Binh resigned from FSSIV).

Pham Van Bon: FSSIV silviculturalist with 5+ years experience. Specific responsibility for:

- Establishment, maintenance and measurement of all satellite trials in the southern part of the project (1/2/12 when Mr Binh resigned from FSSIV);
- Establishment, maintenance and measurement of the Stock Type × Fertiliser Trial;
- From 10/5/12-10/8/12, oversight of the establishment, maintenance, imposition of treatments and measurement of all ACIAR trials (except during period 10/5/12-10/8/12);
- From 10/5/12-10/8/12, providing advice and help as necessary to those responsible for the Core and Satellite sites in southern, central and northern Vietnam.

Vo Trung Kien: FSSIV silviculturalist. Specific responsibility for:

- Supporting a range of project activities in the south in 2012 to cover the absences of Mr Quang and Mr Dat.

Trieu Thai Hung: FSIV silviculturalist with 5+ years experience. Specific responsibility for:

- Establishment, maintenance and measurement of the Core B and C and Satellite trials in the northern part of the project (until 31/12/10).

Mr Hung was awarded a JAF in September 2010. His need to study English led to his replacement in this role by Mr Vu Tien Lam.

Vo Tien Lam: FSIV silviculturalist with 5+ years experience. Specific responsibility for:

- Establishment, maintenance and measurement of the Core B and C and Satellite trials in the northern part of the project (from 1/1/11).

Pham Xuan Dinh: FSIV silviculturalist with 10+ years experience. Specific responsibility for:

- Establishment, maintenance and measurement of Satellite trial in Central Vietnam.

Tran Thanh Trang: FSIV pathologist with 10+ years experience. Specific responsibility for:

- Assessing health status of the experimental plantations, and monitoring symptom development, particularly in relation to heart rot and wood decay.

Mr Trang was awarded a John Allwright Fellowship in the September 2011.

6 Achievements against activities and outputs/milestones

6.1 Objective 1: To quantify the role of fertiliser, pruning and thinning to optimise tree size, log distribution and economic returns from plantations managed for sawn timber

no.	activity	outputs/ milestones	completion date	comments
1.1	Establish experiments to examine responses to pruning and thinning	Nine sites, three each in North, South and Central Vietnam selected (A, PC)	Oct 09	When the project was costed, the exchange rate was marked at 14,900 VND/$AUD. The VND received at the first payment was 20% less than had been costed because of collapse of $AU. It was therefore decided to reduce the total number of sites from nine to seven. However at each of two sites, Ba Vi and Tuyen Quang, two sites Satellite trials were identified
		Nine sites established using best-practice site preparation	Jun 10	The first sites to be planted were in northern Vietnam (at Ba Vi and Tuyen Quang) in June/July 09 and in southern Vietnam at Phu Thanh and Nghia Trung (in August 09). At Ba Vi, *A. auriculiformis* was planted and at Tuyen Quang *A. mangium*, as well as *A.* hybrid. Dong Ha was planted in November 2009, and Xuan Loc and Phu Binh in July 10. Standardised site preparation and establishment procedures were used at all sites. The *A. auriculiformis* at Ba Vi failed in 2010 because of low temperatures
		Form and/or 1st – lift pruning imposed at all sites (PC)	June 11	All from pruning completed and all planned lift-pruning (to at least a 1st-lift of 2.5 m completed
		Early or late thinning imposed at all sites (PC)	June 12	All trials have received their intended thinning treatments. At Phu Binh and Xuan Loc these were modified from intended to support Mr Vu Dinh Huong's PhD project
		Pruning and thinning schedules for acacias produced	June 12	One thinning and two pruning schedules (for form and lift pruning) as part of the series of Technical Information Sheets
1.2	Determine susceptibility to heart rot	Identify the available genetic material in tree improvement trials and new project sites (PC)	Oct 09	Clonal mixtures were generally used as planting stock and it was not possible to individually identify clones at Phan Truong Hai, Nghia Trung or Ba Vi

		All trials assessed for general health problems (A, PC)	Oct 09	Four trials, the Core A trial at Phan Truong 2 and the Satellite trials at Nghia Trung, Ba Vi and Tuyen Quang were assessed in December 10. A major new biotic problem was heart rot associated with pruning wounds. An experimental pruning trial was established at Nghia Trung. Another well-known problem, Pink disease, a stem canker which eventually leads to stem rot, is still observed despite claims of greater tolerance in *Acacia* hybrid.
		A subset of clones at 2-3 contrasting sites inoculated (A, PC)	June 10	Fungal cultures were identified but it was not possible within the timeframe of the project to undertake fungal inoculations. This activity has been incorporated into Mr Tran Thanh Trang's PhD program.
		Disease development of harvested trees assessed (A, PC)	Apr 12	Trees were harvested systematically across the thinning treatments at Phan Truong Hai and in the pruning trial at Nghia Trung and heart rot development and other disease and decay symptoms were assessed
1.3	Measure pruning and thinning responses and quantify yields wrt log/piece-size distribution and economic return	Six-monthly measurements of height/diameter and form completed (PC)	Aug12	The measurement programme was undertaken from the plantings in 2009 until July 2012. There have been significant responses to thinning at all sites, but no responses to fertiliser at thinning except at Ba Vi and Tuyen Quang. Continued measurement will be maintained in the three Satellite trials being used by JAFs
		Relationship between leaf area and basal area, canopy architecture established (A, PC)	May10	It was not possible to include the harvesting of trees in this project so this relationship could be determined. This will now be included in biomass harvests incorporated into JAF PhD programs
		Campaigns to measure physiological parameters completed	May10 to Oct11	The first physiological campaign was undertaken in the wet season in May 11 (gas exchange, water potential, leaf area index, wood cores for C isotope measures). The second campaign was undertaken at the height of the dry season at Phu Binh. Because of the large response to P at the new experiment at Nghia Trung, physiological measurements were also undertaken at that site. Leaf area index was measured at six-monthly intervals at Phan Truong Hai
		Recovery and examination of sawn timber from 1st thinning completed	April12	The mean DBH of trees across the thinning treatments in the #1 thinning at Phan Truong 2 at age 4 years (July '12) varied between 13 and 16 cm. This was considered too small for such a study

		Quantification of yield by piece size, wood value and financial benefit	July 12	Trees were harvested at the Dong Hoi Thinning trial in Quang Binh province ahead of schedule because of typhoon damage. A comparison based on a sawing trial was undertaken between logs from pruned and unpruned trees. Trees from the current project have been offered to another ACIAR project (FST/2008/039 - led by Henri Bailleres though he considers them too small for peeling at the moment)
		Economic analyses carried out	Sep12	These analyses are being undertaken by Mr Cao and are in progress

PC = partner country, A = Australia

6.2 Objective 2: To examine the roles of site and soil management in the sustainable production of community forests grown for sawlog (and pulpwood) production

no.	activity	outputs/ milestones	completion date	comments
2.1	Establish core experiments	Select sites in at least one of North, Central and South Vietnam for sustainability trials (South preferred) (A, PC)	Oct 10	No suitable two-year-old trials were available in the South because of the practice of slash pruning and ploughing for weed and fire control. A 3-month old site at Phan Truong 2 was selected in southern Vietnam (Core A trial). In North Vietnam two adjacent sites planted in 2006 were selected at Ba Vi (Core B and C trials). At-planting fertiliser was applied at age 3 months at Phan Truong Hai, and at age 3 years in the Core C trial
		Install treatments in up to two sustainability (core) trials (PC)	Oct 11	Thinning and at-thinning fertiliser treatments were imposed in July 10 (Thinning #1) and July 11 (Thinning #2) at the Core A trial, and in May 10 in the Core B trial. Thinning treatments (#1, #2, #3) were imposed in the Core C trial in May 10, 11 and 12
		Six-monthly measurements of height/diameter and form (PC)	Aug 12	The first measurement at Phan Truong 2 was done at age six months in Feb 09. There was a noticeable productivity gradient (1.8:1) across the three blocks that upon examination could not be linked to the soil profile to 30 cm depth. At Ba Vi, the measurement program commenced in March 2010. The measurement programs have stayed on schedule. There have been significant responses to thinning at all sites, but not to fertiliser at Phan Truong 2
		Maintenance of all plots in weed-free condition (PC)	Ongoing	Total weed control was undertaken at all sites as necessary. Sites also received herbicide application ahead of thinning and at thinning fertiliser application. The weed-control strategy has been successful and an effective way of dealing with the most competitive weed, bamboo was developed

2.2	Upgrade analytical laboratory procedures	Protocols for sample preparation, digestion and analysis in Ho Chi Minh established (A, PC)	Oct 09	A CSIRO Analyst Ms Tuyen Pham completed a two-week audit of the HCMC Analytical Laboratory in February 09. This included recommendations on protocols for analysis and safety procedures. Her report is in Appendix 11.4
		Test a semi-portable nutrient-analysis system (A, PC)	Oct 10	Mr Quang taught to use this system by Philip Smethurst during his two-week' professional development in Perth. It was not used in Vietnam during the project
2.3	Develop simple indices that describe P requirement	Soils collected from all experimental sites using standard procedure (PC)	Apr 10	Soils collected from all experimental sites using standard procedure (PC)
		Baseline soil analyses completed using standard methods (PC)	Jan 11	Procedures for analysis established in February 2009 by Ms Tuyen and all baseline analyses completed in April 2011. There was considerable variation in levels of total N, available P and organic carbon between sites. The two sites with the highest total N and organic carbon which indicate the best inherent fertility had the highest growth rates
		Potential indices developed (A, PC)	June 12	It was not possible to develop this index. Extractable P was related to the P-fixing capacity of soils which was very high in the basalt-derived soils at Nghia Trung and Phu Thanh. However these sites were associated with the highest growth rates and also responded to P fertiliser
		Test indices against growth responses (A, PC)	June 12	N/A

PC = partner country, A = Australia

6.3 Objective 3: To relate potential productivity of *Acacia hybrid* to site parameters in resource-limited environments in Vietnam

no.	activity	outputs/ milestones	completion date	comments
3.1	Parameterise CABALA™ for A. *hybrid* and *A. auriculiformis*	Integrate new knowledge into CABALA™ parameter set (A)	Dec11	CABALA parameterisation has been completed
		Validation of CABALA™ (A)	Jun12	Validation has been undertaken against soils and productivity information from sites in the southern, central and northern parts of the project
3.2	Develop Decision Support System (DSS)	Description of soils and climatic information for sites produced (PC)	Jun11	This segment has been completed for representative sites in the southern, central and northern parts of the project

		Look-up tables generated (A)	Sep12	This segment has been completed for representative sites in the southern, central and northern parts of the project (see Appendix 11.1)

6.4 Objective 4: To develop tools to support improved management, train Extension Officers to effectively disseminate information to foresters, and provide targeted training to FSIV staff

no.	activity	outputs/ milestones	completion date	comments
4.1	Write Technical Information Sheets TIS)	Six sheets prepared (A, PC)	Six-monthly from Oct 09	Seven sheets have been developed and also translated into Vietnamese
4.2	Assemble Software Package	CD and Hard Copy versions of DSS submitted to ACIAR (A)	Sep12	DSS completed; draft economic analysis undertaken; final version will be based on age 5 year measurements at Phan Truong 2 in July 13
4.3	Undertake Extension Officer Training Workshops	15 Extension Officers trained per workshop (A, PC)	Jul-Aug12	Three workshops were held for extension officers, smallholder growers, company managers and technical staff, and research staff. The average attendance at each workshop was around 25 persons (excluding presenters).
4.4	Run Field Days to disseminate project outcomes	Attract 20 growers to each of three events (PC)	Jun10,11,12	See above. However it was not possible to attract 20 growers to each event.

7 Key results and discussion

7.1 Soils

Analytical Laboratory

In February 2009, Ms Tuyen Pham of CSIRO Process Science and Engineering worked with the senior analytical chemist at FSIV's Sub-Institute in Ho Chi Minh City, Mr Le Thanh Quang and his colleagues, Ms Tran Thi Thu and Ms Nguyen Thi Minh Ty. The focus of this training module was the enhancement of individual methodologies. At the same time, Ms Tuyen completed a two-week audit of the laboratory. This included recommendations on updated protocols for analysis and safety procedures (Appendix 11.4). Following the disposal of old and acquisition of new equipment, it was possible to switch to the new practices within a few months.

Results

The most productive soils were the basalt soils at Phu Thanh and Nghia Trung. These soils are highly P fixing which is mainly driven by iron content. However basalt soil also contains a high level of natural calcium phosphate which can act as a store of nutrients. The soils at Phan Truong 2 (ferralic), Phu Binh (chromic) and Xuan Loc (gleyic) were acrisols which are clay rich but generally of low fertility with toxic amounts of Al which makes them unsuitable for agriculture. At Dong Ha the soil was a rhodic ferralsol which tends to have low porosity and hydraulic conductivity. The soils at Ba Vi and Tuyen Quang were both red-yellow ferric soils, the colour being caused by oxidation state of iron and magnesium.

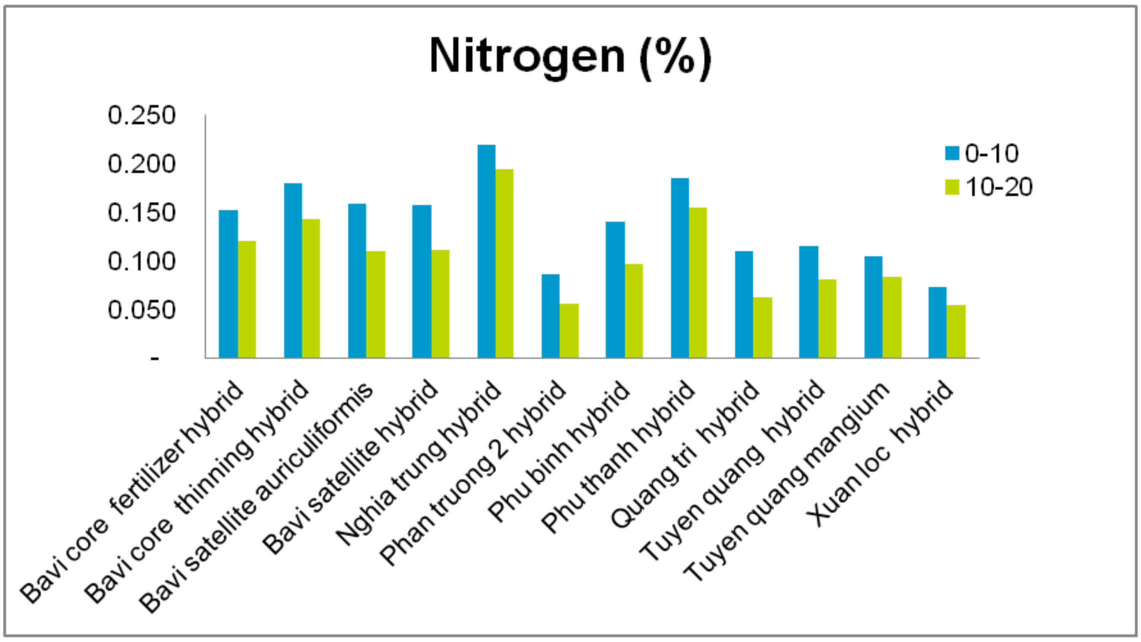


Figure 7.1: Total nitrogen (%) at 0-10 and 10-20 cm depth at the 12 trials used in this project.

- Total nitrogen (N) varied from 0.05 to 0.22% and decreased with soil depth; total N was greatest at the basalt sites, Nghia Trung and Phu Thanh (Figure 7.1);
- Extractable phosphorus (Ext-P) varied from 1-13 mg/kg and decreased with increasing soil depth; Ext-P was greatest at two of the acrisol sites at Phan Truong 2 and Phu Binh (Figure 7.2);

- Organic carbon (C) varied between 0.7-4.0% and decreased with soil depth; organic C was greatest at the basalt sites, Nghia Trung and Phu Thanh (Figure 7.3).

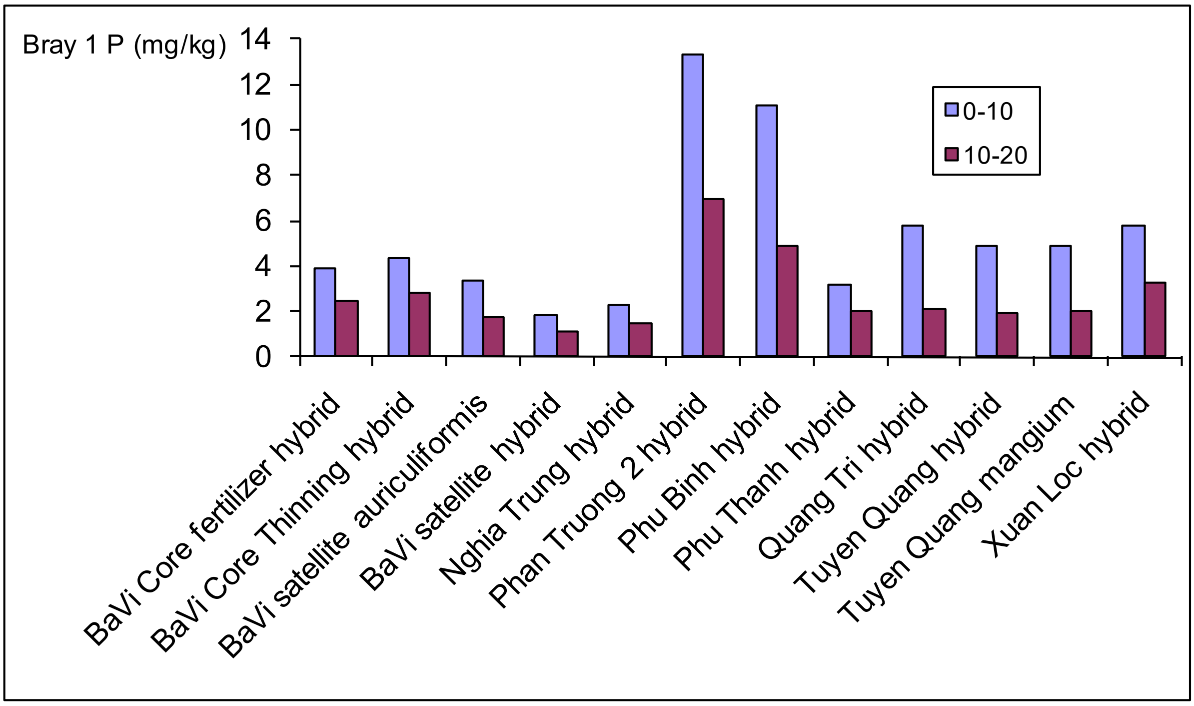


Figure 7.2: Extractable phosphorus (Ext-P; mg/kg) at 0-10 and 10-20 cm depth at the 12 trials used in this project.

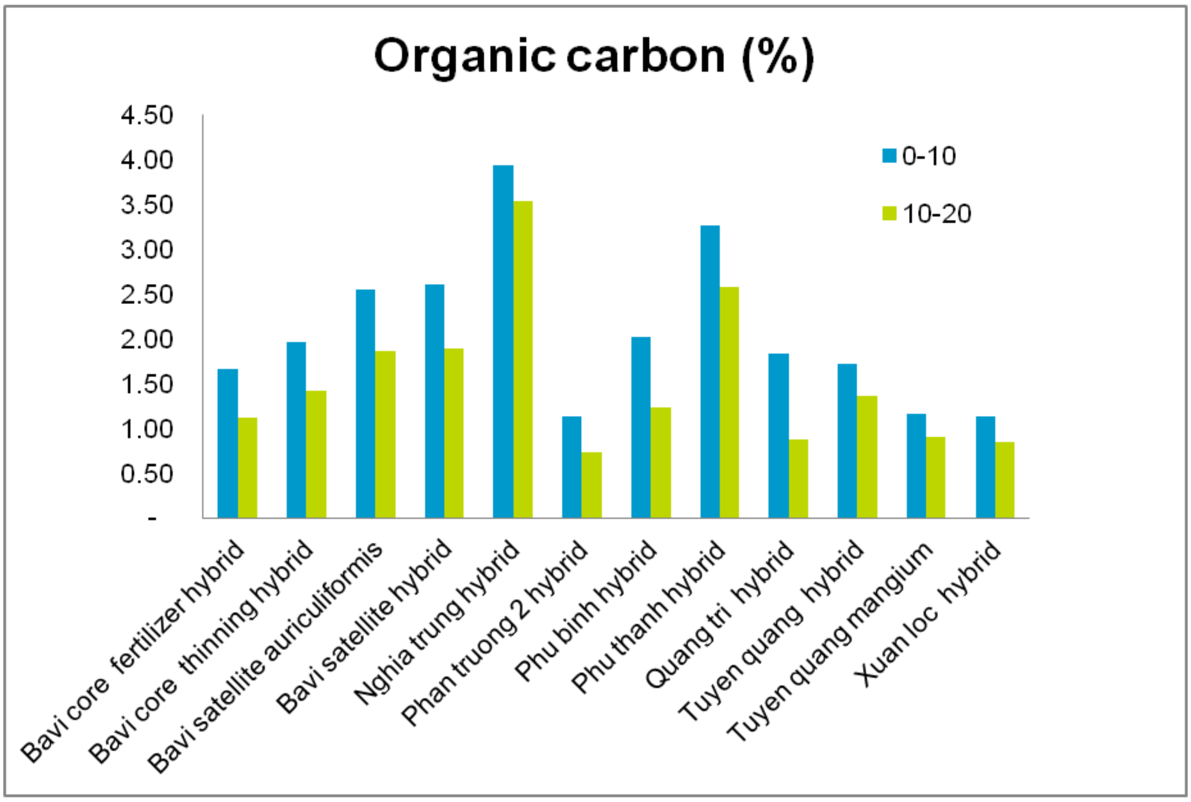


Figure 7.3: Organic carbon (%) at 0-10 and 10-20 cm depth at the 12 trials used in this project

Discussion

- The highest total N and organic C at Nghia Trung and Phu Thanh are indicative of the higher inherent fertility of these sites compared to the others and hence the highest growth rates observed. However these sites had very low levels of Ext-P because of the very high P-fixing capacity of basalt-derived soils. However the soil solution P may be more readily replenished from their large P-storage capacity, so they are still productive. The Stock Type × Fertiliser trial at Nghia Trung also showed that these basalt soils can still be highly responsive to P-fertiliser application at planting.
- These results illustrates the complex nature of the relationship between measured P concentration and P supply and the difficulties confronted when trying to develop simple indices of P requirement.
- Dong Ha had average levels of total N, available P and organic carbon and Ba Vi also average levels of total N and organic C but low levels of available P.
- Ratios of Organic C to total N (C:N) of 10:1 are normally represent fertile soils. The 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, perhaps because of their capacity to fix nitrogen.

7.2 Growth and environment

Results

The Satellite trials examined the growth responses and wood production of *Acacia hybrid* to a consistent and systematic application of fertiliser, pruning and thinning across a range of sites which differed in their potential to support tree growth. These constraints were related to the climatic differences found between the southern, central and northern sites, and also to soil type (see previous section). These sites were also established to enable the validation of the Decision Support System across sites typically used for acacia forestry in Vietnam. In July 2012, just before the end of the project, growth data to age 2 years had been collected from all sites.

DBH at age 2 yr was greatest at the southern sites (7.6-10.4 cm), intermediate in Central Vietnam (7.3 cm) and least at the northern sites (6.3-6.5 cm) (Table 7.1). Growth patterns were similar across all sites. Xuan Loc is very low lying and growth was affected by seasonal flooding. Growth rates were noticeably slower in winter at Ba Vi and Tuyen Quang.

Responses to thinning were slower at Ba Vi and Dong Ha than at Nghia Trung. There was some evidence that growth may be slowing at Nghia Trung. Responses to fertiliser at thinning occurred at Ba Vi only (Figure 7.4).

There was no clear relationship between *DBH* at age 2 years and levels of available P at 0-10 cm depth which were measured at plantation establishment. High rates of growth were associated with both high and low levels of available phosphorus (Figure 7.5).

Table 7.1: Growth (DBH) patterns of *Acacia* hybrid at the seven Satellite trials established by the project. The red numbers refer to DBH at approximately age 2 years.

Nghia Trung		Dong Ha		Phu Binh		Tuyen Quang	
r	*DBH*	yr	*DBH*	years	*DBH*	years	*DBH*
1.1	5.6	1.1	3.3	1.0	4.9	1.8	6.5
1.4	7.6	1.8	6.4	2.0	9.9	2.4	8.5
1.7	8.7	2.0	7.3			2.9	9.2
1.9	9.7	2.4	8.4				
2.4	11.3						

2.9	12.1

Phu Thanh		Ba Vi		Xuan Loc	
yr	*DBH*	yr	*DBH*	yr	*DBH*
1.0	6.0	1.1	4.8	1.1	3.6
1.7	8.1	1.8	6.3	2.0	7.6
2.2	10.4	2.4	7.8		
2.4	11.0	2.9	8.8		
2.8	12.0				

Plate 7.1: The effects of waterlogging at Xuan Loc. Note the variable growth and yellowing of affected trees.

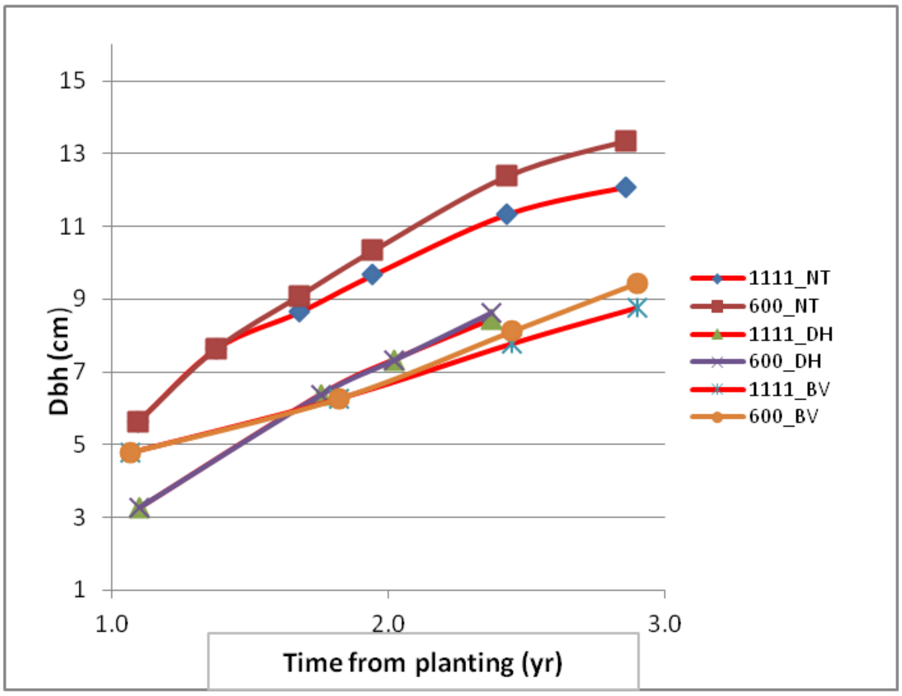


Figure 7.4: Examples of thinning responses at a southern (Nghia Trung, NT), central (Dong Ha, DH) and northern (Ba Vi, BV) site.

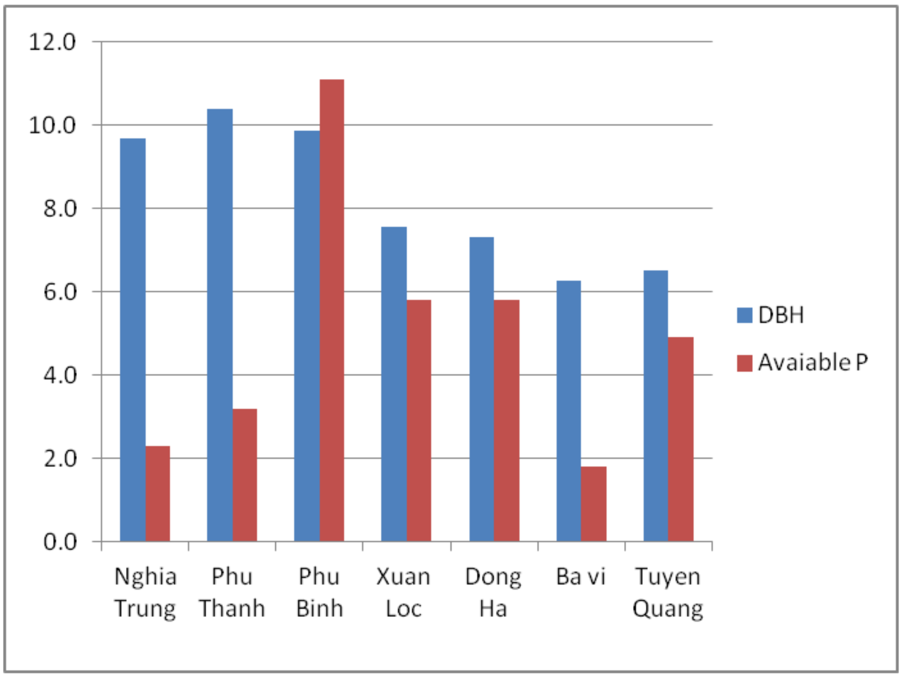


Figure 7.5: The relationship between DBH at age 2 years and available P (Bray1, mg/kg) at the Satellite sites

Discussion

- The trials demonstrated a range of growth rates between the southern, central and northern sites following application of 50 kgP/ha at planting and a consistent silvicultural approach to site preparation, planting, weed control and pruning. The biggest contributing factor to these differences is probably climate. However individual site characteristics, like susceptibility to flooding at Xuan Loc (Plate 7.1), will compromise potential growth rates;
- Patterns of growth appeared distinct between the south and other parts of Vietnam;
- Significant responses of diameter growth to thinning were common across all sites;
- A role for fertiliser application at thinning appears to be site-dependent and has only been observed to date at the northern sites; however, across sites, growth is not clearly linked to a measure of available P.

7.3 The Core A Trial at Phan Truong Hai – responses to thinning

This was the largest and most comprehensive experiment in the project and examined the timing and intensity of thinning on *Acacia* hybrid growth. In conjunction with the Core B Fertiliser and Core C Thinning experiments at Ba Vi, its function was to provide data that could be used to develop a decision support system that quantifies production against information on soils, climate and silvicultural inputs, and can be used by small-holder growers.

Issues arising

- The trees had poor form in spite of the planting stock being approved clones (TB 01, TB 06, TB11 and TB12). This was possibly because the cuttings had been sourced from old hedges. As the hedges age, cuttings taken from them progressively lose their apical dominance and may become unsuitable for plantations being managed for high-value sawlogs. Intensive form pruning was necessary to capture apical dominance. However this was often late and undesirable large branches developed.

- The most persistent and competitive weed encountered in the project was bamboo. An effective weed control strategy was developed which virtually eliminated this weed (Technical Information Sheet No. 1 How to Control Bamboo; Appendix 11.3.)
- A wildfire on 2 January 2010 affected 179 trees and Plots 1 and 10 at one end of the trial were lost. This was dealt with by moving the whole experiment along one section. Plots 2 and 11 became the new plots 1 and 10; plots 45 and 54 were established in the first two of the six buffer plots adjacent to the original positioning of these plots.
- High wind events led to some attrition in this plantation, both before and after thinning. Stem breakage was often associated with pruning of large branches, and/or the development of two large multiple leaders just above the sawlog length. Both appeared to be associated with discoloration, decay and incipient heart rot. In the case of two large multiple leaders, a fissure can develop on the upper side where the leaders join, probably a stress fracture. This is inevitably a portal for the entry of free moisture and decay organisms.

Results

Three plots were established in the adjacent commercial plantation, one each alongside the three replications of the ACIAR experiment. This stand was part of the same plantation as the ACIAR trial. The main differences were that weed (and fire) control was by ploughing, there was one singling only, and no fertiliser was applied at planting.

There was a significant response of *DBH* to thinning intensity and thinning time (Figure 7.6), but no significant response of height (*H*) to thinning intensity. There was also no response of *DBH* to application of fertiliser at thinning.

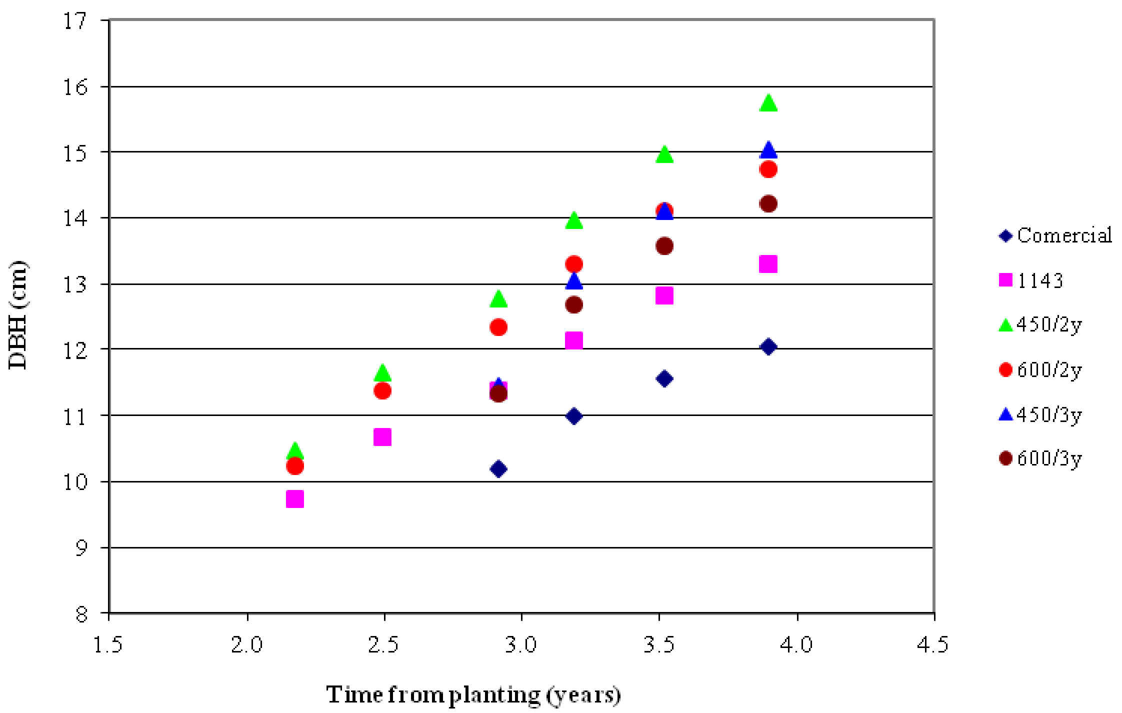


Figure 7.6: The relationship between DBH (cm) and time since planting. The colour coding distinguishes thinning intensity, thinning time and the ACIAR from the commercial plantation.

DBH in the unthinned treatment at age 4 yr was 13.3 cm; in the adjacent commercial plantation it was 12.1 cm. Two years after thinning, *DBH* at age 4 years in the 450 stems/ha treatment was 15.8 cm. Though not significantly different, *DBH* in 450 stems/ha treatment thinned at age 3 yr was > *DBH* in the 600 stems ha^{-1} thinned at age 2 yr.

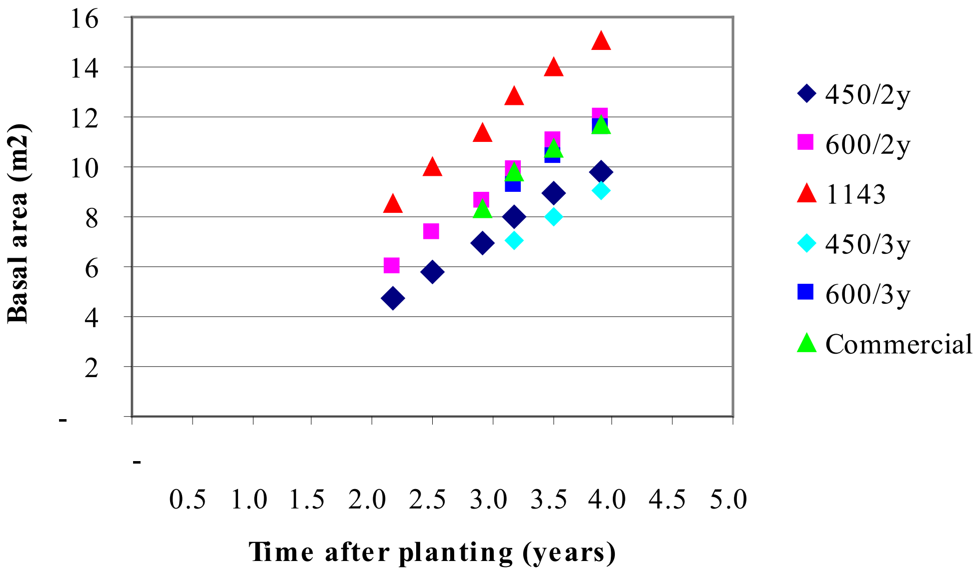


Figure 7.7: The relationship between basal area (m^2/ha) and time since planting. The colour coding distinguishes thinning intensity, thinning time and the ACIAR from the commercial plantation.

Basal areas increased in parallel across all treatments (Figure 7.7). There was no indication of any slowing in basal area accumulation in the unthinned treatments to age 4 yr. At age 4 yr, the basal areas of the unthinned ACIAR and commercial plantations were 15.1 m^2/ha and 11.7 m^2/ha, respectively. Basal area increments in 4th year of growth in 2nd-year thinning treatment were 3.1, 2.7 and 2.3 m^2/ha in 1143, 600 and 450 stems/ha treatments, respectively.

Discussion

- There were very strong *DBH* responses to thinning which became significant as early as six months after thinning. The thinning response increased with thinning rate, and crucially, even as early as one year after thinning, trees thinned to 450 stems/ha (Plate 7.2) were overtaking the diameter of trees thinned to 600 stems/ha two years after thinning. This demonstrates that inter-tree competition for resources was very high in this stand, even in the treatment thinned to 600 stems/ha two years after thinning.

Plate 7.2: Mr Dat in May 2011 with a tree in a stand thinned to 450 stems/ha in July 2010.

- At age 4 years the basal area of the unthinned experimental plantation was 29% greater than in the commercial plantation. It is not possible to state with certainty why this difference occurred; a large contributing factor was possibly the application of 50 kg/ha of P fertiliser. Differences in stocking at thinning between the thinning treatments of unthinned, 600 and 450 stems/ha were in the ratio 100:53:39 respectively; two years after thinning, the ratio of differences in basal area increment were 100:87:74. The probable reason for the rapid recovery of basal area growth after thinning was most likely related to a parallel recovery in leaf area index (see below).
- This very rapid response to thinning was not related to the fertiliser applied at thinning; a similar result was also found at Phu Thanh and Nghia Trung, the southern Satellite sites planted in 2009. This suggests that the capacity of these sites to supply P is being adequately met from the 50 kg/ha applied at age three months (at Phan Truong 2) or at planting (Satellite sites).

7.4 Leaf area index

Leaf area index (LAI) measures the total amount of leaf area vertically above an equivalent ground area (m^2/m^2). The amount of light intercepted by leaves determines the potential growth of all crops; broad-leaved forests like acacias typically have a maximum LAI of 5-6. Measuring LAI provides a means of understanding the current capacity for tree and stand growth.

Results

It was first necessary to calibrate the simple method based on digital photographs (Plate 7.3) against the most accurate way currently available for determining LAI in the field, the LI-COR LAI-2000 Canopy Analyser. Figure 7.8 shows the best relationship obtained.

Plate 7.3: Two images of contrasting canopies (thinned and unthinned treatment) taken with a digital camera pointing vertically upwards.

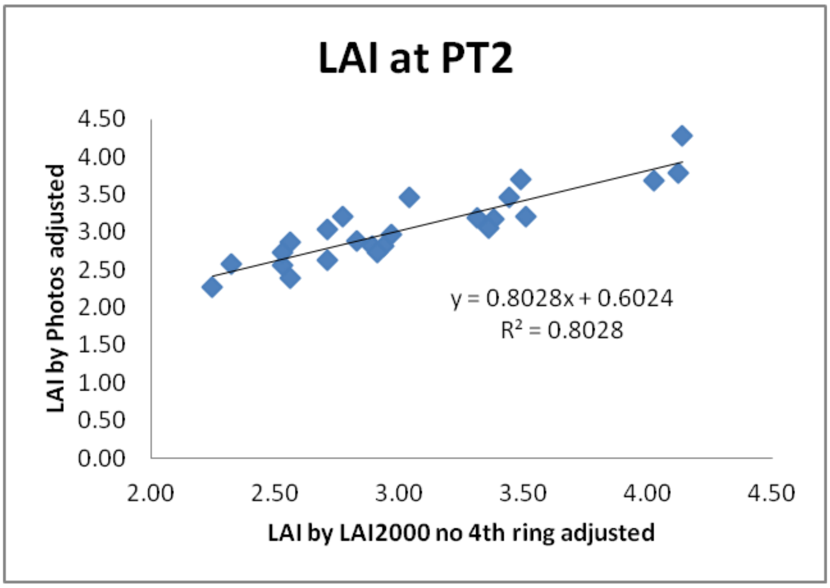


Figure 7.8. The relationship between measures of leaf area index made with the LI-COR LAI-2000 and a digital camera. Each point represents the mean of 10 measurements taken in plots at Phan Truong 2.

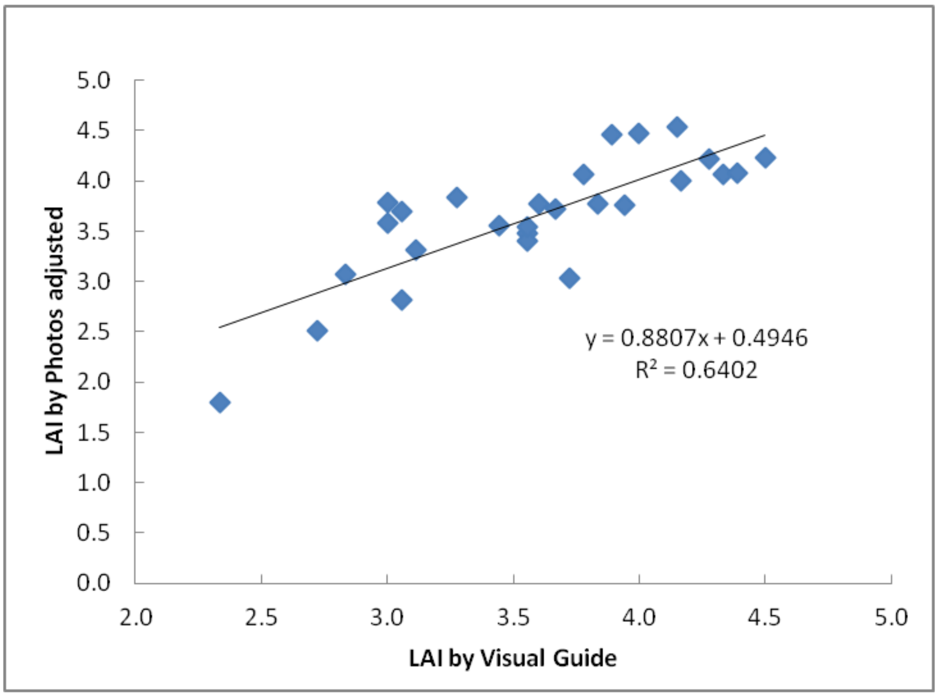


Figure 7.9: The relationship between LAI estimated by The Visual Guide and by digital photographs.

The Visual Guide can produce good estimates (to 1.0 unit) if used correctly by the operator (Figure 7.9) but this requires training and an ability to match what is seen with photographs that represent different canopy sizes. Photo-images can estimate LAI to 0.5 unit and the LAI-2000 to 0.1 unit.

Discussion

- The capacity to use measures of leaf area index to track canopy recovery after thinning are still being developed;
- Early results suggests that both the Visual Guide and digital images can be used to detect canopy recovery from thinning;
- Mr Dat received training in the use of The Visual Guide and photo-images and Mr Hung in the use of the LAI-2000. They have been applying these techniques at Phan Truong 2 and Ba Vi, respectively. Ms Maria Ottenschlaeger was the trainer in both instances.

7.5 The northern sites - responses to fertiliser at thinning

Results Core B – response to fertiliser and thinning

Nineteen months after the application of thinning and fertiliser treatments, there was a significant response of diameter increment to thinning; there was also a significant response to fertiliser application in the unthinned treatment only if basal nutrients were included (Figure 7.10).

Stock-type × fertiliser trial

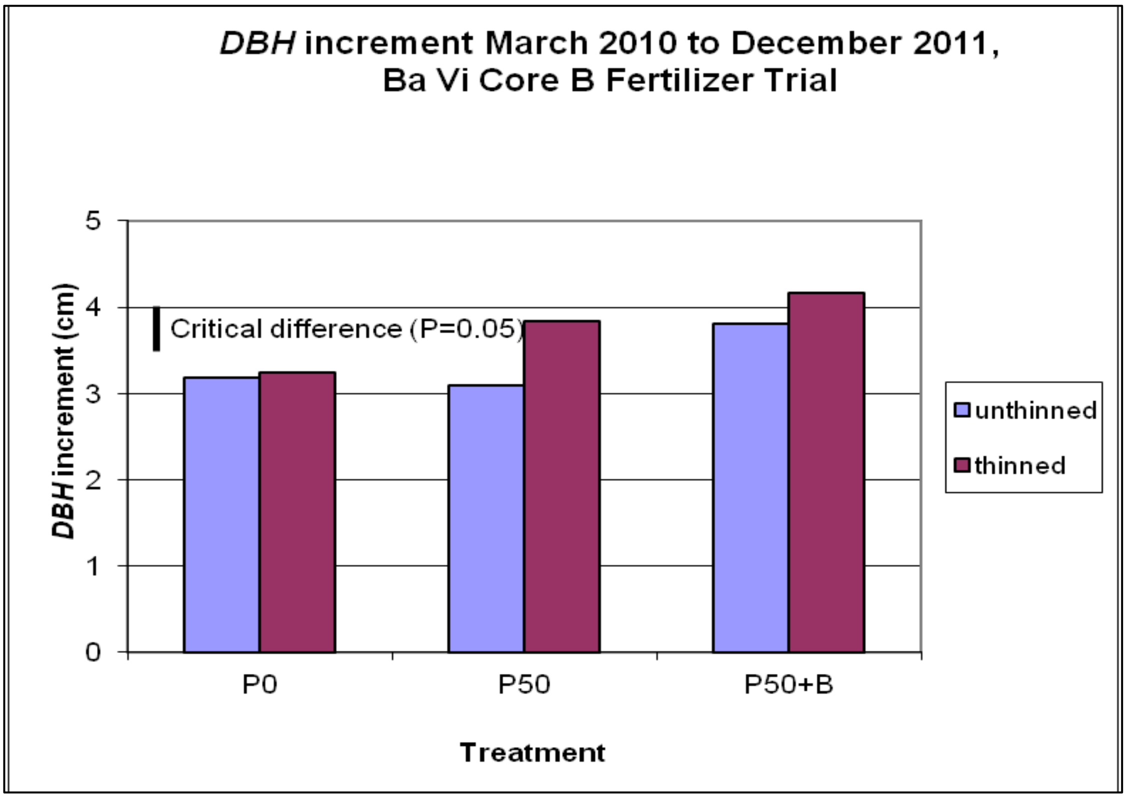


Figure 7.10: The relationship between DBH increment and thinning and fertiliser (either 50 kgP/ha or 50 kgP/ha + basal) treatments, 19 months after their application in May 2010.

Results Core C – response to thinning intensity

Nineteen months after the application of treatment at age 3 yr 9 months there were significant responses to thinning rate, though not between the 600 and 450 stems/ha treatments; *DBH* increment increased with thinning rate (Figure 7.11). In a later thinning at age 4 yr 9 months; there were also significant responses to thinning, but only between the unthinned and thinned treatments (Figure 7.11).

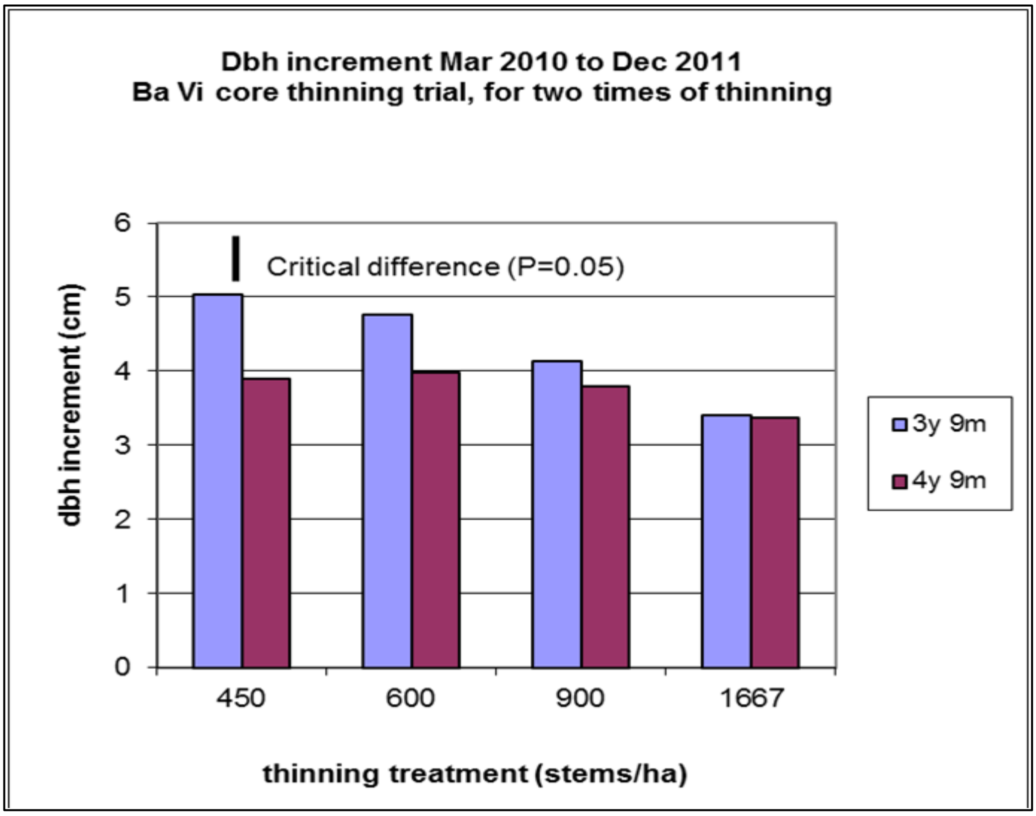


Figure 7.11: The relationship between *DBH* increment and thinning intensity at two thinning times, at age 3 yr 9 months and age 4 y 9 months, respectively May 2010 and May 2011.

Discussion

- Significant responses to thinning can be captured within seven months of treatment, even in the slower-growing sites in northern Vietnam and in later-age plantations. However the benefits of a very high thinning rate to 450 stems/ha had not yet been captured, as it had at Phan Truong 2 in the south after 6 months, 17 months after thinning.
- Significant responses of *DBH* increment to fertiliser addition at thinning can also be captured at these slower growing sites in the north, though in the Ba Vi Core B trial, only in the unthinned treatment, and only if basal fertiliser was applied. This suggests that the supply of a nutrient other than phosphorus is limiting growth at this site. A similar result was obtained at the Ba Vi Satellite trial. At the Tuyen Quang Satellite trial, significant responses of *DBH* increment to fertiliser application 12 months after treatment were also observed, but in both the thinned and unthinned treatments.

7.6 Physiological campaigns

Results

Application of 50 kg P ha^{-1} at planting at Nghia Trung in the Stock Type × Fertiliser trial resulted in significant ($p<0.05$) increases in foliar P (P50 = 0.115; P0 = 0.096 g m^{-2}) and N (P50 = 2.84; P0 = 2.43 g m^{-2}). This led to significant ($p<0.05$) increases in light-saturated rates of photosynthesis (Figure 7.12). There was also a significant fertiliser x time interaction ($p < 0.05$) at 09:00 h at which the P0 trees experienced water stress earlier and recovered earlier than P50 trees.

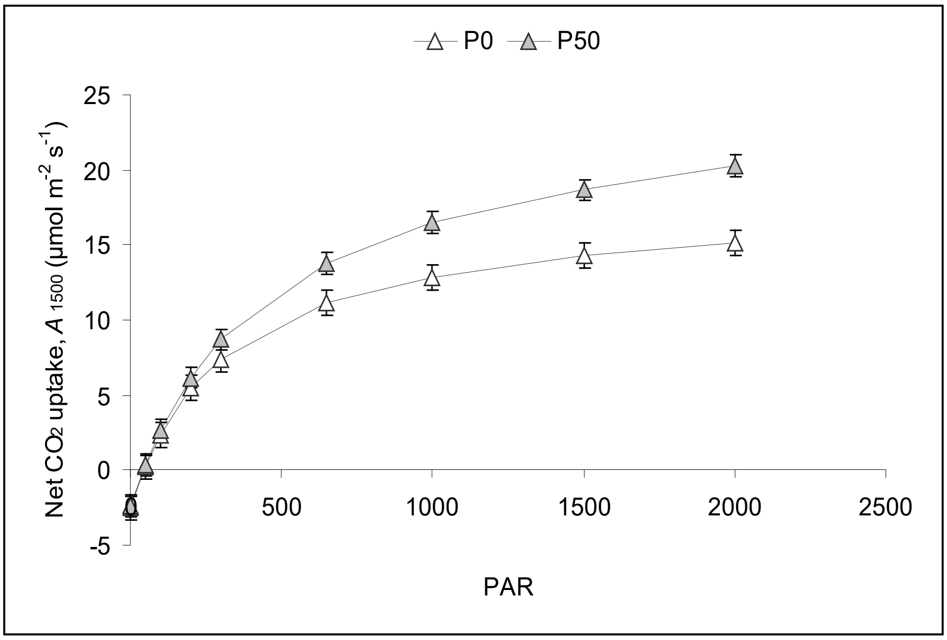


Figure 7.12: The relationship between net photosynthesis (net CO_2 uptake) and incident photosynthetic radiation (PAR, umol m-2 s-1) in two treatments, one receiving no P at planting, the other 50 kgP/ha at planting.

Plate 7.4: Mr Bon receiving instruction from Dr Alieta Eyles in the use of the LI-COR 6400 portable gas-exchange system at Phu Binh.

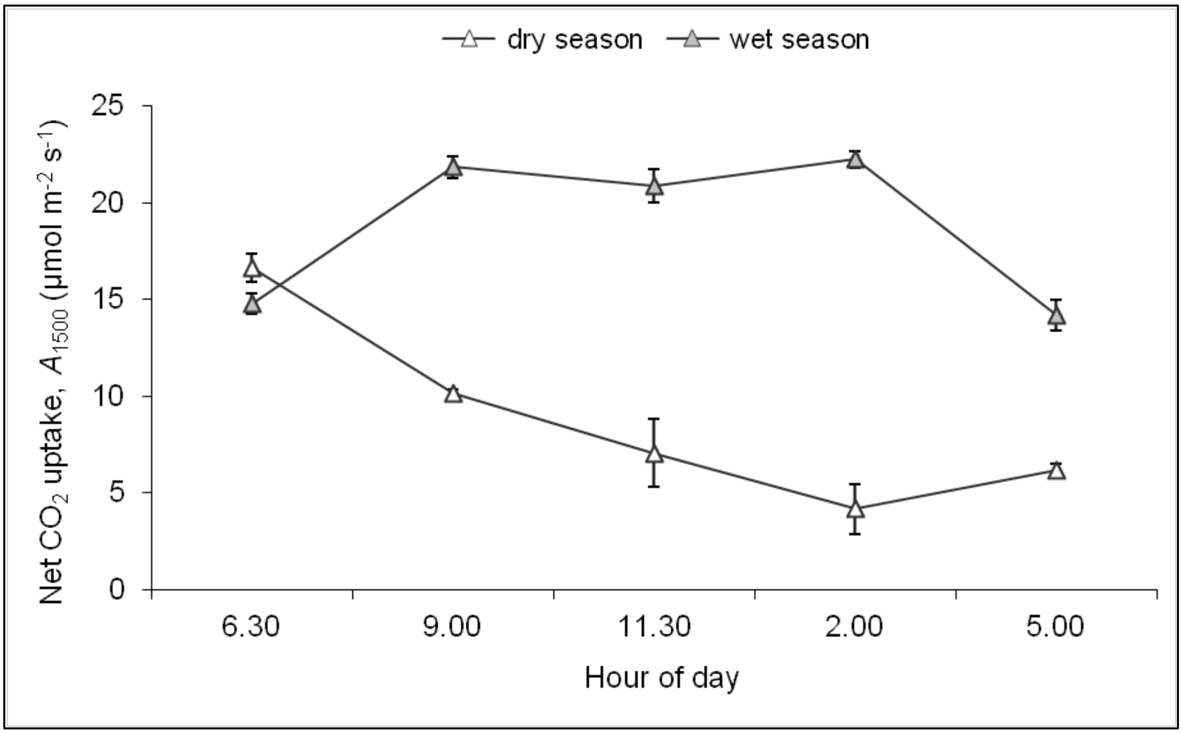


Figure 7.13: The diurnal patterns of net photosynthesis (net CO_2 uptake) in the wet and dry seasons at Phu Binh.

At Phu Binh (Plate 7.4) patterns of light-saturated rates of photosynthesis (A_{1500}) were very different between the wet and dry seasons (Figure 7.13). In the wet season in May 2011, photosynthesis increased in the morning and remained fairly constant throughout the day before declining at dusk. At the height of the dry season in March 2012, pre-dawn water potentials of ψ = -1.1 MPa with a rapid decline to ψ = -2.3 MPa soon after dawn led to significant reductions in A_{1500} by 09:00 h; differences in A_{1500} were still significant at 17.00 h.

Discussion

- The significant response of photosynthesis to the application of 50 kgP/ha at planting was associated with a significant difference in both foliar N and P and in growth rate at age 7 months when the gas-exchange measurements were undertaken. Thus even at sites with basalt soils like Nghia Trung that have a high potential productivity, P may still be limiting growth during the establishment phase of the growth cycle.
- In the wet season at Phu Binh, the supply of water did not appear to be limiting photosynthesis; in contrast at the end of the dry season, there was little gas-exchange activity apart from during the early morning. Such conditions are likely to lead to reduced growth and accelerated litterfall. However the lowest water potentials recorded (-2.3 MPa) in the driest part of the year were not associated with mortality.

7.7 Effects of cutting age × P application at planting

Background

An unanticipated problem confronted by the project was that the growth habit and form of the planting stock was not uniform both within and between plantations. This may have been related to clone type – mixtures as well as single clones were used in the trials, and also to hedge age, cutting position (tip or nodal), site, fertiliser application and timing of form pruning.

A small experiment at Nghia Trung was established in August 2011 to examine some of these issues. The rationale was that the age of the hedge plants from which *Acacia* hybrid cuttings are taken may affect growth rate, branching characteristics and stem straightness. This effect may interact with the rate of fertiliser applied at planting, and different clones may differ in their response. The treatments were as follows:

- Tip cuttings taken from new (< 1-year-old) and 4-year-old hedge plants;
- Two levels of fertiliser at planting, 0 (P0) and 50 (P50) kgP/ ha
- Three clones, BV10, BV32 and BV 33

A split-plot design was used: fertiliser (main plots); cutting age (sub-plots); clone (line plots). Form pruning consisted of one singling only. The faster growth of the fertilised trees meant that this was done earlier in this treatment than the unfertilised treatment.

Results

The application of 50 kg P/ha at planting significantly increased growth to age 9 months. However hedge plant age did not affect growth and there was no clear effect on branching and stem form. There were no differences between the clones.

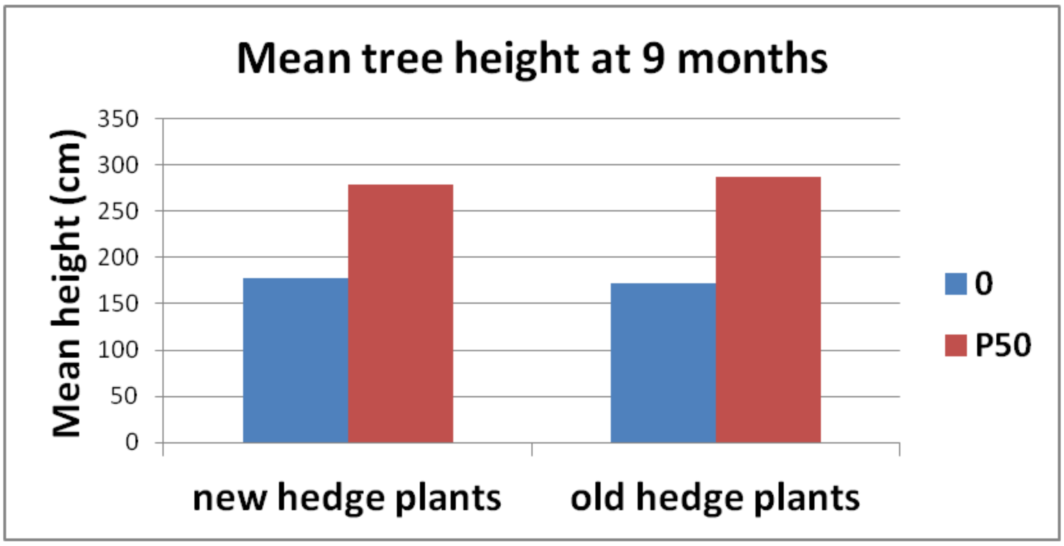


Figure 7.14: Mean tree height of trees from tip cuttings taken from new or old hedge plants and receiving either no or 50 kgP/has at planting.

Discussion

- This experiment provided a clear demonstration of the significant growth responses that can occur to P application at planting, even on an inherently fertile basalt soil (Plate 7.5)
- The role of hedge-plant age and clone on growth and form remained unclear when tip cuttings are used. Even with one singling only, both the fertilised and unfertilised trees had good form and acceptable branch size. This may have been related to the use of tip cuttings only which lead to greater apical dominance than with nodal cuttings.
- The links between hedge age, cutting practice and silviculture warrant more detailed attention.

Plate 7.5: Left: Cuttings (left) without (foreground) and with 50 kgP/ha (background) at age 4 months; and cuttings (right) without (left) and with 50 kgP/ha (right) at age 7 months.

7.8 Heart rot

Background

Acacias are pruned and thinned to optimise the productivity of sawlogs. These operations may negatively affect timber quality because of entry of fungi which cause stem defects e.g. heart-rot fungi, and various canker (including Pink disease) and blue-stain fungi. Where *A. mangium* has been grown in the tropics, stem quality is often severely reduced by heart rot in trees as young as 5-8 years. ACIAR Project FST/2000/123 in researching heart rot in Indonesia, established the importance of developing form and branch pruning regimes which minimise the incidence and severity of heart rot. Species other than *A. mangium* were found to be fairly tolerant to heart-rot due to a more effective biochemical response to infection. In the current project, a survey of heart-rot incidence and severity and an experimental investigative trial were carried out to examine for heart rot in *Acacia* hybrid plantations.

The *survey* was undertaken at Phan Truong 2 (PT2). In July 2011 81 four-year old pruned trees (3 lifts) were harvested at PT2. After felling, each tree was cut into 0.5-m sections. The top of each section was assessed for decay by taking a photo of the cut upper surface of a section through a transparent grid to allow for area calculations. 27 trees were surveyed in un-thinned and 54 in thinned plots. Wood samples were taken from each tree and over 500 fungal isolates obtained.

The *investigative trial* was established at Nghia Trung in December 2010. Its focus was to examine the influence of branch size and form pruning on the incidence and severity of heart rot. The following observations were made prior to setting up the trial:

- A large number of wounds with poor occlusion and with visible fungal growth were present on the surface of form-pruning stubs (Figure 7.6a, b);
- Significant wind damage had caused branches in the top of the crown to break and stripped bark from trees, resulting in large wounds (Figure 7.6c);
- Stem decay was visible in large stubs from branches pruned during the visit (Fig. 7.6d);
- Stem-decay fungal fruiting bodies were visible on debris in the plantation.

From each of 18 treatment blocks, 10 buffer trees of the best form were selected; 5 trees were pruned to 1.5 m and 5 left unpruned. The following measurements were taken:

- Tree diameter and total number of branches or pruning stubs in the stem section up to 1.5 m;

- The number of branches tip-pruned in the stem section up to 1.5 m in unpruned trees; and number of large diameter (> 2 cm) branches in unpruned trees or fresh pruning wounds in pruned trees in the stem section up to 1.5 m;
- The number of older un-occluded wounds in the stem section up to 1.5 m. These wounds had been made prior to the visit and were counted in both unpruned and pruned trees;
- In the stem section above 1.5 m, the number of branches which had split away from the main stem and the number of any large stem wounds.

In July 2012, the 180 trees were destructively harvested.

- For each tree the pruned or unpruned 1.5 m sections were divided into three 0.5-m sections. The different stages of incipient decay or rot were recorded by taking photos at the top end of each section with and without a transparent grid on the cut surface;
- For each of the 18 treatment plots 4 trees, 2 unpruned and 2 pruned were cut into 10 sections, also recording the decay present by taking photos.

Small wooden blocks of infected wood were sampled for fungal isolations from each section of infected wood. Fungi are being identified using molecular tools either from fungal cultures obtained or direct from the wood block.

Figure 7.6a: Wound with poor occlusion and visible fungal growth on surface

Figure 7.6b: Wound with poor occlusion and visible fungal growth on surface

Figure 7.6c: Branch break (wind damage), stripping bark from trees thus providing entry court for fungi

Figure 7.6d: Stem decay already visible in large branches pruned during visit (arrow)

Plate 7.6: Symptoms observed in the investigative trial at Nghia Trung in December 2010

Results - survey

In the survey at PT2, nearly all trees sampled had signs of heart rot and a rating system was developed (0 to 3; Fig 7.7).

In the thinned plots 10 out of the 54 trees (18.5%) were observed with sections Rating 0 or 1 but not above. Most trees (36 or 66.7%) had at least one section with Rating 2. Only 8 or 14.8% of the 54 trees had sections with a more advanced (Rating 3). The incidence and severity of heart rot was similar in un-thinned plots. Only 5 trees did not have any sections above Rating 1 (= 18.5%). Most trees (17 or 63%) had sections with Rating 2. Only 5 or 18.5% of the 27 trees had sections with more advanced decay (Rating 3).

The volume of incipient decay and rot is being calculated. Over half of the fungal isolates are basidiomycete and are being identified by Mr Trang in Hobart from DNA extracted in Vietnam.

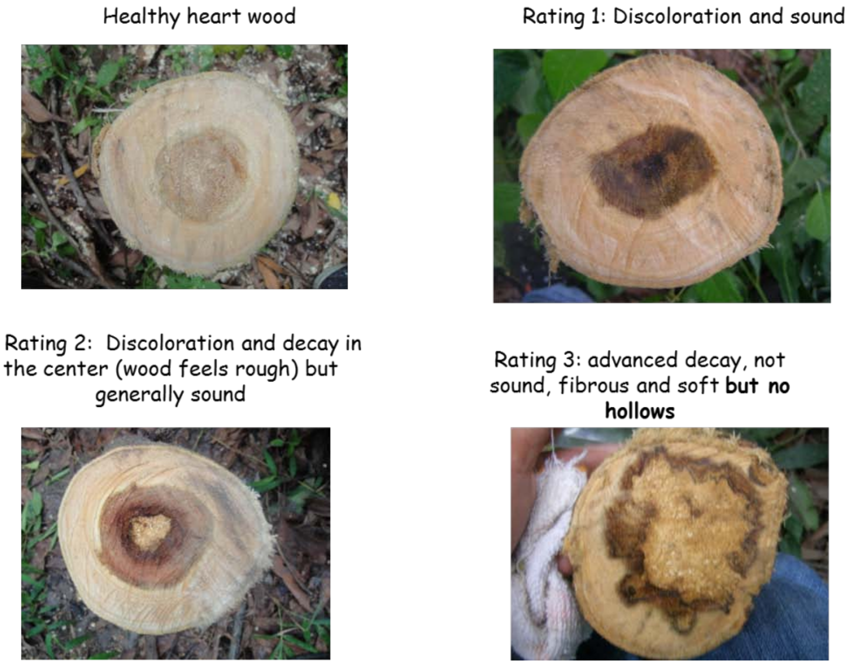


Plate 7.7: Ratings developed for scoring heart rot.

Results – investigative trial

In December 2010, of the 180 trees

- 92 had either fresh pruning wounds or branches in the section of the stem up to 1.5 m which were >2 cm in diameter. The total number of wounds or branches >2 cm in diameter was 148, with between 1 to 4 large branches or wounds per tree;
- 147 trees had older un-occluded wounds in the stem section up to 1.5 m. The total number of such wounds was 337, an average of >2 per tree;
- 21 out had wind damage and branches splitting away from the main stem.

In July 2012:

- Incidence and severity of stem defects were greater above 1.5 m and associated with large wounds, cankers, and wind damage. Breakage meant that it was no always possible to retrieve 10 sections;
- >20 trees had Pink disease. Branches and tree stems were broken, a typical symptom;
- Termite damage was present and many stumps were hollow;
- *Ceratocystis* wilt was occasionally observed in the higher sections;
- Sporocarps of basidiomycete “rotters” were present (e.g. *Ganoderma, Trametes*);

- Up to 1.5 m, heart-rot incidence was generally similar between pruned and unpruned log sections. Pruning a large diameter branch appears to be associated with more advanced heart rot compared to a naturally abscised branch in unpruned logs (Figure 7.8).

Plate 7.8: Examples of heart-rot development following pruning of a large branch (left) and a naturally abscised branch (right).

Discussion

- At PT2, the incidence of heart rot was high but the severity was low. It is necessary to know how quickly the decay will progress in the time between age 4 years and harvest and to record the levels of heart rot at the final harvest.
- The data from Nghia Trung is being further analysed (as part of Mr Trang's JAF program) including identification of fungi associated with heart rot and stem damage. However it is clear that the pruning of large branches, if not associated with an increased incidence of heart-rot infections, may facilitate the entry of fungus and lead to a more speedy development of heart rot. Of most significance is the damage caused by wind or Pink disease in the higher part of the stem which leads to both heart and stem rot.

7.9 Other challenges

Branch size

Acacia hybrid is a very-fast growing species. The degree of apical dominance varies and without singling, multiple stems may develop (Plate 7.9). Branch size on individual trees also varies. One of the challenges confronted by the project was that in some of the stands e.g. Phan Truong 2, Phu Thanh, Nghia Trung Satellite, large branches were a major feature, whereas in others e.g. Phu Binh, they were not (Plate 7.9). These outcomes may have been linked to the planting stock, fertiliser input and timing and frequency of pruning, and are deserving of further investigation.

Plate 7.9: 10-month-old trees at Nghia Trung without (left) and with singling but a predominance of large branches (middle); at Phu Binh branches were small (right).

Branch and stem breakage

The very high growth rates of *Acacia* hybrid are associated with the production of large canopies. Storm events are not uncommon in Vietnam, and most of the ACIAR trials were affected to a greater or lesser extent; Nghia Trung was the worst affected though severe damage was also experienced by the Ba Vi Satellite trial, though not the Core B and C trials at Ba Vi (Plate 7.10). The potential for wind damage is therefore high in Vietnam; one option for minimising this problem is timely and correct pruning technique and management of canopy size. Avoidance of large branches and the need to prune large branches should also reduce branch and stem breakage associated with heart rot (Plate 7.10).

Plate 7.10: Stem breakage at Nghia Trung (left), branch breakage at Ba Vi, and stem breakage at Phan Truong 2 (right) following storm events. At Phan Truong 2, it was associated with the development of heart rot.

Pests

Termites challenge successful seedling establishment and at several sites. Termiticide was applied routinely but it was still necessary to replace up to 20% of the planting stock up to three months after the initial planting. At Xuan Loc, the dor beetle (*Holotrichia morosa* Waterhouse) larvae also compromised establishment in spite of pesticide application (Plate 7.11). The local Forest Enterprise manager commented this pest had not been a problem where slash had been burnt which was routine company practice. Pesticide application is essential at some to ensure successful establishment, otherwise, apart from heart rot, the trials remained relatively free of pests and pathogens that compromise tree growth.

Plate 7.11: The larvae of the dor beetle (*Holotrichia morosa*; left) that contributed to the patchy establishment of the Xuan Loc Satellite trial. This trial was also affected by waterlogging.

7.10 Decision Support System

A **D**ecision **S**upport **S**ystem (DSS) was developed to assist in presenting the findings of this project in a user-friendly format. This is a work-in-progress and a prototype DSS which is probably more useful as a research tool. Extension Officers should therefore use the DSS with caution when providing recommendations to growers.

The DSS uses the CABALA processed-based model of forest growth (Battaglia et al., 2004). ACIAR-funded activity in tropical *Acacia mangium* plantations in Indonesia and northern Australia provided the starting point for adapting the model to work in acacia plantations. Key system attributes that needed further development were nitrogen fixation, allometrics and volume models, and incorporation of knowledge specific to *Acacia* hybrid which had been obtained through the project or experimentally elsewhere.

Whilst CABALA is able to predict productivity reasonably well, and it has been validated to the best of our current ability at the sites that have been accessed, significantly improvements can be made in the future by being able to incorporate full-rotation length information on the existing range of ACIAR sites and treatments.

The key factors in this version of the DSS are climate, soil types, planting densities and thinning regimes. CABALA was used to simulate a factorial combination of a total of 216 combinations of the above, and the predicted volume, height and diameter were used in the DSS.

Information on planting time, P fertilizer, singling/pruning, and weed control on stand productivity and survival was incorporated into the DSS at an empirical level. Each of these parameters can independently modify the productivity, survival and saw-log yield predictions, with the modification represented by a proportional value (usually in the range 0-1) to which the process-based outputs are multiplied. These values are multiplicative in the DSS. The effects of self-thinning and thinning age are also dealt with empirically.

The DSS was developed in an Excel spreadsheet format which is readily accessible to most computer users. The spreadsheet format allows for a simple and transparent approach so that users can see how the information is sourced and the manipulations that are being performed on it to produce the final outcome. Macros are not used so that users do not have to be concerned about security of the workbook. The DSS is structured so that information is provided on key worksheet tabs.

This is a first attempt to allow growers to quantify the likely productivity and log yield of a range of silvicultural options and at a range of site types in Vietnam. The system is open for future modification, and would benefit from further improvement. Key assumptions are that (1) the latest genetic material is used for the planting stock, and clonal material is sourced from young hedges, and (2) the site is suitable for acacia growth.

A full description of the DSS is in Section 11 (Appendix 11.1). The current version of the EXCEL Spreadsheet is appended as a separate document.

7.11 Economic analysis

This economic analysis is designed for Extension Officers to advise growers about the most attractive regimes for producing sawlogs from *Acacia* hybrid plantations. It is based on the experimental plantation established at Hai Vuong Joint Stock Company's Phan Truong 2 Estate, Binh Phuoc province. The plantation was established at a nominal 3.5 m × 2.5 m spacing or 1143 stems/ha (*ca.* 1100 trees/ha). The stand was thinned at one of two ages (age 2 years [early] or age 3 years [late]) to three stockings (1100 [unthinned control], 600 and 450 trees/ha). The height and diameter of the trees was measured on eight occasions at approximately six-monthly intervals to age 5.0 years or 3.0 and 2.0 years after the two thinning times. The economic performance of the adjacent unthinned commercial plantation is presented for comparison. The spreadsheet allows users to examine the full range of the likely costs to be incurred when undertaking silvicultural operations in Vietnam, including materials and labour. Users can also change prices to match those of their local markets.

The study was based on the following assumptions: (1) the benefit of *Acacia* plantations was based on wood volume; (2) all wood was harvested at the end of the rotation; (3) the prices of pulpwood, small sawlog and sawlog were USD 29.52, 38.57 and 79.05 per cubic metre and remained constant through time; (4) there were no losses to pests, diseases or fire; and (5) the average interest rate of the Commercial Bank in 2012 (15%) was used. Wages and costs are for the 4th quarter of 2012. Wood price is mode price for all of 2012 in Bien Hoa Town, Dong Nai province which has the biggest market for sawlogs in south-east Vietnam.

At age 6 years, the highest NPV (USD1601/ha) was found for the 450 stems/ha treatment when the stand was thinned at age 3 years. The lowest NPV (US1427/ha) was found for the commercial pulpwood plantation. NPVs for the other regimes were intermediate. It is interesting to note that at this age, the maximum difference in NPV between the best and worst regime was < USD200. Up to three years after thinning, standing volume remained the highest in the unthinned treatment. However sawlog values had developed in all the thinned treatments; there were no sawlog values in the unthinned treatments. Wood price had the greatest impact on financial returns to growers; discount rate was next in importance and then thinning practice.

These results indicate that in the absence of factors that can downgrade wood yields (poor form, wind damage and heart rot), saw-log regimes can be an attractive option in southern Vietnam if managed at least over a six-year rotation with appropriate silvicultural interventions (weed control, fertiliser inputs, pruning and thinning) to ensure that saw-log values are maximised. However, to best realise the benefits from thinning, longer rotations than six years will be necessary to maximize saw-log values. Saw-log values are unlikely to develop in unthinned plantations.

There is inevitably a level of uncertainty in these results as growth rates are predicted from data collected to age 5 years only. The analysis also excludes any consideration of the potential effects of pests, diseases and fire damage on realised productivity.

A full description of the Economic Analysis is in Section 11 (Appendix 11.2). The current version of the EXCEL Spreadsheet is appended as a separate document.

8 Impacts

8.1 Scientific impacts – now and in 5 years

A working system for thinning Acacia *hybrid*

Acacia hybrid is a very fast-growing species with a high productive potential. Exploiting this potential requires a good understanding of how growth patterns change with time, and for solid-wood production, so that individual rates of tree growth are not prejudiced. The early thinning strategies examined by this project are a new development in Vietnam and have demonstrated that significant commercial harvesting of sawlogs can be achieved in a six-year rotation (in southern Vietnam; it will take longer in central and northern Vietnam). This has created an opportunity for further developing our understanding of how best to manage pioneer species like tropical acacias so that their natural growth patterns can be best exploited in a range of silvicultural systems. This forms the basis of the JAF-funded PhD studies being undertaken by Vu Dinh Huong.

P inputs and matching P inputs to soil type

This proved to be a challenging area and it was not possible to develop a secure relationship between levels of extractable P and tree growth. Previous work in Indonesia had shown that there is a strong and significant early growth response of *A. mangium* to P applied at planting up to 150 kP/ha, even on an inherently productive soil, but that in a pulpwood regime, differences between treatments decline and are largely absent at harvest. This is probably related to the intense intra-species competition that develops very early in the growth cycle in acacia plantations. High P inputs at planting were used in this project, both to maximise early growth rates, but to also allow early thinning and to maximise the growth response to early thinning. The significant responses to thinning that were observed at least six months after treatment supported this strategy. These findings can trigger additional research which can advance our understanding of how to match P inputs to soil type and how to most efficiently exploit P inputs in different silvicultural regimes.

The conundrum of planting stock

For solid-wood production, the ideal tree is straight and has small branches. Singling remains an essential practice in acacia plantations for the creation of single stems. This is because these acacia species tend to have moderate apical dominance at best; removal of competing stems and branches artificially transfers dominance to the selected leader. Form pruning higher up the tree was used in this project, first to avoid double leaders in the pruned part of the stem, but also to prevent the development of large branches. While these practices are secure if the pruning interventions are timely, the planting stock used was highly variable. Commonly used BV and TB clones (which have an *A. mangium* female parent) often presented either very poor initial apical dominance and/or an undesirable number of larger branches and double leaders; only clone AH7 (which may have an *A. auriculiformis* female parent; this remains unknown) used at the Phu Binh and Xuan Loc sites consistently demonstrated relatively high levels of dominance and small branches. The problems with poor planting stock were linked to the use of old hedges and inter-nodal rather than tip cuttings; however there were no differences in form between tip cuttings from old and new hedges in an experiment at Nghia Trung. The scientific impact in this area through the project has been to create an awareness of this problem; what is now required is systematic research to tease out the contributing factors that are clone-based and because of cutting practice.

Form and lift pruning

Lift pruning is absolutely necessary for the production of clear or knot-free wood. As this exposes pruning wounds on the stem, best practice is to lift prune only in the dry season to minimise risk of disease entry. This can be made to work if used in tandem with form pruning. The very high rates of growth mean that unwanted form characteristics can develop while you back is turned, and more so during the wet season when rates of growth are high. Tip pruning that removes around 50% of the competing leader or branch length was used in this project for form pruning. This was adequate for controlling branch size and establishing or maintaining dominance in the selected leader and avoided the creation of exposed pruning wounds on the stem in the wet season. These form-pruned branches could then be removed at the stem through lift pruning in the dry season. Observation suggested that there was no penetration of decay down the length of the cut branch between the time of tip pruning and time of lift pruning. This practice would benefit from a systematic and quantitative investigation.

Protecting wood quality

There is already an awareness of the risk that heart rot can develop in acacia plantations. In Indonesia in *A. mangium* plantations, this was to a large extent associated with the presence (low risk) or absence (high risk) of a long dry season. Defined dry seasons of variable length are found throughout Vietnam, but this study has shown that heart rot can still develop and deleteriously affect wood quality. However there appeared to be two major contributing factors (i) large branches and (ii) stem and branch breakage by wind which were exacerbating this problem. The two most affected sites were Nghia Trung which was high risk for wind damage and PT 2 which was medium risk. Both had heart rot and are sites that had planting stock which expressed poor form and developed large branches and a high frequency of double leaders. The tip pruning technique was not applied optimally at either of these sites. The scientific questions that now need to be answered have been well-defined by the project and will in part be answered through the JAF-funded PhD study of Mr Tran Thanh Trang.

Understanding the relationship between growth and function

Two physiological campaigns were undertaken to examine the effects of water stress and P fertiliser on physiological performance measured using gas-exchange techniques and water potential. Three approaches for measuring leaf area index (LAI) or canopy size were also initiated in the first campaign and used to trigger a program of six-monthly measurements of LAI at the Phan Truong Hai trial. Besides generating much useful information, some of which was incorporated into the DSS, the use of these instruments has been consolidated by the inclusion of these types of measurements into three of the four JAF-funded PhD programmes.

Predicting yield and log distribution

The Decision Support System is a first attempt to introduce a system that allows yields of *Acacia* hybrid and its capacity to produce logs in different size classes to be predicted. While there are inevitable restrictions, it provides users with insights into how soil type and environment, and silvicultural inputs e.g. fertiliser and thinning or lack of inputs e.g. inadequate weed control, affect yield and the proportions of pulpwood and saw logs obtained at harvest. The science behind the development of the DSS is in part based on work undertaken both in this project and in other projects which have involved FSIV staff. It provides a platform for developing new science to iron out the uncertainties which are still contained within the DSS, thereby extending its utility.

8.2 Capacity impacts – now and in 5 years

John Allwright Fellowships (JAF)

Four JAFs were awarded during the course of the project as follows:

2008 round: Tran Lam Dong (commenced studies at University of Tasmania in February 2010). Topic "Using *Acacia* as a nurse crop for establishing mixed native-tree species plantations".

2009 round: Vu Dinh Huong (commenced studies at University of Tasmania in February 2012). Topic "Understanding the physiological basis for response to thinning and fertiliser application in short-rotation tropical *Acacia* plantations".

2010 round: Trieu Thai Hung (commenced studies at University of Tasmania in February 2012). Topic "Optimising the economic and carbon values of *Acacia* plantations in Vietnam through silvicultural practice".

2011 round: Tran Thanh Trang (commenced studies at University of Tasmania in February 2013). Topic "The improvement of sawlog quality in acacia plantations by reducing stem defects caused by fungi".

Mr Huong, Mr Hung and Mr Trang were members of the project when they were awarded their scholarships. The immediate effect of their leaving the project (first to meet IELTs requirements and then to come to Australia) is a reduced capacity in the short-term to deliver on project goals as new Vietnamese staff need to be appointed, trained and then learn by experience. The advantage for these now "postgraduate students" is that they can commence their studies under an existing project umbrella and receive support from Australian project staff as they initiate their research programs. This enables them to more quickly build up a capacity to work at the level required in PhD programmes undertaken in Australia than would otherwise be the case for new students from developing countries who have not previously been exposed to training at this level. An issue for CSIRO staff providing associate supervisory support is that when the project finishes, these staff have no formal means within the organisation of continuing to support these students.

In five years these students will have graduated and returned to Vietnam. Their training in a more rigorous research environment than is possible in Vietnam and their exposure to technologies and techniques which are often not accessible in Vietnam increase their competitiveness for more senior positions within their employment organisations from which they can seek to strengthen its scientific credentials, in part by further developing links between Vietnam and Australia.

English training

From the start of the project, a policy was adopted that training would be provided for all Vietnamese staff who were insecure in the use of English. Training was undertaken by Mr Quang, Mr Binh, Mr Dinh, Mr Bon and Mr Kien. This training was of great service to the project and enabled Mr Bon, Mr Quang and Mr Dinh to make presentation about their work in the project in English at the Final Review. This training has also facilitated good communication between Australian and Vietnamese staff within the project. Accepting the principle that when it comes to languages "use it or lose it", if the former, this benefit will be continuing.

Analytical chemistry

The audit (Section 11.4) of the Analytical Laboratory at the Sub-Institute in HCMC triggered a rapid upgrade of the facility. Ms Tuyen who undertook the audit also provided up-to-date training for the analyst Mr Quang both in his laboratory, and her laboratory in Perth, Australia during a two-week training visit in September 2009. This was of immediate benefit to the project and this benefit will be ongoing, notwithstanding new technological advances in this area.

Use of computer software for data analysis

Dr Chris Harwood provided advanced training in the use of EXCEL for all project staff in his visits to Vietnam during during the project. Staff generally had high-level skills in the use of common software packages before this training. However, after this training, they were able to exploit EXCEL in a more disciplined way so that the recording and analysis of data was common to all parts of the project. This skill is ongoing.

Use of physiological equipment

The physiological campaigns were a focus for training local staff in the use of the LICOR LI-6400 (gas exchange); LICOR LI-2000 (Leaf Area Index, LAI) and PMS600 (Water Potential). A visual Guide and photographic images of the canopy were also used to measure LAI. Dr Alieta Eyles, Dr Daniel Mendham and Ms Maria Ottenschlaeger provided in-field training in Vietnam on the use of this equipment. In Australia Dr Eyles and Ms Ottenschlaeger provided training in the use of software for data analysis. An ongoing capacity in the use of this equipment in Vietnam has been developed through the John Allwright programs of Mr Dong, Mr Huong and Mr Hung.

Presentation skills and use of English

Dr Chris Beadle worked with Vietnamese staff to enhance their presentation skills and use of PowerPoint for their presentations at the Mid-term and Final reviews, and at the Field Extension Workshops (Appendix 11.5). He also assisted Mr Huong with his English training as he was struggling to meet the required standard in his IELTS tests. He benefits from tis training should be ongoing.

Other

Australian ACIAR staff Dr Chris Beadle (Mr Dong, Mr Trang), Dr Daniel Mendham (Mr Huong), Dr Auro Almeida and Dr Caroline Mohammed (Mr Hung), and Dr Caroline Mohammed and Dr Chris Beadle (Mr Trang) are currently supervising the postgraduate programmes of the four John Allwright Fellows attached to the project. Mr Dong is in the final year of his studies and in currently writing papers for his thesis under the direction of Dr Chris Beadle and Richard Doyle (Academic supervisor). Increasing the capacity of Vietnamese staff to write in English has been an important activity in the project and this is now being extended to the writing of scientific papers.

8.3 Community impacts – now and in 5 years

The project demonstrated that *Acacia* hybrid plantations can be managed over short rotations for harvestable solid-wood values. The project has also created the necessary products that can allow dissemination of the information necessary to convert viability into reality in the growing sector. The expectation is that benefits or impacts will flow at economic, social and environmental levels.

8.3.1 Economic impacts

Acacia wood is primarily harvested for pulpwood in Vietnam and is exported as wood chips to regional markets. A growing export furniture industry that is also reliant on acacia wood, but where the majority of the required supply is imported, was one of the reasons this project was funded. During the period of project it would appear that the proportion of acacia wood sourced from domestic supplies into the furniture industry remains low; most still finds its way into pulpwood markets. There are many reasons that this is the case (Putzel et al. 2012). A major one is a reluctance of growers to manage their plantations over longer rotations so that sawlog values can be maximised; growers want to realise their investment sooner rather than later. At the Extension Field Workshops, Extension Officers also indicated that it was difficult for them to persuade growers to adopt the new silvicultural practices (pruning and thinning) that would be required for saw-log silviculture. In the short term therefore, the economic impact of the project may be lower than hoped for, at least in the small-holder sector. Greater success may be possible in the private industrial and public sectors.

The Economic Analysis was conducted over a six-year rotation using growth data collected to age 4.5 yr (Section 11.2). Saw-log regimes with either early (age 2 yr) or late (age 3 yr) thinning were compared with two pulpwood regimes, one using the ACIAR Projects silvicultural model, the other the local commercial model. The best NPVs were for stands thinned to either 600 (USD2364) or 450 (USD2631) stems/ha at age 3 yr. The NPVs for the pulpwood regimes were about half these values. This analysis shows that in the absence of factors that downgrade wood quality, with improved silvicultural management, management for saw logs is more attractive than for pulpwood even over a rotation length commonly adopted for pulpwood.

It will inevitably take time to lower the risk factors associated with the use of more intensive silviculture (mainly adoption of good planting stock) and to provide the training for growers through Extension Officers to make it silviculturally. The demand for locally-grown acacia wood for the furniture industry will also be at the mercy of the market. The opening of FSIS's Southern Center of Application for Forest Technology and Science to be managed by Mr Kieu Tuan Dat who led the work at Phan Truong Hai will potentially provide the knowledge and skills to make this happen in southern Vietnam within a five-year timeframe.

8.3.2 Social impacts

The project has employed casual labour to assist with application of treatments. The removal of litter and soil in the inter-row area and their return following application of fertiliser treatments was undertaken by mainly female labour from a Vietnamese ethnic minority group at PT2 in July 10 and July 2011. At Ba Vi this was done by mixed gender members of the local community in May 2010. (Female members of the local community at Ba Vi were also employed to assist with root biomass harvesting associated with Mr Trieu Thai Hung's JAF-funded PhD programme.)

The social impacts of plantation silviculture in Vietnam are far reaching and still evolving (Pinyopusarerk et al., submitted). The acacia estate is still expanding. The social impacts of this project are therefore likely to be positive within a five-year timeframe if its findings are applied more widely so that a significantly greater proportion of this estate is managed for solid-wood products by 2017. This will lead to more opportunities for employment of labour to undertake silvicultural operations and greater returns to growers.

8.3.3 Environmental impacts

Acacia hybrid, the focus of this study, is a naturally occurring hybrid of *A. mangium* × *A. auriculiformis*. It was chosen for this project because it has become the dominant plantation species for commercial planting since the late 1990s in Vietnam due to its fast early growth, wide adaptation to degraded soils and available product markets, particularly pulpwood. In the prevailing cutting rotation of about five-to-six years this leads to a mean annual increment (MAI) of between 20 - 30 m^3 ha^{-1} yr^{-1} on sites that are well-managed.

Mr Tran Lam Dong, the 2008-round John Allwright Fellow recruited by this project first investigated the potential for these *Acacia* hybrid plantations managed for pulpwood to ameliorate degraded soils in Central Vietnam; one-quarter of the area of Vietnam is at risk of soil degradation because of "Agent Orange" and unsustainable logging practices between the 1960s and 1980s. The following is extracted from the Abstract of a paper he has submitted to Soil Research.

"In this study, the effect of these plantations on the chemical and physical properties of degraded gravelly soils in Central Vietnam was assessed. Soil samples were collected from second- or third-rotation plantations representative of five age classes (0.5- to 5-years old), and in adjacent abandoned lands as controls. Compared to abandoned land, concentration of total soil carbon was only significantly higher in the five-year-old plantations; there were no significant differences in total nitrogen. Soils under plantations had significantly higher concentrations of exchangeable calcium, magnesium and sodium, and electrical conductivity, and lower bulk density; extractable phosphorus and exchangeable potassium were not significantly different; pH was significantly lower under plantations in some age classes. After correction for gravel content and bulk density, total carbon and nitrogen stock became significantly higher in some age classes of plantations. Most soil properties did not change significantly with plantation age, although they appeared to decrease during the first three years; total carbon then recovered to initial levels, but exchangeable cations remained lower. Some soil properties were strongly related to gravel content and elevation, but not with growth rate. We concluded that consecutive plantings of short-rotation *Acacia* hybrid on degraded and abandoned land can lead to changes in some soil properties. In gravelly soils, care is needed in nutrient accounting as changes in soil nutrients in the <2 mm fraction may not equate to changes per hectare after correction for gravel content."

These results suggest that *Acacia* plantations can deliver positive environmental benefits; as plantations managed for sawlogs will be managed over longer rotations (7-8 years in southern Vietnam, longer in central and northern Vietnam), these benefits should accrue at a faster rate. Evidence from work done in other environments with planted acacias supports this contention.

8.4 Communication and dissemination activities

Three field extension workshops were held towards the end of the project:

- Dong Xoai (14th-15th December 2012)
- Dong Ha (18th May, 2012)
- Ba Vi (21st -22nd May 2012)

Lists of Participants

Table 8.1 The following table summarises the attendance at each workshop.

	Growers	Extension	Technical - private	Technical-public	Managers	Students	Research	Other
Dong Xoai	8		9	4	1	5	8	3
Dong Ha	1	7			13		9	
Ba Vi	2		4		7		12	1

Plate 7.9: FSSIV's Mr Dat demonstrating correct practice in lift pruning at the Dong Xoai workshop (left); and Director, Dr Dung, answering questions at the Dong Ha workshop (right)

Presentations were given by the Vietnamese staff of the project. Dr Chris Beadle introduced the project at the start of each workshop. As Mr Quang was on a training course in Korea, Dr Chris Beadle presented the information on soils on his behalf; these talks were simultaneously translated into Vietnamese. At the workshop in Ba Vi, content on work being undertaken by the Research Centre for Forest Tree Improvement through ACIAR Project FST/2008/007 was also included. A full list of all the attendees, a summary of all the presentations at the workshops, and of the respective field visits is given in Section 11 (Appendix 11.4).

A feature of all workshops was a willingness of participants to engage and comment on the information being presented. The longest Discussion session (1.5 hours) was held at Ba Vi. Much of the comment at all sites revolved around the practicalities of applying the technologies and silvicultural techniques that were being promoted, but there was general agreement that attempts should be made to introduce these new practices. The following summarise some of the key points made:

- Seedling or cutting quality has a large effect on the growth and form of the tree;
- Slash retention enhances fire and termite risk;
- *Acacia* hybrid is vulnerable to wind damage and it may be necessary to review where this species is planted;
- An economic analysis is crucial for creating confidence that management for sawlogs over longer rotations will increase the income of growers;
- The rules that need to be followed to obtain FSC certification need to be clarified, particularly in relation to application of chemicals;
- Extension Officers find it very difficult to persuade small-holders grower to apply silvicultural practices which require timely interventions; this also included slash retention.

Comment on "farmer capacity building component" of project

- Small-holder/farmer attendance at the three Field Extension Workshops was less than desirable. In part this was related to the need to offer a financial payment to ensure their attendance. For those farmers that did attend the workshops, it was difficult to get their active participation.
- The statistics show that small-holder farmers are responsible for about half of Vietnam's wood production. However it is important to appreciate that this is facilitated first by the granting of land for tree growing by the Government, and then a link to a Forest Enterprise either in the public or private sector. The Forest Enterprise will then work on a profit-sharing arrangement with the small-holder and may provide resources

like planting stock. Technical support is provided through Extension Officers who are funded at the provincial and district level.

- Vietnam does have a National Forestry Extension Centre based in Hanoi. This Centre can distribute resources to Extension Officers. It is the intention to distribute the Decision Support System, Economic Model and Technical Information Sheets from this project through the Centre. A better model for future ACIAR projects with farmer capacity building components would be include the Extension Centre or selected Provincial Offices providing extension services as project participants. The Centre or Provincial Office would organise “Train the trainers” workshops where we engage with Extension Personnel (the Trainers) and train them in the use of resources developed by the project. The Extension Officers then take these resources out to the small-holder farmers.
- The Discussion section above raises an important point. Extension Officers find it very difficult to persuade small-holder growers/farmers to apply silvicultural practices which require timely interventions; this also included thinning/pruning and slash retention. A suggested way of dealing with this is to develop a network of demonstration plantations which Extension Officers can use to illustrate best practice.

This model should enable ACIAR to better meet its reporting requirements under the Government’s Comprehensive Aid Policy Framework but would also require a greater proportion of the total investment going into this part of project delivery than is currently the case.

9 Conclusions and recommendations

9.1 Conclusions

The project developed new or enhanced existing knowledge in a range of areas of relevance to the production of high-value sawlogs from *Acacia* hybrid plantations in Vietnam. This was made possible by the establishment of 11 new experimental trials variously located southern, central and northern Vietnam; all included slash retention, chemical weed control to at least age 2 years, and except at one site the application of 50 kg/ha P at or near planting:

- The most productive sites were those with the highest total C and N contents. There was no relationship between productivity and extractable P content which was related to the P-fixing capacity of the soils. Even on basalt soils which are productive and have large stores of fixed P, there was a strong response to application of P at planting (Figure 9.1);


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Plate 9.1: A demonstration of a significant growth response to the application of 50 kg/ha P (right) at planting on a basalt soil at Nghia Trung seven months after planting; no fertiliser was applied to trees on the left

- 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 years; in Central Vietnam it was 7.3 cm, and in the north 6.3-6.5 m to age 2 years;
- Significant responses to thinning from 1100 to either 600 or 450 stems/ha were common across all sites when the trees were thinned at either age 2 or age 3 years. This enables harvestable products that include a significant proportion of sawlogs to be obtained in an approximately six-year rotation in the south; in the north the rotation length will be longer, possibly around nine years;
- A role for application of P and basal fertiliser at thinning was site dependent. Significant responses were sometimes observed in the north, but not at the sites in the south where the P applied at planting appeaeds to saturate the sites for the duration of the rotation;
- Light-saturated photosynthetic rate, declined throughout the morning and early afternoon in the dry season; in the wet season, levels remained high and relatively constant throughout most of the day. Trees were able to continue to extract soil water such that pre-dawn ψ remained >-1.5 MPa even at the end of the dry season. The results suggested that while *Acacia* hybrid is well-adapted physiologically to drought,

its growth is likely to be compromised in environments associated with extended dry seasons;

- The very high growth rates were associated with the development of multi-stemming (Figure 9.3) and large branches. Stock type also appeared to influence the expression of form and branch size. Timely form pruning was essential to allow the retained leader to rapidly establish apical dominance;

Plate 9.2: The price of not singling *Acacia* hybrid is poor form and multi-stemming

- Form- (tip) and lift-pruning were successfully combined to develop trees that would maximise the production of saw logs. Stock types associated with the development of poor form and large branches require multiple interventions to produce a straight pruned log. However such stock types will still produce large branches and double leaders above the pruned log; these characteristics appeared to be associated with branch and stem breakage;
- Branches and stem breakage at Phan Truong 2 and Nghia Truong were associated with the development of stem defect and heart rot. This expression of stem defect may have been associated in part with poor planting stock, less than optimal pruning and strong wind events. Besides being more aware and responding to these deficiencies, use of planting stock with genetic tolerance to fungal organisms that cause heart rot would be an additional management strategy to ensure consistently low levels of stem degrade;
- *Acacia* hybrid is susceptible to strong winds and all sites used in the ACIAR trial were vulnerable to a greater or lesser extent. Knowledge of the likelihood of wind damage events as well as optimising planting stock and silviculture is essential if *Acacia* hybrid is to be successfully and commercially grown on such sites. If the wind damage risk is too high, the slower-growing but more wind stable *A. auriculiformis* might be a better choice;
- The experimental information collected during the project was used to develop Technical Information Sheets, a Decision Support System and an Economic Analysis of contrasting silvicultural regimes. These “tools” are designed to enable the creation of a greater understanding of best practice in the field, of how site and silvicultural factors affect yield, and the relationship between management decisions and financial returns in competing pulpwood and saw-log regimes. The package is designed to be used by Extension Officers so that they can be best informed when providing advice to growers of *Acacia* hybrid;
- In the absence of factors that downgrade wood quality, with improved silvicultural management, management for saw logs is financially more attractive than for pulpwood over a six-year rotation, a length commonly adopted for pulpwood.

9.2 Recommendations

Forest products are likely to remain a valuable source of income for rural communities and important contributors to poverty alleviation in Vietnam. The Vietnam Government through its Ministry of Agriculture and Rural Development recognises the need to reduce the reliance of its wood-processing and particularly its furniture industries on imported acacia logs. The project has provided the knowledge and resources to make this possible. To make this a reality the following actions are recommended:

1. **FSIV should hold "Train-the-trainers workshops" for Extension Officers in the practice of silviculture for acacia saw-log production. The primary teaching aids would be the Technical Information Sheets, Decision Support System and Economic Analysis;**
2. **The establishment of demonstration plantations that illustrate best practice should be established in provinces which can make a significant contribution to acacia sawlog supply through the small-holder sector. Extension Officers would use these plantations to illustrate these practices to client small-holders.**

Acacia hybrid is now the most planted species in Vietnam. While the silvicultural practices developed by the project can lead to the production of high-quality sawlogs, the following factors associated with site and silviculture should be noted:

- *A.* hybrid is susceptible to damage from high wind events;
- *A.* hybrid is often established using unsuitable planting stock.

Both hazards lead to poor form which is difficult to manage and increases the risk of stem defect and heart rot which are not acceptable in sawlogs. The following is recommended:

3. **Sawlog plantations using *A.* hybrid should only be established using tip cuttings from young clonal hedges;**
4. **Sites that are vulnerable to frequent high wind events should not be used for *A.* hybrid plantations to be managed for sawlogs.**
5. **FSIV should develop research programmes that focus on (i) the relationships between hedge age, cutting type (tip or intermodal) and cutting frequency on the expression of form and branch size; and (ii) factors that contribute to resistance to high winds and stem breakage.**

Acacia auriculiformis may be a more suitable species on wind-prone sites as it has lighter branching which is less susceptible to breakage. However its growth rate is slower than that of *A.* hybrid.

Because of competition for land and changing climates, forestry will need to be adapted so that it is not compromised by lower levels of productivity associated with a likely shift to more challenging growing environments. To respond to this possibility, the following is recommended:

6. **Research opportunities for adapting acacia and eucalypt species and planting stock to both drier sites and future climates, in the context of their management for wood production and value, and carbon and water-use efficiency should be developed. An important outcome would be a more robust and stable source of income from forest products for rural populations. This course of action aligns with a current FSIV/VAFS priority "Development of technologies for afforestation of sandy soils to reduce desertification of coastal areas of Central Vietnam". Such a project is also of relevance to neighbouring Cambodia and Laos.**

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Eyles, A., Drake, P., Quang, L.T., Bon, P.V., Mendham, D., White, D., Dat, K.T., Dung, P.T., Beadle, C. (submitted). Ecophysiology of three *Acacia* spp. in wet-dry tropical plantations. *Annals of Forest Science* (in review).

At the final Business and Planning Meeting of the project in September 2012 it was agreed that the following additional papers would be written; those with asterisks still require the collection of additional data.

1. Lead author: Chris Beadle

Title: Physiological responses to phosphorus supply in tropical plantation acacias

Summary: Uses results from Nghia Trung collected in the second physiological campaigns

2.* Lead authors: Pham Van Bon and Chris Harwood

Title: Effects of clone, cutting age and P fertiliser on the expression of growth and form at age one year in *Acacia* hybrid

Summary: Based on results from new trial at Nghia Trung

3. Lead author: Pham Xuan Dinh

Title: Growth of *Acacia* hybrid under intensive management to age 2 years at seven sites throughout Vietnam

Summary: Based on results from Satellite trials

4.* Lead authors: Kieu Tuan Dat and Vu Dinh Huong

Title: Growth and leaf area responses of *Acacia* hybrid to timing and intensity of thinning in southern Vietnam

Summary: Based on results to age 5 years at PT2

5.* Lead author: Trieu Thai Hung and/or Vu Tien Lam

Title: Growth responses of *Acacia* hybrid to thinning and fertiliser in northern Vietnam

Summary: Based on Core Fertiliser trial at Ba Vi

6.* Lead author: Trieu Thai Hung and/or Vu Tien Lam

Title: Growth responses of *Acacia* hybrid to timing and intensity of thinning in northern Vietnam

Summary: Based on Core thinning trial at Ba Vi

7. Lead author: Daniel Mendham

Title: CABALA-based decision support system for growing *Acacia* hybrid in Vietnam

Summary: Based on results to date from all trials

8. Lead author: Tran Thanh Cao

Title: An economic analysis of *Acacia* hybrid production across a range of environments in Vietnam

Summary: Based on results from PT2 and current economic data, costs and prices

9. Lead author: Tran Thanh Trang and Caroline Mohammed (in preparation)

Title: The incidence and severity of heart rot in *Acacia* hybrid grown for solid wood in Vietnam

Summary: Based on results from trials at Nghia Trung and PT2

11 Appendixes

11.1 Appendix 1: Decision Support System

Australian Centre for International Agricultural Research (ACIAR)

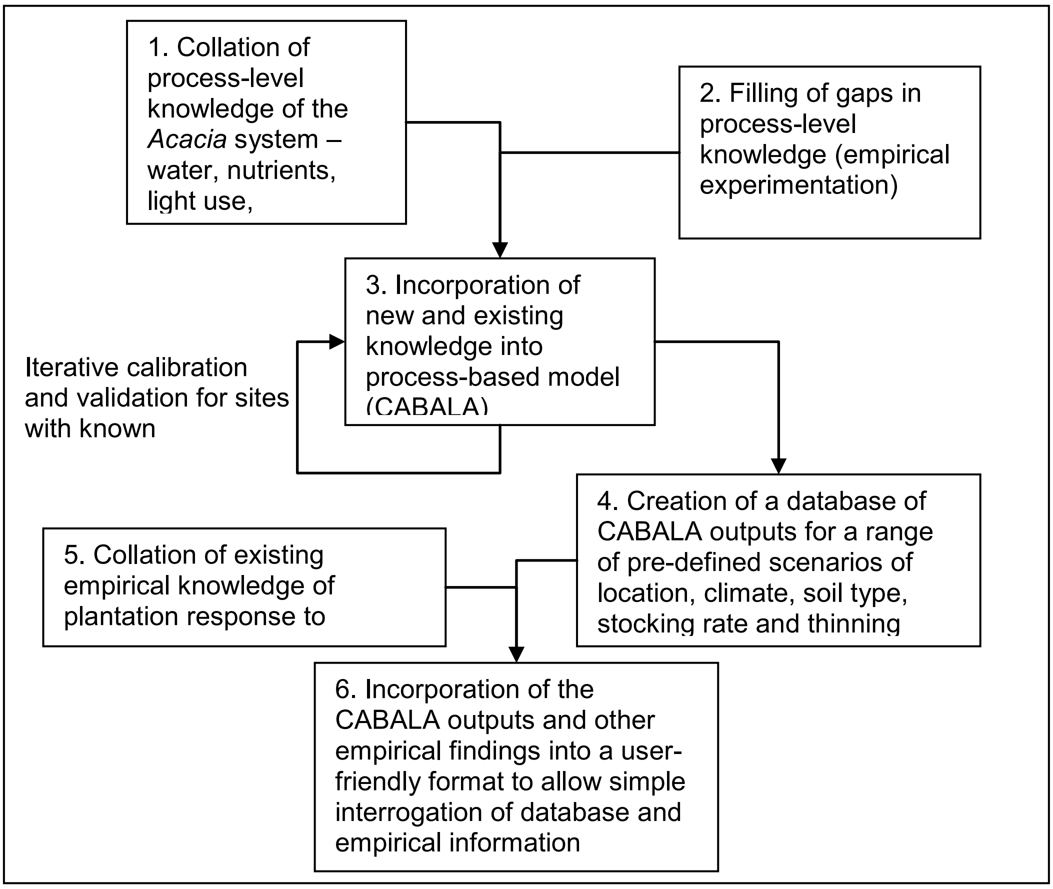
FST/2006/087. Optimising silvicultural management and productivity of high quality acacia plantations, especially for solid wood

Decision Support System for solid-wood production from *Acacia* hybrid plantations

Design and development

A **D**ecision **S**upport **S**ystem (DSS) has been developed to assist in presenting the findings of this project in a user-friendly format. This DSS is built on our existing knowledge. Considerable gaps remain in that knowledge and this must be noted. This is a work-in-progress and a prototype DSS. This version is therefore probably more useful as a research tool until greater confidence and understanding of the key factors affecting growth of *Acacia* hybrid in plantations managed for solid-wood production have been developed. Extension Officers should therefore use the DSS with caution when providing recommendations to growers. Key steps in the development of the DSS are shown in Fig. 1

Fig. 1 – Flow-chart of DSS development steps. CABALA is a processed-based model of forest growth (Battaglia et al., 2004).



The activities in each of these steps are detailed below:

1. Collation of existing knowledge of the Acacia system

Temperate *Eucalyptus* plantations were the initial focus of this modelling. ACIAR-funded activity in tropical *Acacia mangium* plantations in Indonesia and northern Australia provided the starting point for adapting the model to work in acacia plantations. Key system attributes that needed further development were as follows:

1. *Nitrogen fixation*. The nitrogen (N) fixation model from the *A. mangium* work was used for modelling *Acacia* hybrid (*A.* hybrid). It is assumed that N fixation can occur if N is a potential limitation to plant growth, but N fixation has a carbon cost, which is dependent on the soil temperature. The carbon cost is typically between 7 and 12 g C/gN fixed.
2. *Allometrics and volume models.* The volume models required refinement using data from a range of experiments in Vietnam.
3. *Experimental information.* Data from a range of experiments with *A.* hybrid, including weed control, timing of planting, stocking rate, and pruning effects on survival and productivity.

2. Filling of gaps in knowledge

Key gaps in knowledge identified were concerned with the physiological responses of *A.* hybrid to environmental conditions. We focused on improving our understanding of:

1. The rates of gas exchange (photosynthesis and stomatal conductance) and dynamics of water stress under the different thinning and fertilizer treatments, and how these compare to other acacia species studied previously.
2. The dynamics of leaf area index (measured as leaf area per unit ground area) over time, and with thinning treatment.
3. The growth responses to different thinning treatments.

The outcomes from earlier studies have been reported previously. Physiological outputs from this project have been submitted for publication (Eyles et al., submitted).

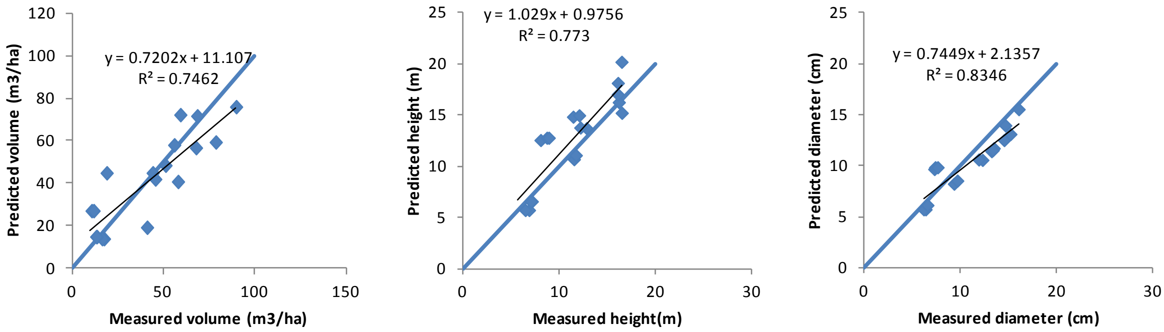
3. Development of CABALA for application in A. hybrid plantations

Key changes to the CABALA parameter set for *A.* hybrid included the following:

1. Photosynthetic rates and conductance parameters were modified in line with our measurements.
2. The tolerance of the trees to cold stress required significant amendment, as growth at the sites in the north of Vietnam appears to slow markedly during the cooler months.
3. Respiration rate parameters needed to be adjusted to reflect the situation in *A.* hybrid plantations.
4. The water stress parameters were modified such that *A.* hybrid is less susceptible to water stress than *A. mangium*, but more susceptible than *Eucalyptus* species.
5. Plant tissue nitrogen concentrations were maintained at the same levels as the *A. mangium* parameter set.
6. Foliage and fine-root turnover times were decreased compared to *Eucalyptus* to reflect the faster turnover and canopy lift observed in *A.* hybrid plantations.
7. Allometrics and structure variables were modified to represent measurements in *A.* hybrid plantations, including the volume model, the relationships between sapwood area and leaf area, and the allocation to bark.

Other minor changes were also made to the *A.* hybrid parameter set.

Fig. 2 – Preliminary CABALA predictions *v.* observed *A.* hybrid productivity across the project experimental sites.



Model outputs of volume, height and diameter were calibrated against the observed data from the ACIAR project experimental sites which were located throughout Vietnam. All sites had optimal P fertility, a consistent approach to management and the same range of thinning treatments. The model adequately represented measured productivity across this range of sites (Fig. 2), but the current data set was found to be limiting because the stands were quite young at the end of the project in 2012 (measurements were all taken on trees that were around 3-years old or less). To improve model predictions to full rotation length, a selection of published *A. hybrid* productivity values from sites similar to the ACIAR sites were used (Que, 2010) to refine the model so that it was more accurately able to forecast observed productivity. This approach has limitations because the sites used by Que (2010) were not well characterised for fertility or water-holding characteristics, and their management was less well defined. This limited its utility for modelling the upper limits of productivity.

Whilst CABALA is able to predict productivity reasonably well, and it has been validated to the best of our current ability at the sites that have been accessed, significantly improvements can be made in the future by being able to incorporate full-rotation length information on the existing range of ACIAR sites and treatments.

4. Creation of the database of CABALA outputs

The combination of model inputs (climate, soil types, stocking and management options) to create the database was chosen based on experimental results from the project and other empirical knowledge. The key factors in this version of the DSS are:

4.1 Climate

Due to the limited nature of the current calibration of CABALA, the first version of the DSS has been developed for the **three** regions where there was capacity to perform some level of validation. This was based on the Tuyen Quang (north), Quang Tri (centre), and Dong Xoai (south) weather stations. Average monthly information was used from these stations.

4.2 Soil types

Although our experiments were only conducted on a limited range of soil types, we were able to use expert knowledge to increase the range of soil types available populate the DSS tables, and to include the **four** main soil types used in the south (Acrisol, Basalt, Alluvial and Ferrosol) and the **two** main soil types in the north (Ferrosol and Alluvial).

4.3 Planting densities

Four of the commonly used planting densities in *Acacia* plantations in Vietnam were entered as inputs to the model as follows:

- 3 x 3 m spacing (1111 stems/ha)
- 4 x 2 m spacing (1250 stems/ha)
- 3 x 2 m spacing (1667 stems/ha)

- 2 x 2.5 m spacing (2000 stems/ha)

4.4 Thinning regimes

Five of the key thinning regimes arising from this project that we feel are likely to be beneficial to farmers were programmed into the DSS as follows:

- Not thinned
- Lighter thinning at age 2 (to 830 stems/ha)
- Moderate thinning at age 2 (to 600 stems/ha)
- Heavier thinning at age 2 (to 450 stems/ha)
- Lighter thinning at age 3 (to 830 stems/ha)
- Moderate thinning at age 3 (to 600 stems/ha)
- Heavier thinning at age 3 (to 450 stems/ha)

4.5 Database creation

CABALA was used to simulate a factorial combination of the above combinations of climate, soil type, planting density and thinning regime (ie. a total of 216 unique scenarios), and the predicted volume, height and diameter were used in the DSS.

5. Collation of other empirical information

Other information was incorporated into the DSS at an empirical (rather than process) level. This is important because it can influence the way that farmers use the information presented from the process-level side of the DSS. Key information included the effect of planting time, P fertilizer, singling/pruning and weed control on stand productivity and survival, and each of these parameters can independently modify the productivity, survival and saw-log yield predictions, with the modification represented by a proportional value (usually in the range 0-1) to which the process-based outputs are multiplied. Note that these values are multiplicative in the DSS.

5.1 Planting time

Table 1 – Influence of planting time on the predicted volume yield, sawlog yield and survival used in the DSS.

Planting times	proportional effect on volume	proportional effect on sawlog yield	proportional effect on survival
Early wet season	1	1	0.97
Mid wet season	0.95	1	0.97
Late wet season	0.9	1	0.92

It has been shown that planting early in the wet season leads to greater survival and greater yield as it gives the young trees the best opportunity to occupy the site before the onset of the dry season. Some experimentation conducted by FSIV (Duyen 2008) suggested that planting in the late wet season compared to the early-mid wet season can result in a decline in survival of around 5%, and a reduction in final productivity of around 30%. The reduction in final productivity seems quite extreme, so this was modified in the DSS to result in a productivity decline commensurate to the survival. This issue needs further testing to allow more accurate output in regard to planting time. The modifying factors used are shown in Table 1.

5.2 P fertilizer

The direct effects of P fertilizer on yield have not been tested thoroughly as yet, but observationally through our project we have shown that P fertilizer can have a large influence on volume yield and indirectly on sawlog yield through increasing the branchiness of the plantations. These influences are captured through the modifiers as shown in Table 2.

Table 2 - Influence of P fertilizer on the predicted volume yield, sawlog yield and survival used in the DSS.

Fertiliser at establishment	proportional effect on volume	proportional effect on sawlog yield	proportional effect on survival
With phosphorus fertilizer	1	0.9	0.95
No phosphorus fertilizer	0.9	1	0.95

5.3 Singling/pruning

The stage of singling and pruning can be important for determining the quality of the final log, as delayed singling and pruning can result in the need to prune larger branches, which degrades the quality of the log for sawing through larger knots and more likelihood of disease entry. The modifying factors used in the DSS are shown in Table 3.

Table 3 – Influence of singling/pruning stage on predicted volume yield, sawlog yield and survival used in the DSS.

Singling/pruning stage	Proportional effect on yield	Proportional effect on sawlog yield	proportional effect on survival
< 2 cm diameter branches	1	1	1
> 2 cm diameter branches	1	0.7	1

5.4 Weed control

Weed control can influence both survival and yield, and the key information used in the DSS was based on the study of Huong et al. (2008), that examined the influence of a range of weed control treatments on productivity and survival of *A. auriculiformis* at a site in southern Vietnam. The factors used in the DSS are shown in Table 4.

Table 4 – Influence of weed control on predicted volume yield, sawlog yield and survival used in the DSS.

Weed control	Proportional effect on yield	Proportional effect on sawlog yield	proportional effect on survival
pre-planting only	0.61	1	0.88
strip weed control 2x per year	0.94	1	0.99
complete, 1 x per year	0.89	1	1
complete, 2 x per year	1	1	1

5.5 Self thinning

Self thinning is a prominent feature of acacia plantations, with a significant proportion of all stands being lost due to self-thinning. Table 5 shows the self-thinning rates used in the DSS for different stocking rates. These were selected based on typically observed residual stocking rates at age 8 years.

Table 5 – Influence of treatment on self-thinning applied in the DSS.

Stocking/thinning regime	Mortality per year after year 3 (%)
Unthinned, planted at 2000 stems/ha	6
Unthinned, planted at 1667 stems/ha	5
Unthinned, planted at 1250 stems/ha	3
Unthinned, planted at 1111 stems/ha	2.4
Thinned to 830 stems/ha	3
Thinned to 600 stems/ha	2
Thinned to 450 stems/ha	1

5.6 Thinning age effect

Our project experiments have shown that earlier thinnings may be more effective than later thinnings because they allow the stand to stay in its rapid growth phase for longer, but this effect is not currently well understood at a process level and so we won't be able to incorporate it into the model until we understand the mechanism further. In the interim, we have included an empirical relationship into the DSS to account for this effect, as shown in Table 6.

Table 6 – Influence of thinning age on final yield as used in the DSS

Thinning age	Multiplier
2	1
3	0.9

6. Development of the DSS framework

The DSS was developed in an Excel spreadsheet format which is readily accessible to most computer users. The spreadsheet format allows for a simple and transparent approach so that users can see how the information is sourced and the manipulations that are being performed on it to produce the final outcome. Macros are not used so that users do not have to be concerned about security of the workbook. The DSS is structured so that information is provided on key worksheet tabs as follows:

6.1 'Welcome'

Is an opening screen that lists the authors and attributions (including ACIAR).

6.2 'Read me first'

Provides a brief description of the DSS, and a list of the key assumptions and known shortcomings of the current version.

6.3 'Disclaimer'

The disclaimer explains that all care but no responsibility can be taken by the developers

6.4 'Productivity Prediction'

This is the key page where users can characterise their site and management, and where the tool provides the corresponding outputs. Fig. 3 shows the key input screen, where the user can choose (from drop-down lists) the province that they are interested in modelling, the soil type (dependent on province), the planting density, the planting time, P fertilizer use, Singling/pruning phase, thinning regime (age and intensity), weed control and rotation length. The interface allows the user to compare two different scenarios.

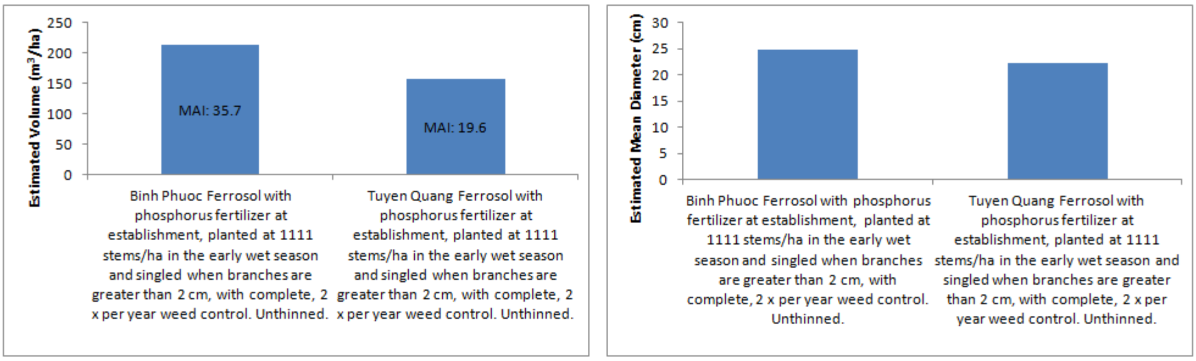
Fig. 3 – The key input screen of the '*Acacia* hybrid Productivity Predictor' for characterising the site and management variables for the two scenarios. The 'planting time' options are shown in the drop-down list for Scenario #2.

	Scenario #1	Scenario #2	
Province	Binh Phuoc	Tuyen Quang	**Different Province
Soil type	Ferrosol	Ferrosol	
Planting density (stems/ha)	1111	1111	
Planting time	Early wet season	Early wet season	
P Fertilizer at establishment	With phosphorus fertilizer		
Singling/pruning when branches are:	greater than 2 cm		
Age at thinning	Unthinned		
Thinning intensity	Unthinned		
Weed control	complete, 2 x per year		
Rotation length	6	8	**Different Rotation length

Early wet season
Mid wet season
Late wet season

The DSS updates the output each time a different value is chosen from one of the drop-down lists, with the output available in graphical (Fig. 4) or tabular format. At this stage, the predictions are for the total standing volume.

Fig. 4 – Example output - predicted volume and mean diameter for the chosen scenarios.



The system then allows the user to classify the logs into **four** size classes, and the minimum billet lengths that the market will take for each size class. Fig. 5 shows the format of the size-class information that is required for the DSS.

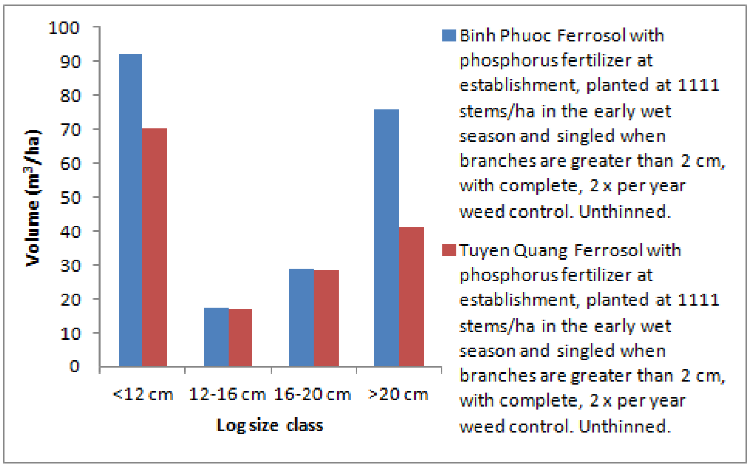
Fig. 5 – Size class input cells. Yellow highlighted cells require input from the user.

		size range	Minimum billet length
Log class 1 upper diameter	12	<12 cm	1.2
log class 2 upper diameter	16	12-16 cm	1.2
log class 3 upper diameter	20	16-20 cm	1.2
Log class 4		>20 cm	2

The system uses a conical approximation to estimate the proportions of log lengths and volume that are within each size class for a given output. Note that this works on average output of height and diameter only, so it is necessarily going to provide a crude estimate only of the proportions of logs likely to be recovered in each class.

Fig. 6 – Example of output of estimated log recovery in each of the log size classes.

Estimated log recovery (m^3/ha)	Scenario 1	Scenario 2
<12 cm	92.1	70.5
12-16 cm	17.5	17.1
16-20 cm	28.9	28.2
>20 cm	75.8	41.0



The DSS does not explore the economic returns from the different options, but these outputs should help growers to estimate the value of logs recovered under the different scenarios.

6.5 'Sawlog calculations'

This sheet is for calculations only and does not directly require the user to input any information. The outputs from this sheet are presented in the previous 'Productivity prediction' worksheet. The user can, however, follow the steps taken by the DSS in calculating the volumes of the different size class logs that are predicted to be recovered.

6.6 'Output database'

This worksheet holds tables of CABALA outputs for volume, diameter and height.

6.7 'Info tables'

This worksheet is where the empirical relationships (see section 5 above) are stored, and the calculations that populate the drop-down lists are also contained here. This sheet can be viewed by the user, but **should not be modified** unless the user wants to explore the inner-workings of the DSS.

Summary

The DSS we have produced in this project is a first attempt to allow growers to quantify the likely productivity and log yield of a range of silvicultural options and at a range of site types in Vietnam. The system is open for future modification, and would benefit from further improvement. Key assumptions that are explicit (see 'Read me first' tab of the spreadsheet DSS) include that (1) the latest genetic material is used for the planting stock, and clonal material is sourced from young hedges, and (2) the site is suitable for acacia growth, for example it is not prone to waterlogging.

Other known limitations of the DSS include the following:

1. The confidence in the model predictions could be improved by expanding its validation to a larger range of sites and conditions
2. The volume and sawlog recovery model uses a simple conical function and needs further work. The actual composition of sawlogs may vary markedly to those predicted

depending on this model, but also on the timing and accuracy of management operations.

3. The empirical data on (1) response to establishment fertilizer, (2) response to weed control, (3) planting at different times of the year, (4) responses to singling and pruning are based on experiments at few sites and/or expert knowledge, and the results may not necessarily extrapolate very well to other situations.
4. The climate information used in the model is for long-term average monthly conditions, and doesn't account for extended droughts or wet seasons

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Daniel Mendham

Vu Dinh Huong

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11.2 Appendix 2: Economic Analysis

Australian Centre for International Agricultural Research (ACIAR)

FST/2006/087. Optimising silvicultural management and productivity of high quality acacia plantations, especially for solid wood

Economic analysis for for solid-wood production from *Acacia* hybrid plantations

Tran Thanh Cao, Pham Van Bon, Kieu Tuan Đat

Summary

This analysis was based on the Core experiment at Hai Vuong Joint Stock Company's Phan Truong 2 Estate in Binh Phuoc province. There were three stockings after thinning (1100, 600 and 450 stems/ha) and two times of thinning (age 2 and age 3 years). An adjacent commercial plantation was also included. Growth data was collected on eight occasions from 2009 to 2013. Prices and costs are those for 2012. At age 6 years, standing volume remained the highest in the unthinned treatments. However sawlog values had developed in the thinned treatments; there were no sawlog values in the unthinned treatments. For a 7 financial-year rotation, the highest NPV (USD1,601/ha) was found for the 450 stems/ha treatment when the stand was thinned at age 3 years. The lowest NPV (US1427/ha) was found for the commercial pulpwood plantation. NPVs for the other regimes were intermediate. Wood price had the greatest impact on financial returns to growers; discount rate was next in importance and then thinning practice. The results of this economic analysis analysis can be used for Extension Officers to advise growers about the most attractive regimes for producing sawlogs from *Acacia* hybrid plantations.

Glossary

Dbh	Diameter over bark at breast height
IRR	Internal rate of return
NPV	Net present value
BCR	Benefit-cost ratio
PT2	Hai Vuong Joint Stock Company's Phan Truong 2 Estate
P	Price
Lbrs	Labour
450/2-year	thinning at 2 years to 450 trees/ha.
450/3-year	thinning at 3 years to 450 trees/ha.
600/2-year	thinning at 2 years to 600 trees/ha.
600/3-year	thinning at 3 years to 600 trees/ha.

Introduction

To date, plantations in Vietnam have been managed primarily for growth rate and pulpwood. Rotation lengths for *Acacia* plantations are short (5-7 years) and the returns to growers from pulpwood are relatively low. To improve the financial attractiveness to smallholders of growing plantation acacias, the project of "Optimising silvicultural management and productivity of high-quality acacia plantations, especially for sawlogs" was implemented. The project targeted the development of silvicultural practices that used thinning to enable a high yield of sawn timber products. Intensive silviculture requires higher levels of investment than for pulpwood and the economic benefits remained uncertain. The project therefore needed to identify the best silvicultural model that maximizes the economic benefits of saw-log production. This requires linking factors that affect economic return to an optimisation of rotation for length. This report presents economic analyses based on: (1) yield prediction; (2) silvicultural regimes; (3) a sensitivity analysis with wood prices, yields and discount rate, and (4) optimising rotation length.

Methods

3.1 Establishment of trial

The Core trial was established at a two-month-old second-rotation site at Hai Vuong Joint Stock Company's Phan Truong 2 Estate. This site is located in Binh Long district, Binh Phuoc province in a region of south-east Vietnam that has potential for saw-log production.

3.1.1 Experimental design

There were three thinning treatments (1143 [nominal and also stocking in adjacent commercial plantation], 600 and 450 stems/ha and two thinning times (age 2 and age 3 years). Square net plots (as best as possible) were used. The spacing is nominally 3.5 m × 2.5 m. The net plots are 6 rows* wide (21.0 m). The seven trees that nominally occupy each row would deliver a 17.5 m net-plot row length. However, the non- uniform spacing within the row meant that that the net row length was 2 m less at either end of the plot than the gross-plot row length (i.e. 22.5 m minus 4 m = 18.5 m); the gross plot size was 28.0 m × 22.5 m.

3.1.2 Planting

The techniques used for site preparation and planting were standardised for ACIAR experimental plantations (Table 1). Form (tip) pruning, lift pruning and thinning were not done in the commercial plantation.

3.2 Data

Growth data was collected on eight occasions (Table2). Economic data were collected from An Hoa and Nhu Y Ngoc companies in 2012 which are 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 including standing wood price, wages for processing wood, harvest expenditure, transport, wood price at the sawmill gate and historical fluctuations in wood price. This information was collected by interview.

Table 1. Dates of measurement (x) for two thinning treatment

Measure date	Age (years)	2-year thinning	3-year thinning
21/10/2010	2.2	x	
14/02/2011	2.5	x	
19/07/2011	2.9	x	x
16/10/2011	3.2	x	x
23/02/2012	3.5	x	x
10/07/2012	3.9	x	x
20/03/2013	4.6	x	x
30/06/2013	4.9	x	x

Table 2. Planting, maintenance and thinning strategies applied at Phan Truong 2

Regimes	Site preparation	Planting	Fertiliser	Maintainance and weed control	Pruning and thinning
Commercial	Cut and remove all vegetation	Stock: *Acacia* hybrid cuttings. Spacing: 3 m x 3 m Pit planting: 30 x 30 x 30 cm hole	Fertilizing at planting: none Fertilizing after planting:80 kg of NPK/ha in 1st year.	1st year: Combination of ploughing and manual (twice) 2nd year: 4 litres of glyphosate/ha and ploughing (twice) 3rd year: 4 litres of glyphosate/ha and 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. Spacing: 3 m x 3 m Pit planting: 30 x 30 x 30 cm hole	Fertilizing at age 2 months: 440 kg of P_20_5 16.5% + 114 kg of 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; 2-year thinning					1st year: Singling 2nd year: Tip pruning and lift pruning 3rd year: Lift pruning and thinning
600 trees/ha; 3-year thinning					1st year: Singling 2nd year: Tip pruning and lift pruning 3rd year: Lift pruning 4th year: Thinning
450 trees/ha; 2-year thinning					1st year: Singling 2nd year: Tip pruning and lift pruning 3rd year: Lift pruning and thinning
450 trees/ha; 3-year thinning					1st year: Singling 2nd year: Tip pruning and lift pruning 3rd year: Lift pruning 4th year: Thinning

3.3 Analysis

3.3.1 Yield prediction

Growth data were used to build predictive functions between D_{bh} (y) and Age (x) of the form $y = ax^b$ using regression procedures in EXCEL. % sawlog was calculated using Beadle et al. (2012):

$\%sawlog = 247.84*D_{bh} - 2188$

Allocation of logs to products was based on Harwood et al., 2007. There were three product types: $D \leq 10$ cm (pulpwood); $10 < D \leq 18$ cm (small sawlog); $D > 18$ cm (sawlog)

3.3.2 Economic analysis

The rotation was 7 financial years (similar to current popular rotation lengths) and the discount rate 10% (similar other popular international investment projects). The economic indicators analyzed were NPV, IRR and BCR. Models were developed for the commercial forest and the ACIAR control (unthinned), 600 stems/ha early and late thinning and 450 stems/ha early thinning and late thinning. Wages and costs are for the 4th quarter of 2012. Wood price is mode price for all of 2012 in Bien Hoa Town, Dong Nai province. All analyses used EXCEL.

3.3.3 Sensitivity analysis

Rather than do an economic comparison of different regimes for just one set of log prices and one set of volumes and proportions of log types at harvest, comparisons were undertaken for 3 different likely log price regimes, 3 different volume projections and 2 discount rates (18 combinations). The log prices were the mode price (P2); mode price + 10% (P1) and mode price - 10% (P3). The 3 volume projections were for the 450/3-year, 6000/3-year 1143 stems/ha (control) treatments. The discount rates were 10% and 15%.

3.3.4 Optimising rotation length

A decision problem is one of comparing annual growth in timber value against cost of holding the timber for an extra year. If holding the timber for another year would lead to a net loss, we should harvest now (Figure 1; Pearse, 1967). Stumpage value S(A) is the maximum price competitive buyers would be prepared to pay for standing timber of age A where:

$S(A) = Return - Cost$

A forester wanting to select the harvest age that maximises profit must consider the marginal benefits and marginal costs (MC) of growing the timber crop one more year. MC is the return that could be earned on the proceeds of a harvested timber stand, i.e. the opportunity cost of capital (the discount rate, r). The marginal benefit of growing the stand for one more year is:

$\Delta S = S(A+1) - S(A)$

Where ΔS is amount by which timber value will increase if the stand is left to grow for another year. The incremental growth rate in value, $\Delta S/S(A)$, represents the rate of return on the forest owner's invested capital. Because of the sigmoid relationship between S(A) and A, $\Delta S/S(A)$ declines with stand age. The owner could harvest the timber crop, and invest the proceeds at an interest rate r. So the economically optimal rotation for a single rotation tree crop is where (Seang and Them, 2009):

$\Delta S/S(A) = r$

The study was based on the following assumptions: (1) the benefit of *Acacia* plantations was based on wood volume; (2) all wood was harvested at the end of the rotation; (3) the price pulpwood, small sawlog and sawlog were USD 29.52, 38.57 and 79.05 per cubic metre and remained constant through time; (4) there were no losses to pests, diseases or fire; and (5) the average interest rate of the Commercial Bank in 2012 (15%) was used.

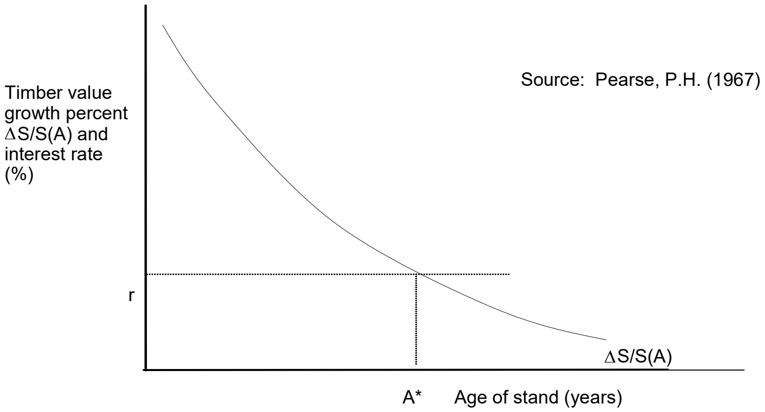

Figure 1: Per cent growth in timber value and interest rate (%)

Results

4.1 Yield prediction

4.1.1 Growth of Dbh and Volumes

Table 3. Average D_{bh} (cm) of different treatments at PT2

	Treatments					
Time of measurement (age in y)	450/2y	600/2y	450/3y	600/3y	1143	Comm.
2.2	10.5	10.2			9.7	
2.5	11.6	11.4			10.7	
2.9	12.8	12.4	11.4	11.3	11.4	10.2
3.2	14.0	13.3	13.1	12.7	12.1	11.0
3.5	15.0	14.1	14.1	13.6	12.8	11.6
3.9	15.8	14.8	15.0	14.2	13.3	12.1
4.6	16.6	15.4	16.0	15.2	13.8	
4.9	17.1	15.9	16.7	15.7	14.2	13.2

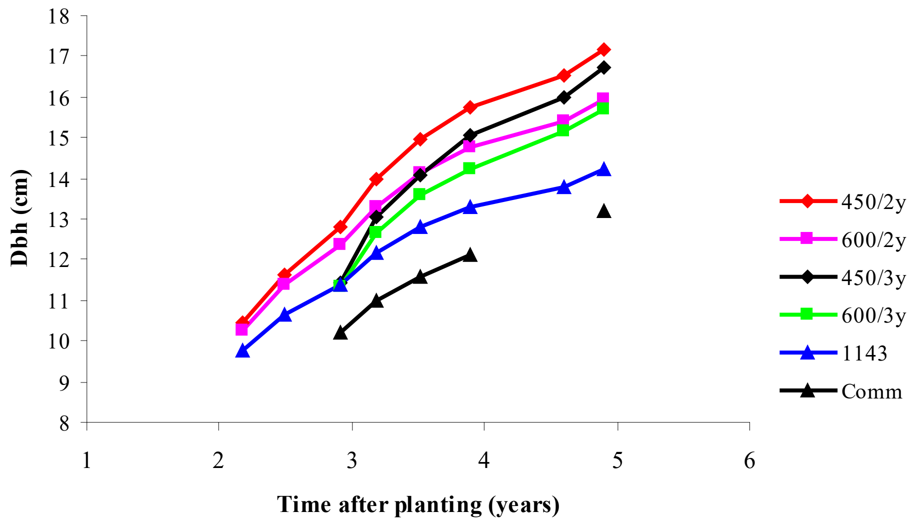

Figure 2. Growth of D_{bh} in different thinning regimes at PT2

There were significant response of Dbh to thinning at both times of thinning; Dbh for all thinning treatments were higher than for the controls. The largest Dbh was in the 450 stems/ha treatments. Two years after thinning (and 5 years after planting), Dbh of both the early- (at age 2 years) and late- (at age 3 years) 450 and 600 stems/ha were not significantly different at each thinning intensity.

Table 4. Standing volumes at age 5 years

Regimes/Treatments	Volume of thinning logs (m^3)	Volume of standing trees after thinning (m^3)	Total volume (m^3)
450/2-y	9.3	92.2	101.5
600/2-y	7.8	105.2	112.9
450/3-y	22.7	87.8	110.5
600/3-y	19.4	102.2	121.6
1143-control		121.7	121.7
Commercial		99.0	99.0

A similar result is apparent for stand volume which also shows that stand volume of the thinned treatments remains significantly less than for the unthinned ACIAR 1143 control. At the same density, total volumes, including that of the thinned trees, is higher for the age 3 than age 2 thinning because the thinned volumes are higher for the later thinning.

4.1.2 Yield prediction

The relationships between Dbh and tree age are as follows:

Dbh = 6.7215*A^0.6070

Dbh = 6.9651*A^0.5363

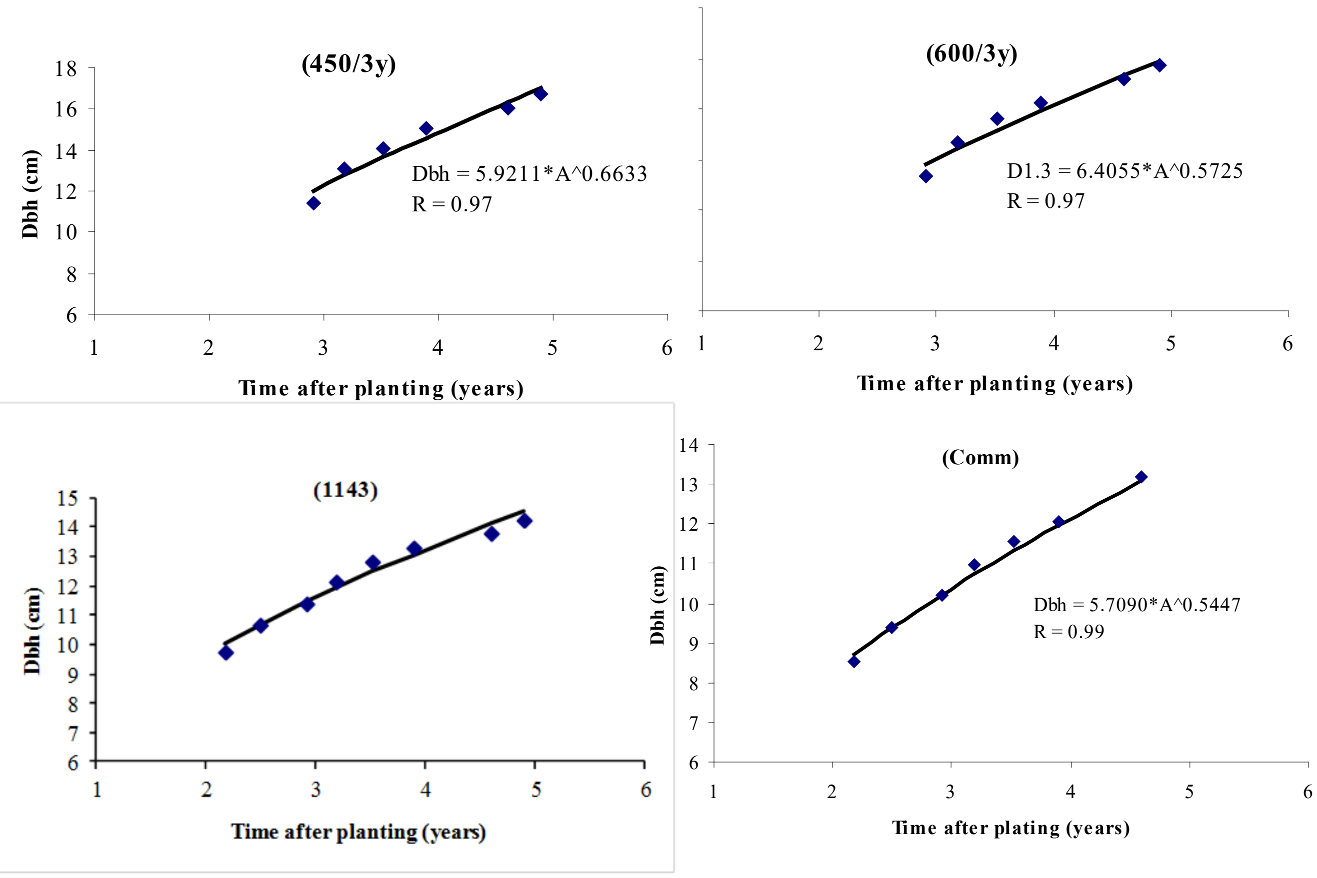

Figure 3. Relationships between Dbh and tree ages for the different thinning regimes

In South-eastern Vietnam, logs are classified in the market by end diameter there are three kinds of wood products: pulpwood (end diameter 4-10 cm, length 2.2 m); small sawlog (end diameter 10-18 cm, length 1.2 m); sawlog (end diameter >18cm, length 2.2 m). Base on end diameter the realtionships between DBH and product proportion are as follows:

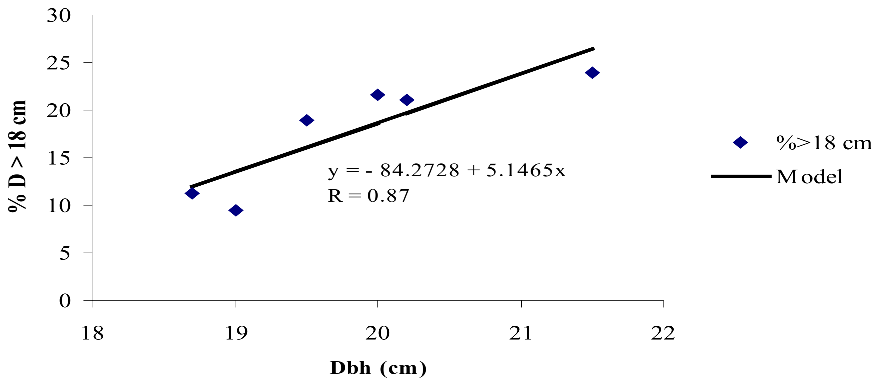

Figure 4. Relationships between D_{bh} and per cent sawlog proportion (D > 18cm)

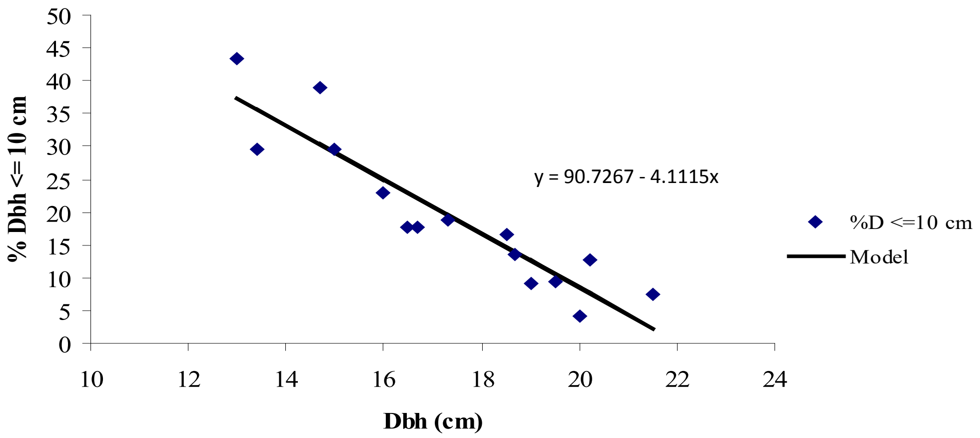

Figure 5. Relationship between Dbh and % pulpwood (D < 10cm)

Table 5. Yield prediction of different regimes at age 6 years (7th financial year)

Treatments	Dbh (cm)	Volume (m^3/ha)	% Sawlog	% Small sawlog	% Pulpwood
450/2-year	19.9	124.0	18.4	72.7	8.9
600/2-year	18.2	139.5	9.4	74.5	16.1
450/3-year	19.4	118.3	15.7	73.2	11.0
600/3-year	17.9	134.4	-	82.5	17.5
1143 (control)	15.9	160.6	-	74.5	25.5
Commercial	15.2	143.2	-	71.4	28.6

At age 6 years, the standing volume of the control and commercial plantations remained higher than those of the thinned treatments. However, the pulpwood proportion of these unthinned plantations was also higher and there were no sawlog values.

4.2 Economic analysis

4.2.1 Costs (Table 6)

- Site preparation. Costs were same for all treatments: USD71.43 for 10 lbrs for clearing vegetation.
- Planting. Costs were same for all treatments: USD57.14 for 1200 cuttings/ha; USD35.71 for 5 lbrs planting layout; USD107.14 for 15 lbrs of digging pits; USD37.71 for 5 lbrs of transporting cuttings to pits; USD71.43 for 10 lbrs for planting/refilling holes; USD14.29 for 2 lbrs of replanting.
- Fertilizer
    - Hai Vuong: USD45.71 for 80 kg NPK; USD14.29 for 2 lbrs for application. This was done again in the second year.
    - ACIAR: USD73.34 for 440 kg P; USD65.31 for 114 kg NPK; and USD 85.71 for 12 lbrs for application. Fertiliser applied in first year only.
- Weed control
    - Hai Vuong: Year 1: USD52.38 for 2× ploughing; USD42.86 for 6 lbrs for herbicide spraying and clearing inter-row vegetation. Year 2: USD22.86 for 4L glyphosate; USD 7.14 for 1 lbr for spraying; USD 52.38 for 2× ploughing . Year 3: As for Year 2.
    - ACIAR: Year 1: USD45.71 for 8 L glyphosate for 2× herbicide; USD14.29 for herbicide spraying and USD42.85 for clearing inter-row vegetation. Year 2: As for Year 1. Year 3: Half cost of Year 1.
- Pruning and thinning
    - Hai Vuong: USD 35.71 for 5 lbrs for singling.
    - ACIAR's trials: Year 1: USD 35.71 for 5 lbrs for singling and form (tip) pruning; Year 2: USD85.71 for 12 lbrs for tip pruning and lift pruning; Year 3: USD57.14 for 5 lbrs for lift pruning; USD 107.14 for 15 lbrs for thinning in 600/2-year treatment; USD 158.27 for 18 lbrs for thinning in 450/2-year treatment; Year 4: USD 107.14 for 15 lbrs for thinning in 600/3-year treatment; USD 158.27 for 18 lbrs for thinning in 450/3-year treatment;
- Security protection: USD35.71 for 5 lbrs for each treatment.
- Fire protection
    - Hai Vuong: USD21.43 for 3 lbrs/ha/year.
    - ACIAR: USD42.86 for 6 lbrs/ha/year.
- Land rental: USD11.9 /ha/year; tax ratio is 4% value of total harvested products but discounted by 50%. Almost all plantations in Binh Phuoc province require this payment.
- Management board: 10% of labour cost.

4.2.2 Wood prices (Table 7)

In south-eastern Vietnam, the biggest market for saw-logs is at Ho Nai, Bien Hoa City. The distance from Phan Truong 2 to Ho Nai is 200 km. Wood-processing companies there make competitive bids for standing timber but the successful bidder may share bids with other processors. This is a common way of buying and selling standing timber. The wood price at the mill gate is also common to the area. The price for standing timber is equal to the price at the mill gate minus costs of harvesting and transport and other related expenditure. Wood prices vary with season: they are highest in the 3rd quarter because poor weather conditions lead to higher costs of harvesting and a decrease in wood supply. The lowest price is in 1st quarter as festivals at this time mean a reduced labour supply in the processing units and a build-up of wood in factory stockpiles. Nevertheless, wood prices fluctuate within a narrow range of about 10% of the average price.

Table 6. Collection of indices for economic analysis of treatments (unit: USD)

	Contains	Regimes					
		PT2-1.111	PT2-600-2y	PT2-600-3y	PT2-450-2y	PT2-450-3y	Comm
A	EXPENDITURES	1,860.09	1,957.23	1,967.23	1,981.51	2,005.80	1,509.05
1	Year 1	930.09	930.09	930.09	930.09	930.09	717.62
	Land cost (annual rent)	11.90	11.90	11.90	11.90	11.90	11.90
	Site preparation	71.43	71.43	71.43	71.43	71.43	71.43
	Planting stock	57.14	57.14	57.14	57.14	57.14	57.14
	Planting	264.29	264.29	264.29	264.29	264.29	264.29
	Fertiliser	224.37	224.37	224.37	224.37	224.37	60.00
	Weed control	107.62	107.62	107.62	107.62	107.62	95.24
	Silviculture costs	35.71	35.71	35.71	35.71	35.71	35.71
	Fire protection	42.86	42.86	42.86	42.86	42.86	21.43
	Security	35.71	35.71	35.71	35.71	35.71	35.71
	Other cost (management board)	79.05	79.05	79.05	79.05	79.05	64.76
2	Year 2	313.33	313.33	313.33	313.33	313.33	286.67
	Land cost (annual rent)	11.90	11.90	11.90	11.90	11.90	11.90
	Fertiliser	-	-	-	-	-	60.00
	Weed control	107.62	107.62	107.62	107.62	107.62	82.38
	Silviculture costs	85.71	85.71	85.71	85.71	85.71	57.14
	Fire protection	42.86	42.86	42.86	42.86	42.86	21.43
	Security	35.71	35.71	35.71	35.71	35.71	35.71
	Other cost (management board)	29.52	29.52	29.52	29.52	29.52	18.10
3	Year 3	223.33	320.48	223.33	344.76	223.33	184.29
	Land cost (annual rent)	11.90	11.90	11.90	11.90	11.90	11.90
	Weed control	53.81	53.81	53.81	53.81	53.81	82.38
	Silviculture costs	57.14	142.86	57.14	164.29	57.14	21.43
	Fire protection	42.86	42.86	42.86	42.86	42.86	21.43
	Security	35.71	35.71	35.71	35.71	35.71	35.71
	Other cost (management board)	21.90	33.33	21.90	36.19	21.90	11.43
4	Year 4	100.95	100.95	208.10	100.95	246.67	76.67
	Land cost (annual rent)	11.90	11.90	11.90	11.90	11.90	11.90
	Silviculture costs	-	-	107.14	-	128.57	-
	Fire protection	42.86	42.86	42.86	42.86	42.86	21.43
	Security	35.71	35.71	35.71	35.71	35.71	35.71
	Other cost (management	10.48	10.48	10.48	10.48	27.62	7.62

	Contains	Regimes					
		PT2-1.111	PT2-600-2y	PT2-600-3y	PT2-450-2y	PT2-450-3y	Comm
	board)						
5	Year 5 - 6 per year (Land cost, fire protection, security, management)	**201.90**	**201.90**	**201.90**	**201.90**	**201.90**	**153.33**
	Year 7	**90.48**	**90.48**	**90.48**	**90.48**	**90.48**	**90.48**
B	RETURNS	5,824.92	5,973.27	5,646.44	5,919.95	5,989.64	5,152.54
1	Thinning	-	263.98	674.73	316.96	791.96	-
	Pulpwood volume	-	112.86	237.55	133.74	271.00	-
	Small sawlog volume	-	151.13	437.18	183.21	520.96	-
	Sawlog volume	-	-	-	-	-	-
2	Final harvest	5,824.92	5,709.29	4,971.71	5,602.99	5,197.68	5,152.54
	Pulpwood volume	1,207.46	661.05	692.63	326.32	384.59	1,210.17
	Small sawlog volume	4,617.46	4,008.41	4,279.08	3,476.89	3,341.40	3,942.37
	Sawlog volume	-	1,039.83	-	1,799.78	1,471.70	-
C	INDICES OF ECONOMIC ANALISYS						
1	Net Present Value (NPV)	1,481.78	1,547.79	1,431.61	1,514.80	1,601.30	1,426.64
2	Internal Rate of Return (IRR)	0.26	0.27	0.27	0.27	0.29	0.28
3	Benefit Cost Ratio (BCR)	1.98	1.98	1.91	1.95	2.00	2.17

Table 7. Wood prices and expenditures after harvest in 2012 (unit: USD)

Products (price type)	Price at Mill gate (USD/m^3)	Harvest	Collection	Bark peeling	Transport	Price standing trees	Log diameter (cm)/ length (m)
Pulpwood (P1)	55.00	3.33	3.33	4.29	9.52	34.52	04 - 10/2.2
Pulpwood (P2)	50.00	3.33	3.33	4.29	9.52	29.52	
Pulpwood (P3)	45.00	3.33	3.33	4.29	9.52	24.52	
Small sawlog (P1)	56.05	3.33	2.86	-	6.19	43.67	10 - 18/ 1.2
Small sawlog (P2)	50.95	3.33	2.86	-	6.19	38.57	
Small sawlog (P3)	45.86	3.33	2.86	-	6.19	33.48	
Sawlog (P1)	99.52	2.86	2.38	-	6.19	88.10	> 18/ 2.2
Sawlog (P2)	90.48	2.86	2.38	-	6.19	79.05	
Sawlog (P3)	81.43	2.86	2.38	-	6.19	70.00	

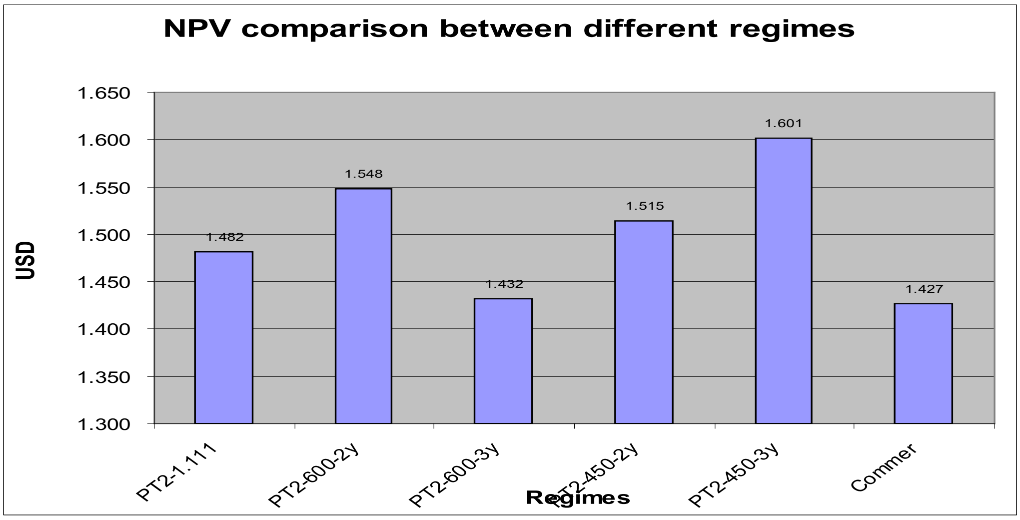

Figure 6. NPV comparison between different regimes in 7-financial year rotation

4.2.3 Returns

At age 6 years, the highest NPV (USD1,601/ha) was found for the 450 stems/ha treatment when the stand was thinned at age 3 years. The lowest NPV (US1427/ha) was found for the commercial pulpwood plantation. NPVs for the other regimes were intermediate. It is interesting to note that at this age, the maximum difference between the best and worst regime was < USD200 (see below).

4.3 Sensitivity analysis on thinning regimes using range of discount rates and prices

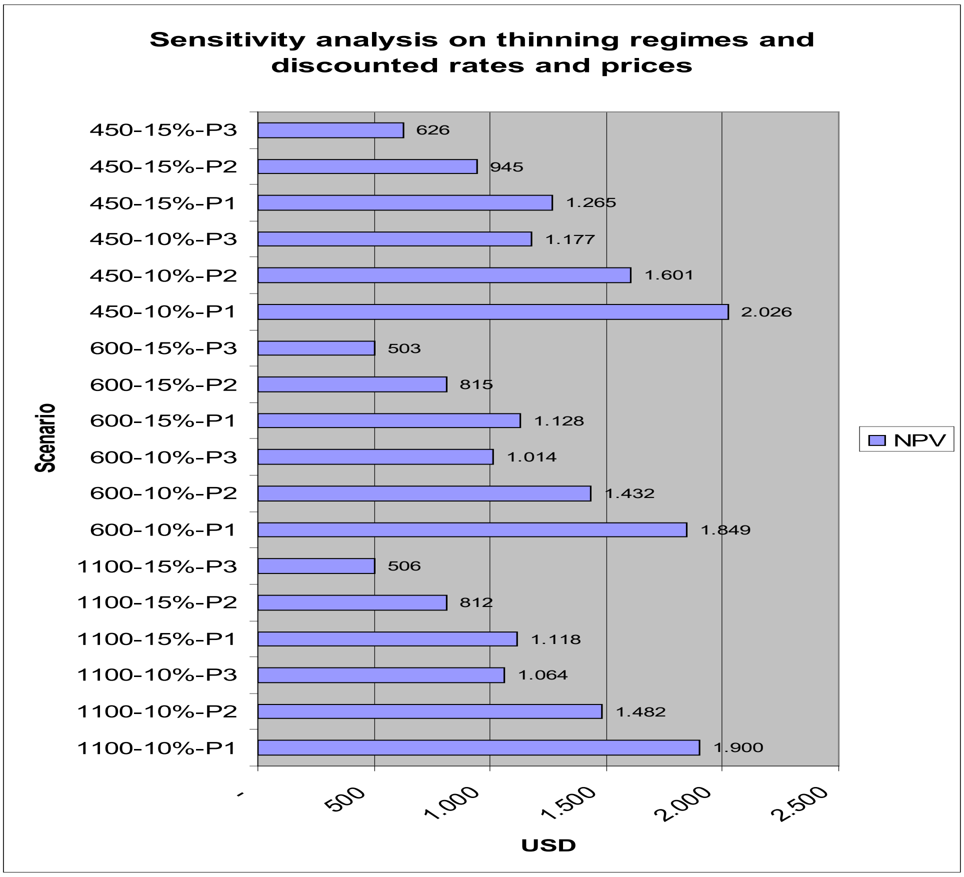

Figure 7. Sensitivity analysis on the three thinning regimes using two discount rates (10 and 15% and three prices (mode, mode + 10% and mode – 10%; see Table 7)

Table 6. NPV/ha between different thinning regimes and discount rates for mode prices

Density (stems/ha)	Discount rate 15%		Discount rate 10%	
	NPV (USD)	Index %	NPV (USD)	Index %
450 > 600	130	15.9	170	11.9
600 > 1100	4	0	-50	-3.4
450 > 1100	134	16.5	120	8.1

Three years after thinning, the yield and wood product mix between treatments had changed but large differences in NPV between the regimes had not developed. The greatest difference was USD170 between the 450/3-year and 600/3 treatments at a 10% discount rate. To maximize the benefits from thinning, longer rotations than 6 years will be necessary to maximize saw-log values. Saw-log values are unlikely to develop in unthinned plantations.

Table 7. NPV/ha between different prices and discount rates for 450 trees/ha

Price factor	Discount rate 15%		Discount rate 10%	
	NPV (USD)	Index %	NPV (USD)	Index %
P1 > P2	319	33.8%	425	26.5%
P2 > P3	319	51.0%	425	36.1%
P1 > P3	639	102.0%	849	72.2%

Wood price caused the greatest changes in NPV. A 10% increase in price increased NPV by USD425 at a 10% discount rate. Thus growers should link selling their standing timber depending on market prices if they want to maximise profit.

For the mode price (P2), when the discount rate is changed from 15% to 10%, NPV /ha of 450, 600 and 1143 stems/ha (control) increased USD 656, 616 and 670 respectively. Thus discount rate has the strongest effect on economic returns but cannot be controlled by the growers.

4.4 Optimum Rotation

Table 8. Determining economically-optimum rotation length (Seang and Them, 2009)

Year	Cost (USD)	Return (USD)	Revenue (USD)	Value growth per cent %	Discount rate %
1	930	-	-930		
2	313	-	-313		15
3	223	-	-223		15
4	247	792	545		15
5	101	2.409	2.308		15
6	101	3.439	3.338	44.6	15
7	101	5.198	5.097	52.7	15
8	101	6.981	6.880	35.0	15
9	101	8.758	8.657	25.8	15
10	101	10.634	10.533	21.7	15
11	101	12.602	12.501	18.7	15
12	101	14.654	14.554	16.4	15
13	76	16.785	16.709	14.8	15

This analysis (Table 10) indicates that the economically optimum rotation length for *Acacia* hybrid plantations in Binh Phuoc province would be 13 years at an interest rate of 15% and under the conditions tested. There is inevitably a high level of uncertainty in this result as growth rates are predicted from data collected to age 5 years only and it excludes any consideration of the potential effects of pests, diseases and fire damage on realised productivity.

Conclusion

- At age six years, and following thinning treatments from 1143 (ca. 1100) stems/ha to 600 and 450 stems/ha at either age two or age three years, standing volume remained the highest in the unthinned treatment. However sawlog values had developed in the thinned treatments; there were no sawlog values in the unthinned treatments.
- For a six-year rotation (seven financial years), the regime that was thinned to 450 stems/ha at age three years delivered the highest economic benefit (NPV = USD1601/ha). However, the difference in NPV between the regimes was small (< USD200).
- At age six years, wood price had the greatest impact on financial returns to growers; discount rate was next in importance and then thinning practice.

Tran Thanh Cao, Pham Van Bon and Kieu Tuan Đat

July 2013

11.3 Appendix 3: Technical Information Sheets

Seven Technical Information Sheets were compiled and are available in both English and Vietnamese. They form part of the package of materials to be distributed to users through the National Extension Centre. The seven sheets are as follows:

1. How to Control Bamboo (Prepared by Kieu Tuan Dat)
2. How to Apply Fertiliser at Planting (Prepared by Kieu Tuan Dat)
3. How to Tip Prune (Prepared by Vu Dinh Huong)
4. How to Lift Prune (Prepared by Pham Van Bon)
5. How to Thin for Saw Logs (Prepared by Kieu Tuan Dat)
6. How to Sample Soil (Prepared by Le Thanh Quang)
7. How to Describe Soil (Prepared by Le Thanh Quang)

These sheets are appended below.

How to control bamboo

TECHNICAL INFORMATION SHEET **_ACACIA_ HYBRID SERIES**

BAMBOO AS A WEED

- Bamboo species (Poaceae) are widely distributed in Vietnam.
- "Le" (*Pseudoxytenanthera nigro-ciliata* (Buese)) (Vietnamese names: Le đen; Le lông đen; Tre ria đen) is widely distributed in provinces of the South-east and Central Highlands and has become a persistent weed in some acacia plantations.
- "Le" has fast growth, strong ability to regenerate after forest harvesting, and forms multiple branches after cutting.
- If not controlled, "Le" has the capacity to vigorously compete with young acacia saplings during the first year of growth.

CONTROL

1. Cutting and regeneration

- Apply treatment before the "Le" starts to compete with the acacia saplings (**Plate 1**).
- Cut the bamboo as close to the ground as possible (**Plate 2**).
- Allow the bamboo to regenerate until about 30 cm in height (**Plate 3**).

Plate 1. "Le" before treatment

Plate 2. After cutting

Plate 3. One month after cutting

2. Mixing the herbicide spray

- Mix Glyphosate (200 ml Roundup 480SC) with Pulse penetrant (20 ml) (**Plate 4**) in 16 L water.

Plate 4. Pulse and Roundup

3. Application

- Spray early morning or late afternoon when windspeed is very low.
- Thoroughly wet each bamboo plant.
- Use shrouded spraying equipment only.

HOW TO CONTROL BAMBOO

Plate 5. Three weeks after spraying

4. Assessment

- First signs of senescence should be apparent one week after spraying.
- Severe decline should be apparent three weeks after spraying (**Plate 5**).

5. Recommended frequency

- Application 1: before planting
- Application 2: when plantation is age 6 months (**Plate 6**)
- Application 3: as required (**Plate 7**)

Plate 6. Two applications

Plate 7. Complete control after three applications

Health, safety, and environment

- Always wear protective clothing, including PVC gloves/face protection and wash at end of each day.
- Do not contaminate waterways.
- Keep out of reach of children.
- After use, wash hands, arms and face thoroughly before eating, drinking or smoking.
- If poisoning occurs, contact a doctor or Poisons Information Centre.

Product information

- Roundup 480SC is a systemic herbicide distributed in Vietnam by HAI Joint Stock Company, 28 Mac Dinh Chi St, District 1, Ho Chi Minh City.
- Pulse is a wetter/spreader for improved herbicide penetration; it is a product of Nufarm Technologies USA Pty Ltd.

Useful information

- Application 1 and possibly Application 2 may coincide with a broadacre treatment of all weed species. For one hectare (1 ha), apply 4.0 L Roundup + 200 ml Pulse per 100 L of spray mixture.

Acknowledgments: Thanks to Chris Beadle for his help with the English text.

For more information contact:

Kieu Tuan Dat
Forest Science Sub-Institute of Vietnam
01 Pham Van Hai St
Tan Binh District
Ho Chi Minh City
E-mail: kieutuandat2005@yahoo.com

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How to apply fertiliser at planting

TECHNICAL INFORMATION SHEET — ***ACACIA* HYBRID SERIES**

FACTS

- Fertiliser can have a positive effect on the growth of trees and is commonly used in commercial plantations
- Forest soils in Vietnam are generally low in available phosphorus (P) and this commonly affects the productivity of plantations
- *Acacia* species fix atmospheric nitrogen (N_2) and this process requires an adequate supply of P
- The amount of fertiliser applied and the method of application will determine the effectiveness of the added nutrients
- P may be rapidly fixed in soil and become unavailable; to maximise uptake, P fertilisers should therefore be applied in concentrated form and not broadcast

PRACTICE AND RESPONSE

1. Types of fertiliser and dose rate

- Superphosphate fertiliser has a P_2O_5 content of 16.5% P and P content of 7.1% (**Plate 1**)
- P can also be applied using N:P:K fertilisers; additional P is applied as superphosphate
- The amount of P applied should be related to (i) the soil type and (ii) the silvicultural system being used. Apply 10-20 kg P/ha

Plate 1. Superphosphate fertiliser

2. Superphosphate dose: e.g. 10 kg P/ha for three spacings

- Planting density 1666 trees/ha (3 m × 2 m): apply 83 g/tree (double for 20 kg P/ha)
- Planting density 1333 trees/ha (3 m × 2.5 m): apply 103 g/tree (double for 20 kg P/ha)
- Planting density 1111 trees/ha (3 m × 3 m): apply 125 g/tree (double for 20 kg P/ha)
- Calibrate containers to match dose (**Plate 2**)

Plate 2. Calibrated containers

3. Application

- Remove soil to create a 40 × 40 × 40 cm planting pit
- Fertiliser and soil mixed in bottom 10 cm of pit
- Refill the pits with soil; plant trees after 7 – 10 days (**Plate 3**)

Plate 3. Pit with added fertiliser, refilling pits with soil, and planted seedling

HOW TO APPLY FERTILISER AT PLANTING

4. Fertiliser response

- Application of P fertiliser can be associated with healthy and vigorous early growth **(Plates 4,5)**
- High dose rates of P fertilisers may increase the number of large branches, so form pruning is essential (see How to "tip" prune)
- In Binh Duong province at age 2.5 years, *Acacia* hybrid receiving 50 kg P/ha at planting and chemical weed control had mean a diameter at breast height (DBH) of 10.7 cm; those receiving 18 kg P/ha and weed control by ploughing had a mean DBH of 9.4 cm (**Plate 6**)

Plate 4,5. *Acacia* hybrid without and with P fertiliser

Plate 6. *Acacia* hybrid: left (50 kg P/ha); right (18 kg P/ha)

Health, safety and environment

- Always wear protective clothing, including PVC gloves and face protection while applying fertiliser
- After working, wash hands and take a shower before eating or drinking
- Ensure there is no risk of contamination of lakes, rivers and streams

Product information

- Lam Thao Superphosphate (16-16.5% P_2O_5), manufactured and distributed by the Lam Thao Chemical & Superphosphate Joint Stock Company, Lam Thao District, Phu Tho Province
- Van Dien Phosphate (15-17 % P_2O_5) manufactured and distributed by the Van Dien company in Hanoi

Useful information

- Instead of superphosphate, N:P:K fertiliser is commonly applied at planting, e.g. 100 g N:P:K (16:16:8) per tree provides 26.7 kg P/ha at 1666 trees/ha
- Fertiliser responses to P are best captured at planting. If P was not applied, growth responses may still be obtained by applying P within 2-3 years after planting.

For more information contact:

Kieu Tuan Dat
Forest Science Sub-Institute of Vietnam
01 Pham Van Hai St
Tan Binh District
Ho Chi Minh City
E-mail: kieutuandat2005@yahoo.com

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How to "tip" prune

TECHNICAL INFORMATION SHEET **_ACACIA_ HYBRID SERIES**

FACTS

- Tropical acacias often display poor apical dominance and are commonly "singled" at age 4-to-6 months to create a single stem. Competing stems and branches are excised at their base, resulting in large pruning wounds.
- *Acacia* hybrid has very high early growth rates and, without intervention, many clones will be multi-stemmed, often with large branches (**Plate 1**).
- Form pruning, the removal of undesirable competing stems and branches, is an essential silvicultural requirement if the stand is managed for saw logs.
- Tip pruning removes a proportion of the length of these undesirable stems and branches. The advantages of tip pruning are:
  - Dominance of competing stems or leaders is removed but leaf area and therefore growth potential is retained;
  - Excision of unhardened stems/branches at the point where they join the retained stem is avoided, potentially reducing the potential for disease entry.

INTERVENTION

Three tip prunings may be required to produce a straight, single stem to 4.5 m. Pruning of trees that require intervention should be undertaken when their top heights are:

Plate 1. Before tip pruning

Plate 2. Excised competing stem

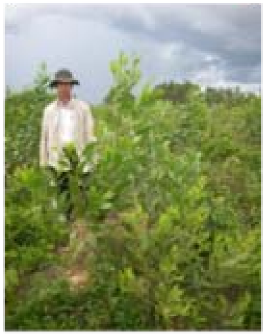

Plate 3. After tip pruning

1.0-to-1.5 m

- Select the stem or leader that is to be retained. This will usually be the longest with the largest basal diameter, but should also be growing in an upwards direction.
- Reduce the length of the competing stems/branches by one-half (50%) (**Plates 2, 3**)

2.5-to-3.0 m and 4.5-to-5.0 m

- Select the leader that is to be retained using the above criteria (**Plate 4**).
- Note competing branches, i.e. those that will grow to a basal diameter > 3cm
- Reduce the length of the competing leaders and large branches by one-half (50%) (**Plate 5**).
- A step ladder will be required for the third intervention; do not lean ladders against acacia stems at this age; they are brittle and may break!

Plate 4. Competition for dominance at 2.5-3.0 m height

Plate 5. Excising competing leaders/branches

HOW TO "TIP" PRUNE

CAPTURING GOOD FORM

Reducing the length of competing stems, leaders and branches slows their growth relative to the retained stem or leader. This allows:

Plate 6. Tip-pruned branches 5 months after treatment at 1.0-to-1.5 m height (a) before and (b) after pruning at base with pruning saw and (c) 7 months after treatment at 2.5-to-3.0 m height. Note the capture of good form in the retained leader.

- The retained leader to establish dominance in this part of the stem (**Plates 6a, c**).
- The "tip" pruned branches to contribute to growth and then be excised at a later date that coincides with lift pruning (**Plate 6b**) (see How to lift prune).

MANAGING DISEASE ENTRY

"Tip" pruning also:

- Reduces the wound area because pruning is undertaken where the branch is narrower;
- Leaves behind a long pathway between the point of excision and the point of insertion into the retained stem.

Cuts using sharp and clean tools, preferably secateurs, are recommended for "tip pruning". This optimises the conditions for wound healing and absence of decay at lift pruning (**Plates 7a, b**).

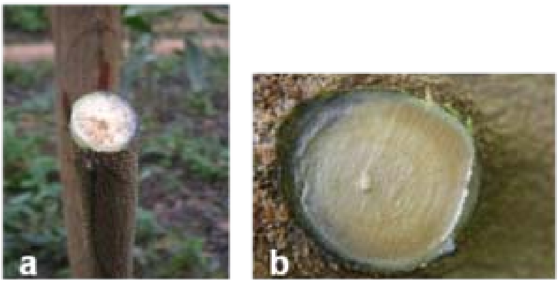

Plate 7. The condition of a tip-pruned branch 7 months after treatment (a) just behind the original cut surface (b) at the point of insertion into the main stem. Note that decay entry close to the surface has not reached the stem.

Extra useful information

The expression of form in *Acacia* hybrid is not well understood, but may be affected by :

- Stock type: some clones appear to express better form than others, so require less tip pruning;
- Age of hedge: cuttings from old hedges have less dominance and poorer form than cuttings from new hedges;
- Site and nutrient supply: high rates of growth mean that problems with form are expressed rapidly, requiring more frequent tip pruning.

For more information contact:

Vu Dinh Huong
Forest Science Sub-Institute of Vietnam
01 Pham Van Hai St
Tan Binh District
Ho Chi Minh City
E-mail: vudinhhuong@yahoo.com

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Acknowledgments: Thanks to Chris Beadle for his help with the English text.

How to "lift" prune

TECHNICAL INFORMATION SHEET **_ACACIA_ HYBRID SERIES**

FACTS

- *Acacia* hybrid (*A. mangium* x *A. auriculiformis*) produces many branches (**Plate 1**) which form knots; knots and associated wood decay reduce the value of sawn timber and veneer.
- Lift pruning progressively removes live branches from the base of the tree upwards; wood that develops after the branch has been removed is free of knots and is referred to as clear wood.
- Pruning of large branches and dead branches, and pruning in the wet season is associated with the development of decay leading to wood defect.
- Tip pruning (see How to "tip" prune) is used before lift pruning to avoid the development of large branches.
- Lift pruning must be undertaken in the dry season, and branches must be removed while still alive.

INTERVENTION

- The first- (1st) lift pruning should be done when trees are 7-8 cm in diameter at breast height (1.3 m above ground) and 7-8 m in height and just before the canopy closes. The pruned height is 2-2.5 m above ground (**Plate 2**) or approximately 25-30% crown height.
- The 2nd-lift pruning to 4.5 m above ground should be done when tree height is 10-11 m (**Plate 3**); a 3rd-lift pruning to 6.5 m above ground (to produce a 6-m log) can be undertaken when tree height is 12-14 m.

Plate 1. Before 1st-"lift" pruning

Plate 2. 1st-"lift" pruning to 2 m

Plate 3. 2nd-"lift" pruning to 4.5 m

TECHNIQUE

- Remove all "living" branches to the appropriate level for each pruning lift.
- Branches < 3 cm diameter should be removed with pruning shears (**Plate 4**); and branches > 3 cm diameter by a pruning saw (**Plate 5**), including an under-cut to avoid bark tearing.
- The cut surface should be parallel to and just to the outside of the branch collar.
- Pruning tools must be kept sharp to ensure clean and smooth cuts and to avoid tearing stem-bark (**Plates 6, 7**); damaged wood and bark inhibits wound healing and promotes decay entry.

HOW TO "LIFT" PRUNE

Plate 4. Pruning with shears

Plate 5. Pruning with a saw

Plate 6. A clean cut (good)

Plate 7. Bark tearing (bad)

GOOD PRACTICE

- Always make sure that "tip" pruning stays ahead of "lift" pruning; if necessary do them at the same time (**Plate 8**).
- Failure to tip prune can lead to the development of large branches and stress fractures between stem and branch. The branch and stem may then break in a strong wind (**Plate 9**).

Plate 8. Tree with lift and tip pruning

Plate 9. Tree after poor pruning practice

Extra useful information

Research results and field observations showed that:

- "Dead" knots caused by dead branches and large branch traces are the main causes of defect in wood boards.
- Multi-leaders and large branches above the pruned height are susceptible to breakage in strong winds.

For more information contact:

Pham Van Bon
Forest Science Sub-Institute of Vietnam
01 Pham Van Hai St
Tan Binh District
Ho Chi Minh City
E-mail:
Pvbon.fssiv@yahoo.com

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Acknowledgments: Thanks to Chris Beadle for his help with the English text

How to thin for saw logs

TECHNICAL INFORMATION SHEET ***ACACIA* HYBRID SERIES**

FACTS

- By reducing stand density, thinning promotes diameter growth by providing the retained trees with greater access to light, nutrients and water.
- *Acacia* hybrid has very fast early growth rates; between-tree competition for resources leads to a reduction in individual tree growth in unthinned stands.
- To maintain high tree growth rates, thinning should be undertaken around the time of stand closure.
- In some environments, thinning can help to reduce disease incidence e.g. Pink disease *Corticium salmonicolor*.
- Thinning is an effective silvicultural tool for managing acacia plantations established for saw logs at 3 m × 3 m spacing (1111 trees/ha), 3 m × 2.5 m spacing (1333 stems/ha) or 3 m × 2 m spacing (1667 trees/hectare).

PRACTICE

1. Thinning time

- Thinning should be undertaken at the start of the wet season to maximise the growth response.
- A first thinning should be undertaken when the average diameter of the trees is 8-9 cm (**Plate 1**), or 11-12 cm.
- On sites supporting high rates of growth (see How to apply fertiliser at planting), the first thinning will be applied at age 2 to 3 years.

2. Thinning intensity

- For stands established at 1111 and 1667 trees/ha, thin to stand density of 600 (**Plate 2**) and 900 trees/ha, respectively. At harvest, the trees will have average diameters of at least 20 cm (600 stems/ha) or 17 cm (900 stems/ha) on productive sites.
- If larger trees are required, a second thinning is necessary (**Plate 3**).

3. Thinning strategy

- Thinned stands are unstable and subject to bending, wind throw and stem breakage (**Plate 4**). Plantations on steep sites or in areas susceptible to frequent storm damage should be thinned more gradually (in two to three stages) to maximise the stability of the stand.

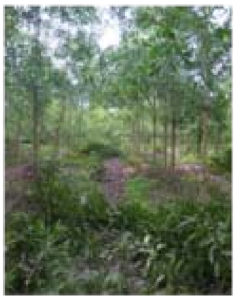

Plate 1. Unthinned (1142 stems/ha) aged 2 years

Plate 2. Thinned to 600 trees/ha at age 2 years

Plate 3. Thinned to 450 trees/ha

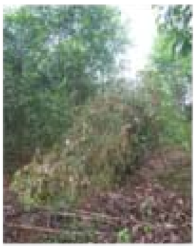

Plate 4. Trees bent (left) and broken (right) by a storm

HOW TO THIN FOR SAW LOGS

4. Tree selection

- Retain trees that have good form, one leader, larger diameter, small branches, and free of pest and disease damage (**Plate 5**).
- Thin trees that have poor form (not straight), more than one leader, smaller diameter, large branches, and been affected by pest and disease damage (**Plate 5**).
- To ensure approximately even spacing, do not remove more than two trees that are adjacent to each other in any row.

Plate 5. Retained (left) and thinned (right) trees.

5. Cutting and removal

- Fell the trees into the inter-row area in a way that ensure there is no damage to the stems and crowns of retained trees (**Plate 6**).
- Only remove the harvested stem; the branches and leaves should be left on site to decompose and return their nutrients to the soil.
- Only use vehicles in designated areas to prevent soil compaction and damage to retained trees.

Plate 6. Felling practice

6. Response to thinning

- After thinning, height growth slows. However individual tree leaf area increases rapidly, increasing the capacity for tree growth and contributing to the thinning response.
- Two years after thinning at age two years, the average diameter of trees can be up to 1.5 cm greater than in the unthinned plantation (**Plate 7**).
- At Dong Hoi in Central Vietnam, the percentage recovery of saw logs increased from 6.7% of total harvest volume in an unthinned stand (1000 stems/ha) to 18.8% in a stand thinned to 600 stems/ha), two years after thinning.

Plate 7. Thinned plantations

Extra useful information

- Thinning should be preceded by form (see How to "tip" prune) and lift (see How to lift prune) pruning to improve the saw-log values of the tree.
- Application of phosphorus fertilizer after thinning may increase the growth response on sites of low fertility.
- Thinning and tree size at harvest should be managed within a maximum rotation of 8 to 10 years to minimise the potential for heart rot to reduce the value of the log.

For more information contact:

Kieu Tuan Dat
Forest Science Sub-Institute of Vietnam
01 Pham Van Hai St
Tan Binh District
Ho Chi Minh City
E-mail: kieutuandat2005@yahoo.com

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How to sample soil for analysis

TECHNICAL INFORMATION SHEET ***ACACIA* HYBRID SERIES**

FACTS

- Soil chemical properties may be important for deciding whether a plantation needs fertiliser to reach its potential productivity
- Collection and processing of soil for analysis requires careful attention to detail to ensure the samples are representative and repeatable.

In the field

1. Sampling required

Surface soils are notoriously heterogeneous, so a sample can only be representative of a site if it is an aggregate of several sub-samples. Thus we recommend that the sample is comprised of 9 subsamples (locations) within a plot. Separate samples should be taken from the 0-10 cm and 10-20 cm depths.

2. Procedure

For the both 0-10 cm and 10-20 cm depth ranges, a long corer will be used. The steps are as follows:

- Clear surface of litter down to the mineral soil boundary; the topsoil must not be disturbed
- Push the corer to 10 or 20 cm, with rotation or percussion if necessary (**Plate 1**)
- Rotate the corer to break the soil column
- If necessary, use the inner steel rod to compact soil within the core prior to removing corer from the soil. This helps to keep the soil within the corer
- Rock the corer from side-to-side in a circular motion to compact the sides and enlarge the hole
- Extract corer from the soil
- Empty the soil from the corer into a bucket and/or a labelled bag. If the full 20 cm depth has been sampled, care needs to be taken to partition the 0-10 cm and the 10-20 cm increments into separate containers (**Plate 2**)
- Alternatively, the cores from each depth can be removed independently. After completing the above process for the 0-10 cm sample, in the same hole push the corer for a further 10 cm and follow the instructions above. Do not let soil from the 0-10 cm layer contaminate this 10-20 cm sample.

Plate 1. Insertion of the corer

Plate 2. Separation of the layers

HOW TO SAMPLE SOILS FOR ANALYSIS

2. Procedure (continued…)

- Repeat steps 1-9 for a total of 9 times in each plot, putting the soil into one bag per depth range per plot. The nine subsamples should be taken from a representative range of locations within the plot.
- Soils can be subsampled in the field to reduce the bulk if required. Mix the soil by rolling in a plastic sheet, then flatten it out (**Plate 3**) and remove opposing quarters. This procedure can be repeated as many times as required to reduce the sample size to a manageable amount. Generally a minimum of 200 g of <5 mm fraction soil should be retained.

Plate 3. Sub-sampling in the field

In the Laboratory

3. Soil processing

Freshly sampled soil should be returned to the laboratory and processed as follows:

- Using a 5 mm sieve, separate the <5 mm fraction from the >5 mm fraction. Discard the > 5 mm fraction
- Air dry the <5 mm fraction at 40-60°C and weigh
- Using a 2 mm sieve, separate and weigh a 50-100 g subsample. This should provide sufficient soil for the desired analyses (typically around 50-100 g)
- Oven dry the <2 mm fraction at 105°C for 24 h, and then re-weigh to obtain oven-dry moisture content. Soil analyses are generally reported on an oven-dry or air-dry basis (specified by analysis methodology)
- If necessary, air-dried soil can be stored in plastic containers until ready for analysis.

For more information contact:

Le Thanh Quang
Forest Science Sub-Institute of Vietnam
01 Pham Van Hai St
Tan Binh District
Ho Chi Minh City
E-mail:
quangfssiv@yahoo.com

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Australian Centre for International Agricultural Research

Acknowledgments: Thanks to Daniel Mendham for his help with the English text

HOW TO DESCRIBE SOIL FOR SITE SELECTION

Describing the soil continued...

5. Soil strength

- Strength of the soil is resistance to breaking or deformation. Strength is tested on a 20 mm diameter piece of soil

Strength	Force required to break/deform soil particles
Loose	No force
Very weak	Very small force, almost nil
Weak	Small but significant force
Firm	Moderate or firm force
Very firm	Strong force but within power of thumb and forefinger
Strong	Beyond the power of the thumb and forefinger. Crushes underfoot on hard, flat surface with small force
Very strong	Crushes underfoot on hard, flat surface with full body weight applied slowly
Rigid	Cannot be crushed underfoot by full body weight applied slowly

6. Other soil characteristics

McDonald and Isbell (2009) describe more detail on other soil features, which should be noted and described where present, including the following:

- Descriptions for organic soils
- Rocks
- Soil fabric
- Cutans
- Voids
- Consistence
- Water repellence
- Hard pans
- Roots
- Drainage

Health and safety

- Soil pits of greater than 1 m depth are a significant safety hazard and are illegal in some jurisdictions. Deeper pits must be shored to prevent any possibility of collapse.

Reference

This information sheet draws heavily on the "Australian Soil and Land Survey Field Handbook, 3rd Edition" by the National Committee on Soil and Terrain, CSIRO Publishing, 2009, and specifically the "Soil Profile" chapter by R. C. McDonald and R.F. Isbell. The book should be used as the ultimate reference and contains much more detail on describing soil profiles and other features.

For more information contact:
Le Thanh Quang
Forest Science Sub-Institute of Vietnam
01 Pham Van Hai St
Tan Binh District
Ho Chi Minh City
E-mail:
Compiled by Maria Ottenschlaeger, CSIRO
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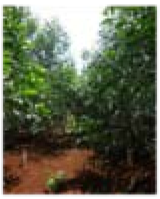
Acknowledgements:
Thanks to Daniel Mendham for his help with the English text

How to describe soil for site selection

TECHNICAL INFORMATION SHEET — *ACACIA* HYBRID SERIES



FACTS

- Site selection is a critical step towards ensuring that the plantation has the capacity to grow productively and profitably
- Soil depth and fertility are key factors that need to be accounted for in selecting a suitable site
- Soil profile descriptions offer a good way to assess these factors and determine the suitability of the site for planting Acacia hybrid.

Plate 1 and 2. Face and step of soil pit

Exposing the soil

Soil pits are the most common way to expose the soil to around 1 m depth. Coring or drilling is usually required to go deeper than this. Soil pits should be dug to expose a single face of about 1 m width on one side and stepped for ready access on the opposite side (**Plate 1 and 2**).

Describing the soil

1. Horizon depths

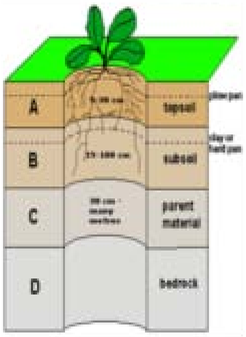
Record the depths of the different horizons with a tape measure placed down the side of the pit. Note that not all soils have all horizons, so only those horizons present need to be described. The possible horizons (**Plate 2**) are as follows.

O Horizons are dominated by organic materials and may or may not be present

- O1 is predominantly undecomposed debris
- O2 is predominantly decomposed

Mineral soil

- A horizons are surface mineral horizons with some accumulation of organic matter
  - A1 is at or near the surface, is the darkest horizon and has the most biological activity
  - A2 usually has some organic matter but not as much as A1
  - A3 is a transitional horizon between A and B
- B horizons generally have less organic matter than A horizons, and are defined as follows
  - B1 is a transitional horizon between A and B
  - B2 (B3, B4...) has one or more of the following:
    - Different structure and/or consistency and/or stronger colours
    - An illuvial, residual or other concentration of silicate clay, or iron, aluminium or humus, either alone or in combination
- C horizons are usually only partially weathered, and are characterised by lack of pedological development
- Depth to bedrock should be recorded if known



HOW TO DESCRIBE SOIL FOR SITE SELECTION

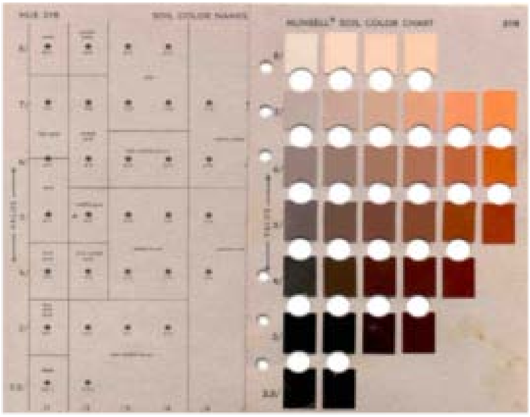
Describing the soil continued...

2. Soil colour

Colours from each of the layers defined above should be recorded, by matching it to the closest colour on the Munsell Colour system in the chart opposite.

Record Hue value and chroma, for example 10YR4/2

- Soil colours should be recorded for moist soil, so water may need to be added to dry soil
- Note any mottling based on its abundance, size, contrast, and colour



Field texture	Soil bolus characteristics	Ribbon length
Sand	No coherence, bolus cannot be moulded	No ribbon
Loamy sand	Slight coherence	~5 mm
Clayey sand	Slight coherence, many sand grains stick to fingers	5-15 mm
Loam	Coherent but sandy to touch	15-25 mm
Loam	Coherent and spongy, no obvious sandiness	~25 mm
Silty loam	Coherent bolus, very smooth/silky when manipulated	~25 mm
Sandy clay loam	Strongly coherent, sandy to touch	25-40 mm
Clay loam	Coherent plastic bolus, smooth to manipulate	40-50 mm
Silty clay loam	Coherent smooth bolus, plastic and silky to touch	40-50 mm
Light clay	Plastic bolus, smooth to touch, slight resistance to ribbon creation	50-75 mm
Light medium clay	Plastic bolus, smooth to touch, slight to moderate resistance to ribbon creation	~75 mm
Medium clay	Smooth plastic bolus, can be moulded into rods without fracture, moderate resistance to ribbon creation	~75 mm
Medium heavy clay	Smooth plastic bolus, can be moulded into rods without fracture, moderate to firm resistance to ribbon creation	>75 mm
Heavy clay	Smooth plastic bolus, can be moulded into rods without fracture, firm resistance to ribbon creation	>75 mm

3. Field texture

- Field texture should be done on the fine earth (<2 mm) fraction for each of the horizons identified above. Soils with coarse fragments may need sieving first. Field textures are assessed on a bolus of soil, prepared as follows:
- Take a sufficient soil sample to fit comfortably into the palm of the hand
- Moisten the soil with water, but use a little at a time
- Knead until the ball of soil just fails to stick to your fingers; this is known as the sticky point
- Continue kneading and moistening, usually for 1-2 minutes, until there is no apparent change in the soil ball
- Press out a ribbon of soil between forefinger and thumb
- Key field textures likely to be encountered are shown in the table opposite

4. Soil structure

- Soil structure is the distinctness, size and shape of peds or soil aggregates, and has the categories shown in the table adjacent

Structure	Description
Single grain	Loose, incoherent mass of individual particles. No pedal structure
Massive	Coherent but no obvious pedal structure
Weak pedality	Peds are indistinct and barely observable
Moderate pedality	Well-formed and evident peds
Strong pedality	Peds quite distinct

11.4 Appendix 4: Audit of FSSIV's Analytical Laboratory February 2009

Background

The chemistry laboratory is an essential component of the planned ACIAR project and we need to have confidence in the results that it provides to support scientific outcomes and to make recommendations about plantation management. A two-week visit during the first six months of the project was planned to examine ways of upgrading their protocols for sample preparation, digestions and analysis. In particular a review of FSSIV capacity to undertake the following analyses was requested:

Soil

Organic carbon

Total P

Available P

Total N

Available nitrogen

pH

Conductivity

Exchangeable cations (Ca, Mg, K)

Plants

Total N

Total P

Total Ca

Total Mg

Total K

The review of capacity included serviceability of available infrastructure (equipment and instruments) and the training and skills of the laboratory staff. Where possible, both of these aspects of the capacity were improved to ensure a satisfactory outcome from the laboratory.

The FSSIV staff members trained were:

Mr Le Thanh Quang

Ms Tran Thi Thu

Ms Nguyen Thi Minh Ty

Individual methodologies

Plant and Soil certified standards were purchased from ASPAC (Australasian Soil and Plant Assurance Council). Laboratory staff were trained in, and practised on, the use of these standard samples.

1. Soil organic carbon

The current methodology for Soil Organic Carbon (SOC) relies upon Walkley Black manual digestion and titration. This part of the methodology was working satisfactorily.

However, two significant safety issues were identified in this first part of the analysis:

A critical step in the procedure requires addition of 20 mL concentrated H_2SO_4 to the reagent mixture. The equipment currently used (a rubber bulb and pipette) is inappropriate. It led to acid spillage and the strong possibility of acid burns to laboratory staff.

The acid addition step results in emission of dichromic acid fumes, which are toxic and according to MSDS are:

"…..extremely destructive to tissues of the mucous membranes and upper respiratory tract. May cause ulceration and perforation of the nasal septum. Symptoms may include sore throat, coughing, shortness of breath, and labored breathing. May produce pulmonary sensitization or allergic asthma. Higher exposures may cause pulmonary oedema."

OUTCOME: Acid addition should not be done on an open bench as practised currently.

ACTIONS:

1. **Procure H_2SO_4 acid dispenser (Optifix or similar). Cost is approximately $750. (obtained during the period of training)**
2. **Procure two auto-pipettes (2 mL, 10 mL). Cost is approximately $600**
3. **Acid must be added in a well-ventilated environment where fumes are extracted away from operator**
4. **The exhaust fan must be on at all times when operating the digestion system.**

The current method of measuring SOC is based on titration of the dichromate digestate. Colorimetric determination is more efficient (more samples per hour) and less prone to operator error, and will lead to a more consistent result.

OUTCOME: Laboratory staff members were trained in colorimetric determination of SOC; the equipment is already available.

Testing against ASPAC samples

Sample	Expected value	Obtained value	Within tolerance?
A	3.3%	3.4%	Yes
B	0.99%	1.00%	Yes

Conclusion

- Colorimetric determination of SOC using UV spectroscopy is working well

2. Soil exchangeable K, Ca, Mg

The current procedures for extracting soil cations are generally acceptable. A swirling-type shaker rather than a rolling shaker is employed, but this may not greatly affect the extraction of cations, as both have a relatively gentle action (This was not the case and purchase of a rolling shaker is now recommended). Otherwise, consumables and equipment for this procedure are readily available.

Potassium (K) can be analysed on the flame photometer. This instrument has relatively low sensitivity, but the samples that are being examined in this project should have sufficient levels for this not to be an issue.

Calcium (Ca) and magnesium (Mg) must be analysed on the atomic absorption spectrometer (AAS). We achieved good calibrations for both elements. However the calibration for Mg was curvilinear and had relatively low sensitivity above 5 ppm.

OUTCOME: A calibration spreadsheet was produced to allow accurate curve fitting and sample calculations for Mg concentration.

The determination of low levels of Ca will be problematic because sensitive Ca analysis requires a nitrous oxide flame. Ostensibly the equipment is installed correctly to allow this to occur, but apparently the instrument installer nearly incinerated the laboratory upon instrument commissioning, so this technique has not been used.

ACTIONS:

1. **Continue to analyse Ca using acetylene flame (not nitrous oxide)**
2. **Use a curvilinear function (spreadsheet provided) for Mg analysis, and ensure samples are below 5 ppm. Dilute to get into this range if necessary.**
3. **Remove N_2O cylinder from the lab and secure the acetylene cylinder against the wall by means of a chain to prevent accidental knocking over.**

Testing against ASPAC samples

Element	Sample	Expected value	Obtained value	Within tolerance?
K	A	1.59%	1.33%	Yes
	B	0.325	0.341%	Yes
Ca	A	21.6% - 23%	29% - 32%	No – too high
	B	1.7% -1.9%	1.7% - 2.2%	Yes
Mg	A	8.6% - 9.2%	9.8% - 8.15%	Yes
	B	0.65% - 0.73%	0.83% - 0.62%	Yes

Conclusion

The performance of the AAS is acceptable

Deviation of the Ca analysis is quite high, compared to certified sample results, most probably due to difference of speed and motion of shaking. The result can potentially be improved if the extraction is using a rolling shaker at slow speed.

ACTION:

1. **Procure a rolling shaker to standardise exchangeable cation extraction methodology**

3. Soil total N

The current methodology for soil N analysis requires a perchloric acid digest, followed by titration. This method has potential safety issues because perchloric acid is quite unstable and can explode if it is not well managed. An alternative method is the H_2SO_4/H_2O_2 Kjeldahl digest; the current equipment is capable of reaching temperatures required for this method.

OUTCOME: Laboratory staff trained in H_2SO_4/H_2O_2 Kjeldahl digestion.

ACTIONS:

1. **Use sulphuric acid digest method only.**
2. **Ensure that any remaining perchloric acid is disposed of appropriately**

Testing against ASPAC samples

Sample	Expected value	Obtained value	Within tolerance?
A	0.29%	0.3%	Yes
B	0.078%	0.052%	Yes – see note below

Conclusions

Digestion method and titration determination are working well on samples that have high N concentration (Sample A)

The deviation at low N content (Sample B) is high due to detection limit/error of titration method

ACTION:

1. **If expected value of Soil Total N is low, increase the weight of the sample**

4. Soil available N

Soil available nitrogen requires measurement of mineral N pools (ammonium and nitrate). These have not been assessed to date in this laboratory. To commission this laboratory for analysis of ammonium and nitrate is not a trivial task as these are typically assessed on an auto-analyser. Manual analysis based on colorimetry is potentially possible, but was not explored in more detail on this visit, in order to focus on higher priority analyses.

5. Soil total P

Soil total P is assessed on the same digest as total N, but with a colorimetric assessment of the digest. Thus the same recommendations apply to the digest phase of the analysis. The remainder of the analysis is satisfactory.

Results of testing against ASPAC samples

Sample	Expected value	Obtained value	Within tolerance?
A			
B	0.013%	0.012%	Yes

Conclusion

Sample A will be repeated as the results suggested contamination

6. Soil Available P

Two methods of available P were assessed: Olsen and Bray. Olsen has a basic extracting medium, whilst Bray has an acidic extracting medium. Laboratory staff were trained in use of a modified Bray method that has been commonly employed in the Perth laboratory. This method involves a longer shaking time (5 minutes compared to 1 minute), which has the benefit of being more repeatable and also extracting more P from forestry soils. Both the Olsen and modified Bray methods were satisfactorily tested.

OUTCOME: Modified Bray method taught to laboratory staff

Results of testing against ASPAC samples

Element	Sample	Expected value	Obtained value	Within tolerance?

Olsen	A	27.8	27.6	Yes
	B	15.8	15.4	Yes
Bray (1'shaking)	A	20.7	22.3	Yes
	B	29.6	31.6	Yes

Conclusion

Olsen and modified Bray determinations are working well

7. Soil pH and conductivity

The instrumentation for measuring soil pH is of good quality and working well. The laboratory does not own a conductivity meter, so the Ec can not be assessed.

OUTCOME: Purchase conductivity meter could be considered but this is not really necessary as we are unlikely to be working with saline soils

8. Plant analyses

Many of the techniques and instrumentation for plant analyses are the same as for soils, so they are grouped together here. As the material must first be digested, and the laboratory staff have been using the digestion methodology based on H_2SO_4/H_2O_2, as recommended for soils.

Results of testing against ASPAC samples

Element	Sample	Expected value	Obtained value	Within tolerance?
N	A	2.47%	2.40%	Yes
	B	2.81%	2.85%	Yes
P	A	0.147%	0.140%	Yes
	B	0.241%	0.237%	Yes
K	A	0.68%	0.71%	Yes
	B	2.51%	2.6%	Yes
Ca	A	0.83%	0.70%	Yes
	B	1.35%	0.96%	No – too low
Mg	A	0.14%	0.17%	Yes
	B	0.23%	0.23%	Yes

Conclusion

With the exception of one determination (Ca Sample B to be rechecked), all analyses are working well

Overall QAP recommendations

General laboratory hygiene and quality assurance practices were assessed and the following actions are recommended:

- Purchase two auto-pipettes 2ml and 10ml (50 ml dispenser already been supplied by Dr Chris B)
- Purchase smaller size (20 ml) titration burette (to facilitate more accurate measurement of lower volumes), and 30 × 100 ml volumetric flask
- Purchase about 30 × 250 ml digestion flasks to suit the exhaust system for revised digestions of Soil Organic Carbon
- Purchase of roller shaker (Mr Quang to provide the quotes)
- Include standard soil and/or plant samples in each batch of samples being analysed, and check that values are within expected tolerances
- Include blanks (treated the same as the samples) in each batch to check for any contamination
- Keep a continuous record of the value of standard material
- Remove all glassware from the chemical cabinet to avoid contamination
- Store cleaned glassware only in a separate cabinet

Major safety recommendations

- Purchase safety glasses. Laboratory staff expected to wear protection gear when working with the dangerous chemicals
- Modify the digestion and distillation systems as discussed during the Business and Planning Meeting on 20th February. This requires:
- Moving the digestion system up to bench height
- Moving distillation system down to the bench height.
- Reconfiguring the exhaust system
- The purchase about 30 × 250 ml digestion flasks to suit the revised exhaust system

The bench will also facilitate the transfer of chemical from the floor (current system) to bench height.

Tuyen Pham, CSIRO

11.5 Appendix 5: Field Extension Workshops

Australian Centre for

International Agricultural Research

FST/2006/087. Optimising silvicultural management and productivity of high-quality acacia plantations, especially for sawlogs

Report on participation, presentations, discussion and field visits for three Field Extension Workshops held at Dong Xoai (14th-15th December 2012), Dong Ha (18th May, 2012) and Ba Vi (21st -22nd May 2012)

Lists of Participants

Dong Xoai

No	Name	Role	Affiliation
1	Chris Beadle	Research Scientist	CSIRO, Australia
2	Phạm Thế Dũng	Director	FSSIV, HCMC
3	Vương Đình Tuấn	Deputy Director	FSSIV, HCMC
4	Kiếu Tuấn Đạt	Research Scientist	FSSIV, HCMC
5	Phạm Văn Bốn	Research Scientist	FSSIV, HCMC
6	Võ Trung Kiên	Research Scientist	FSSIV, HCMC
7	Nguyễn Ngọc Hưng	Accountant	FSSIV, HCMC
8	Nguyễn Thị Thùy Dương Ái Quyên	Cashier	FSSIV, HCMC
9	Trần Bá Phú	Technical	FSSIV, HCMC
10	Tạ Tấn Lợi	FSSIV, HCMC	FSSIV, HCMC
11	Bùi Văn Nhự	Technical	PT2 - Hai Vuong Joinstock company, Binh Phuoc Prov.
12	Phạm Văn Tám	Grower	Minh Duc commune, Hon Quan dist., Binh Phuoc Prov.
13	Trần Thị Sáu	Grower	Minh Duc commune, Hon Quan dist., Binh Phuoc Prov.
14	Võ Thị Thanh	Grower	Minh Duc commune, Hon Quan dist., Binh Phuoc Prov.
15	Hồ Thị Mai	Grower	Minh Duc commune, Hon Quan dist., Binh Phuoc Prov.
16	Phạm Thị Minh	Grower	Minh Duc commune, Hon Quan dist., Binh Phuoc Prov.
17	Phạm Văn Sinh	Grower	Minh Duc commune, Hon Quan dist., Binh Phuoc Prov.
18	Nguyễn Văn Sơn	Grower	Minh Duc commune, Hon Quan dist., Binh Phuoc Prov.
19	Hoàng Văn Hùng	Grower	Minh Duc commune, Hon Quan dist., Binh Phuoc Prov.

20	Hoàng Văn Tấn	Technical	Minh Duc commune, Hon Quan dist., Binh Phuoc Prov.
21	Đỗ Bình	Technical	Kim Tin MDF Joinstock company, Dong Phu, Binh Phuoc.
22	Cao Xuân Hưng	Officer	Forest Department in Binh Phuoc prov.
23	Trần Trung Dũng	Technical	PT2 - Hai Vuong Joinstock company, Binh Phuoc Prov.
24	Trần Công Năm	Manager	PT2 - Hai Vuong Joinstock company, Binh Phuoc Prov.
25	Phan Văn Toại	Technical	PT3 - Hai Vuong Joinstock company, Binh Phuoc Prov.
26	Trần Đạo Trung	Technical	PT1 - Hai Vuong Joinstock company, Binh Phuoc Prov.
27	Trần Văn Tuất	Technical	Ta Thiet Forest Unit - Hai Vuong Joint Stock company, Binh Phuoc Prov.
28	Nguyễn Quang Thành	Technical	PT4 - Hai Vuong Joint Stock company, Binh Phuoc Prov.
29	Nguyễn Thanh Trí	Technical	Phu Thanh - Hai Vuong Joint Stock company, Binh Phuoc Prov.
30	Bùi Văn Trương	Technical	Bu Gia Phuc Forest Unit - Hai Vuong Joint Stock company, Binh Phuoc Prov.
31	Bùi Tấn Lộc	Officer	Bình Dương Forest Enterprise
32	Trần Văn Đăng	Researcher	Tan Phu Forest Experimental Station
33	Nguyễn Thanh Minh	Researcher	South East Forest Scientific and Production Center
34	Nguyễn Hữu Thế	Student	Agro-Forestry University, HCMC
35	Doãn Thi Thu Hằng	Student	Agro-Forestry University, HCMC
36	Cao Thị Trang	Student	Agro-Forestry University, HCMC
37	Nguyễn Ngọc Trí	Student	Agro-Forestry University, HCMC
38	Phùng Đức Dũng	Student	Agro-Forestry University, HCMC

Dong Ha

No	Name	Role	Affiliation
1	Le Xuan Tien	Director	North Central Forest Scientific and Production Center
2	Nguyen Xuan Hoang	Vice-Director	North Central Forest Scientific and Production Center
3	Pham The Dung	Director	FSSIV, HCMC
4	Kieu Tuan Dat	Research Scientist	FSSIV, HCMC
5	Chris Beadle	Research Scientist	CSIRO, Australia
6	Pham Xuan Dinh	Researcher	North Central Forest Scientific and Production Center
7	Dang Minh Khanh	Extension	Agricultural Extension Quang Binh

8	Nguyen Minh Chau	Extension	Agricultural Extension Thua Thien Hue
9	Cao Duy Hong	Manager	Forest Protection Department of Quang Tri
10	Ho Dinh Phuc	Vice-Director	Forest Development Department of Quang Tri
11	Nguyen Xuan Thanh	Manager	Trieu Hai Forest Company Ltd
12	Le Lu	Director	Duong 9 Forest Company Ltd
13	Nguyen Cuu Tuan	Extension	Agricultural Extension Dakrong
14	Le Van Hoa	Vice-Director	Forest Development Department of ThuaThien Hue
15	Nguyen Huu Huy	Manager	Forest Development Department of ThuaThien Hue
16	Dang Thi Bay	Extension	Agricultural Extension Cam Lo
17	Dang Thi Men	Extension	Agricultural Extension Trieu Phong
18	Nguyen Thi Lieu	Manager	North Central Forest Scientific and Production Center
19	Nguyen Thi Ngan	Extension	Agricultural Extension Gio Linh
20	Nguyen Xuan Minh	Vice-Director	Ben Hai Forest Company Ltd
21	Nguyen Van Thien	Manager	Ben Hai Forest Company Ltd
22	Pham Ngoc Dong	Extension	Agricultural Extension Quang Tri
23	Pham Xuan Thanh	Manager	Forest Development Department of Quang Binh
24	Le Van Diem	Farmer	Trieu Do - Trieu Phong - Quang Tri
25	Nguyen Van Han	Manager	Forest Protection Department Quang Binh
26	Pham Tien Hung	Researcher	North Central Forest Scientific and Production Center
27	Nguyen Hai Thanh	Researcher	North Central Forest Scientific and Production Center
28	Nguyen Hoa	Researcher	North Central Forest Scientific and Production Center
29	Nguyen Tung Lam	Researcher	North Central Forest Scientific and Production Center
30	Le Cong Dinh	Researcher	North Central Forest Scientific and Production Center

Ba Vi

No	Name	Role	Affiliation
1	Ha Huy Thinh	Director	Research Centre for Forest Tree Improvement
2	Phi Hong Hai	Research Scientist	Research Centre for Forest Tree Improvement
3	Pham The Dung	Director	FSSIV, HCMC
4	Kieu Tuan Dat	Research Scientist	FSSIV, HCMC
5	Chris Beadle	Research Scientist	CSIRO, Australia
6	John Kellas	Observer	Australian Volunteers International, FSIV

7	Do Thanh Tan	Technician	An Hoa Paper Joint-Stock Company, Tuyen Quang
8	Duong Minh Tuan	Director	Forest Department of Quang Ninh
9	Nguyen Thi Thanh Ha	Vice-Director	Forest Department of Quang Ninh
10	Hoang Van Chuc	Director/ Manager	Bac Giang Forest Company Ltd
11	Nguyen Van Nam	Technician	Bac Giang Forest Company Ltd
12	Tran Van Dang	Manager	Forest Department of Lao Cai
13	Tran Quang Dai	Manager	Forest Department of Lao Cai
14	Nguyen Duc Hai	Extension	National Agricultural Extension, Ha Noi
15	Nguyen Ke Tiep	Extension	National Agricultural Extension, Ha Noi
16	Nguyen Anh Dung	Vice-Director	Cau Hai Silvicultural and Experimental Research Centre, Phu Tho
17	Do Van Noi	Technician	Sustainable Development Joint-Stock Company, Quang Ninh
18	Nguyen Huy Vien	Manager	Yen Hung Joint-Stock Company , Quang Ninh
19	Do Thanh Van	Technician	Yen Hung Joint-Stock Company , Quang Ninh
20	Vu Tien Lam	Researcher	Silvicultural Division, FSIV
21	Duong Thanh Hoa	Researcher	Research Centre for Forest Tree Improvement
22	Can Thi Lan	Researcher	Research Centre for Forest Tree Improvement
23	Mai Trung Kien	Researcher	Research Centre for Forest Tree Improvement
24	Dong Thi Ung	Researcher	Research Centre for Forest Tree Improvement
25	Nguyen Van Tan	Researcher	Research Centre for Forest Tree Improvement
26	Do Hoang Anh	Researcher	Research Centre for Forest Tree Improvement

Presentations

Introductions to workshop

Mr Dat (Dong Xoai) **Mr Dinh** (Dong Ha), **Dr Hai** (Ba Vi) welcomed participants to the workshop

Opening address

Dr Dung, Director of the Forest Science Sub-Institute of Vietnam (Dong Xoai), **Mr Tien** (Director of FSIV Dong Ha Research Centre (Dong Ha) and **Dr Thinh**, the Director of FSIV's RCFTI Research Centre (Ba Vi) gave the Opening Addresses.

Presentations at all workshops

Dr Chris B introduced the project and the logic developed for undertaking the work. A financial analysis had shown that gains could be made by smallholders by managing acacias for sawlogs rather than pulpwood. Vietnam was also then importing 80% of its acacia logs. He spoke about the importance of uniformity of approach to scientific experiments when comparisons were being made on response of tree growth across a range of environments. Establishment practices were uniform across the project and phosphorus (P) had been applied to ensure that trees were not limited by P supply. The rate chosen had been based on an experiment in Indonesia. One of the biggest issues with *Acacia* hybrid was that its vigour was associated with poor form. Pruning practice to produce single straight stems had been a large part of the project. Site quality was a major determinant of yield and it was necessary to understand potential basal area at harvest and use this to work out stocking and tree size at harvest. A pilot experiment in a 2.5-year-old Acacia hybrid experiment near Dong Hoi between 2006-2008 had established that significant diameter responses to thinning are observed as early as six months and sustained until at least two years after treatment, and are associated with and these were associated with significant differences in total basal area between treatments during the same period. Thinning also led to substantial increases in harvestable saw-log volume by age 4.5 years. The ACIAR Project was intended to develop the detail on preferred approaches to thinning in particular but in the context of well-defined pruning and fertiliser practices.

Dr Dung examined issues relating to sustainability of production. Erosion, slash and litter burning can have damaging effects on soils. Burning can lead to up to 700 kgN/ha being lost from sites in Australia. Intensity of harvest and site management can also have consequences for nitrogen lost from the system. Percentage of N lost can be as little as 5-10% if only wood is removed at harvest but as high as 40-80% if slash is removed or burnt. In a local context, he illustrated the effects of slash removal and poor site preparation at Dong Ha which had led to soil erosion. However slash retention increases fire risk. The trade-offs are not clear at the present time. Slash retention, however, is associated with improved nutritional balances. This has been illustrated in a range of experiments where slash is either removed, retained or doubled. This has positive effects on growth after planting, particularly on the supply of N and P.

Mr Dat (1st presentation) spoke to four Technical Information Sheets (TIS) on Bamboo control, Fertiliser at planting, Tip pruning and Lift pruning. These are appended to this summary. At the Dong Xoai workshop, **Mr Bon** assisted Mr Dat, presenting the TIS on Tip and Lift pruning.

Mr Dat (2nd presentation) first spoke to a fifth Technical Information Sheet on Thinning (see attached).

He then considered the design and management of the project's longest running experiment at Phan Truong Hai. Significant diameter responses to thinning are apparent for both thinning times. There have been no responses to fertiliser at thinning at this site. Because of the delay in thinning, diameter growth is less in the same treatments in Thinning #3 (at age 3 years) than Thinning #2 (at age 2 years), except for the unthinned treatments. A second unthinned control was monitored in the adjacent unthinned commercial plantation. This plantation received 18.3 kgP/ha and weed control was by inter-row ploughing. The trees were singled. Height growth is currently about 1 m less and dbh 1.3 cm less than in the unthinned treatment in the ACIAR plantation. Heart rot associated with pruning of large branches exacerbates the incidence of branch and stem breakage.

Mr Quang (presentation given by Dr Chris B as Mr Quang's was absent in Korea. He examined the soil physical and chemical properties of the ACIAR plantation sites, and using information on soil total nitrogen, extractable phosphorus and organic carbon, interpreted their relationship to observed growth rates. All soils are P-fixing and basalt soils are the most strongly P-fixing. However the basalt soils also had the highest levels of organic C and total N. These were associated with the highest growth rates. In spite of their high P-fixing ability, the soil solution is more readily replenished from the very high stores of P. 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. This may be related to their high N-fixing ability.

Presentation at Dong Ha

Mr Dinh considered the Satellite trials and detailed the thinning and fertiliser treatments. The plantation had been established in November 2009. The thinning and fertiliser treatments were applied in December 2011. Diameter at age 2 years was 7.3 cm. Across the various trials at age 2 years, dbh has varied between 6.7 and 9.7 cm. The faster-growing sites are in the south, the slower-growing sites in central and northern Vietnam. As treatments at Dong Ha had only been applied 4 months ago, treatment differences are emerging but not yet significant.

Presentation at Ba Vi

Mr Lam described the establishment and management of the Core Trials at Ba Vi. One examines growth responses to four thinning treatments and three thinning times, the second responses to two thinning treatments and three fertiliser treatments. He detailed the formulation of the basal fertiliser and the preparation and application of the fertiliser. Two years after thinning #1 at age 3.8 years, there have been significant responses to thinning two years after thinning. In the other trial, there have been significant responses to thinning and fertiliser application at thinning. However, there was no significant response to P50 alone in the unthinned treatment, and there was no difference between the fertiliser treatments in the thinned treatments. He then talked about the Satellite trials at Ba Vi and Tuyen Quang. Both trials were growing at similar rates, approximately 8 cm diameter at age 2.5 months. He placed these in the context of growth rates at all the Satellite trials. They were similar to those in Central Vietnam but lower than those in the south.

Dr. Hai provided information on RCFTI research activities related to improvement of both acacias and eucalypts in RCFTI. For both, the focus has been not only on growth increment, but also on the genetic variation of wood properties for saw-log and pulpwood. To date, 130 stock types have been approved by the Ministry of Agriculture and Rural Development. These include clones of *Acacia* hybrid, *Acacia auriculiformis* and *Eucalyptus* hybrids which have characteristics suitable for sawn-timber plantations. Growth increment of these clones can reach up 25 to 40 m^3/ha/year. RCFTI are able to transfer all improved materials to production organisations for wider deployment.

The names of suitable clones and the addresses of nurseries where participants can buy the genetic materials were passed on to participants.

Discussion

Dong Xoai

Questioner not identified: Quality of planting stock was important to the success of the plantation.

Answer: There has been no systematic examination of planting stock in this project, but we agree with the questioner. It does appear that cuttings taken from old clonal hedges lead to trees with poor form. However, our understanding is that how cuttings are taken from clonal hedges also affects expression of form. A new experiment planted in August 2011 is examining the effects of hedge age (new andn old hedges) and fertiliser addition on the growth and form of three clones of *Acacia* hybrid. The results from this experiment should be available at the end of 2012.

Questioner not identified: Slash retention increases fire and termite risk.

Answer: Slash retention has positive effects on the early growth of trees in the next rotation by conserving nutrients on site and also by protecting soils from erosion during the inter-rotation period. These values have to be traded off against increased fire risk. At an ACIAR plantation at Xuan Loc, damage to seedlings by the black chafer **(*Holotrichia morosa*)** may have been associated with slash retention. Thus pest damage is also a risk that must be considered if slash is retained.

Mr Nam, Manager, Hai Vuong Phan Truong Hai: The company had not used thinning as part of its silviculture because of the uncertainty about how long it would take to deliver a financial benefit. Pulpwood markets for thinnings also meant long transport distances.

Answer. A pilot study at an *Acacia* hybrid plantation in Quang Binh province had shown that thinning from 1000 to 600 stems/ha at age 2.5 years could lead to sustained and significant increases in diameter growth for at least two years after treatment. This was associated with substantial increases in the proportion of the stem which was harvestable saw-log at age 4.5 years. At current prices for pulpwood and saw-logs at the mill gate, there was little difference in total value between the unthinned stand (7% saw-log) and the thinned stand (19% saw-log). This suggests that financial benefits can be delivered by age 5 years if stands are thinned early, without including pulpwood values from thinning, if the stand is thinned at age 2 years. The ACIAR Project is undertaking a financial analysis based on the regimes and productivity outputs of plantations like Phan Truong Hai which will be made available to project participants.

Dong Ha

Mr Hoa, Vice-Director, Thua Thien Hue Forest Department considered the workshop as providing useful information for the practice of sawlog silviculture. In his province, *Acacia* hybrid is highly vulnerable to wind damage. He considered it necessary for tree improvement programs to work on developing better planting stock. Trees are also vulnerable to fungal attacks. At present the majority of wood is grown for pulpwood. The price for pulpwood at the mill gate is $50/m^3$, for sawlogs $125/m^3$.

Answer: It is widely recognised that *Acacia* hybrid is vulnerable to wind damage; in contrast *Acacia auriculiformis* is not but has lower growth rates. Breeding programs for *Acacia* hybrid need to include resistance to wind damage and development of small branches only as selection criteria.

Mr Huy, Hue Provincial Forestry Department, noted that defect was a factor limiting production of sawlogs. The economics of sawlog production also needs to be part of the way that this project is delivered.

Answer: Mr Dat will include reference to potential heart rot associated with growing sawlogs in his talk this afternoon. The project is undertaking an economic analysis and this will be distributed to workshop participants, probably in about six months, just after the end of the project.

Mr Lu, Director of Forest Company No 9, Quang Tri province asked about rotation lengths for *Acacia* hybrid and the value of sawlogs v. pulpwood.

Answer: The case illustrated for Dong Hoi showed that sawlog recovery could be up to 30% within two years following early and heavy thinning. Rotation lengths will be longer than for pulpwood and will depend on the size of tree for the final crop. On average one might anticipate 7-10-year rotations to final harvest, with at least one or two thinnings.

Mr. Dong, Extension Officer, Dong Ha commented that the workshop is very practical and the information useful for his own work. He worked with growers who liked to plant at high densities and was also concerned about the length of time before a harvestable product was available. Even 600 stems/ha would be considered too low a final stocking.

Answer: In addition to the answer to the previous question, he was referred to Dr Chris's talk and the links between site quality, stocking and tree size. Commercial high-value sawlogs could not be grown at high stockings and some thinning would always be necessary. Thinning and particularly early thinning, also led to increased growth rates and shortened the rotation.

Mr. Phuc, Forest Department, Quang Tri Province found the presentations very interesting and useful. However, for extension purposes, it is necessary to fit the technical details to the grower's site e.g. matching sites to fertiliser treatment? How does one assess the potential height growth? As the rotation length is longer than for pulpwood, how do you measure the economic benefit? Slash retention and tip pruning would be new practices in Quang Tri province and he was interested in examining its possibilities.

Answer: The workshop has provided some general guidelines. Most sites in Vietnam will respond to some P fertiliser at planting, but much fewer sites will respond to P fertiliser at thinning. Growth rates are higher in the south than central and northern Vietnam. As indicated above, an economic analysis is being conducted. Tip pruning is necessary to control branch size and can be used throughout the year. The Technical Information sheet is designed to provide a clear guideline for Extension Officers.

Ba Vi

Ms Ha, Vice-Director, Forest Department, Quang Ninh, asked three questions. She considered Round-up was ineffective herbicide against bamboo; most growers apply N:P:K (5:10:3) at planting and she wanted to know how best to calculate how much fertiliser was required; and how do you manage for branch size in plantations. She later commented: growing sawlogs on steep slopes is difficult; permits may be required for Round-up if FSC certification required; slash is fire risk; what is the economic cost of thinning pruning?

Answers:

- The project has developed a successful procedure for dealing with bamboo in plantations using Roundup; Mr Dat will describe the procedure later this morning; a technical information sheet has been included in your folders;
- A technical information sheet has also been included on how to apply fertiliser at planting which includes calculations of the amount to apply; Mr Dat will also talk to this sheet;
- One key to managing branch size is to plant at high stockings. However fast-growing *Acacia* hybrid can still develop large branches and Mr Dat will describe a tip pruning technique to prevent this happening. There appears to be variation in branch size between trees but it is not clear whether this is linked to clone. Unfortunately heritability of branch size is low, but nevertheless breeding programs are required which include branch size as a selection criterion;

Mr Dai, Manager, Forestry Department, Lao Cai asked whether the project investigated termite control.

Answer: No. The only pest and disease activity was related to the incidence of heart rot which at one site in southern Vietnam was associated with the pruning of large branches. Termites and other pest may be associated with slash retention but this had not been investigated systematically.

Mr Hai, Manager, National Agricultural Extension, Hanoi. Why, how much and when should fertiliser be applied; how does the response work; can fertiliser be applied if FSC certification is being sought?

Answer: Application of fertiliser at planting accelerates establishment and early growth of trees. Mr Dat will refer to the amount that should be applied. As acacias fix N, the greatest benefit is received by applying P which is required for the N-fixing process. Most research indicates that benefits from applying P are maximised by its application in a concentrated form at or near planting. However this does not exclude the possibility that growth responses to P may occur later in the rotation and we will see this tomorrow when we visit the plantations. I am unable to comment on FSC rules on use of fertilisers.

Mr Tan, Technician, An Hoa Paper Joint-Stock Company asked about the links between thinning, survival and wind damage.

Answer: Thinning does increase the risk of wind damage and fast-growing *Acacia* hybrid is particularly susceptible to stem and branch breakage. This can affect unthinned stands and we will see this tomorrow in the Satellite trial. How to manage for wind damage remains one of the big questions that needs to be resolved for acacia forestry in Vietnam.

Mr Noi, Sustainable Development Joint-Stock Company, Quang Ninh asked how do we manage thinning?

Answer: As indicated, the final stocking is determined by the tree size which is required at harvest. Multiple thinnings are likely to be the best approach to minimise the potential for wind damage but this means that markets are required for thinnings. An early first thinning when the trees are 8-9 cm in diameter is anticipated to lead to the largest growth responses. The thinned trees are of sufficient size for pulpwood.

Mr Dung, Cau Hai Silvicultural and Experimental Research Centre, Phu Tho asked if was possible to match the quantity of P to a particular site

Answer: As you will have noted from the talk, linking the requirements for P fertiliser to measures of available P is very difficult. This is why we are recommending that all sites will probably benefit from application of between 10-20 kgP/ha.

Field visits

Dong Xoai

Two trials were visited, the ACIAR Satellite Trial and National Trial at Phu Binh on the afternoon of the 14th and the ACIAR Core Trial at Phan Truong Hai on the morning of the 15th. Mr Bon described the background to the establishment of the Satellite Trials. An awareness had been created within the project about the use of planting stock raised from old hedges leading to trees of poor form which required many pruning interventions to create trees suitable for saw-log production. At Phu Binh, the planting stock had been raised from tissue culture and participants were looking at Acacia hybrid which had magnificent form and had required very little tip pruning. At age 1.4 years, trees were already nearly 7 cm in diameter, were nearing crown closure, but still had green crowns down to ground level. He compared these to other trees from cuttings planted at the same time but which had not received P fertiliser at planting. These had relatively poor form, slower growth rates and smaller crowns.

At Phan Truong Hai, Mr Nam, the local Hai Vuong manager, first described silvicultural practices which were being used by the company. Mr Dat then used the ACIAR trial to show participants how effective early thinning at age two years can be in maintaining high growth rates of individual trees; the largest trees were already 17 cm in diameter 3.5 years after planting in the most heavily thinned treatments (450 stems/ha). The adjacent commercial plantation provided a clear illustration of what can be achieved with intensive weed control, particularly of bamboo, and increased rates of P application at planting. This site used planting stock from old hedges and in spite of tip pruning, many trees developed large branches before they were removed; in addition, double leaders forming above the pruned height lead to stress fracturing where they join. Both are portals for the entry of heart rot and this is affecting a number of trees in this plantation. Mr Dat also used crown development in the various treatments to illustrate how individual crown size determines tree growth whereas stand leaf area determines stand growth. An adjacent one-year-old plantation was used to illustrate the practice of tip pruning.

Dong Ha

Participants visited two trials, the ACIAR Dong Ha satellite trial and the CARD Project Sustainability trial. In the former, participants were able to see how silvicultural inputs of 50 kgP/ha at planting, chemical weed control and tip and form pruning had created fast and straight-growing trees. They were also able to see plots thinned to 600 trees/ha four months previously and how vulnerable *Acacia* hybrid was to stem and branch breakage. Trees were of two distinct types, those with many small branches and others with fewer but often much larger branches. Extension officers promoted the view that they would find it very difficult to persuade smallholders to adopt these silvicultural practices; most just wanted to plant the trees and let them grow without any interventions. A suggestion was made that the only way to persuade growers to do otherwise was to have a network of demonstration plantations where interested smallholders were located and use these to encourage their acceptance of better silvicultural practices. The sustainability trial which was established in 2007 was used to demonstrate how responses to P applications at planting diminish after stand closure.

Ba Vi

Participants visited three ACIAR Trials and two others being managed by RCFTI. The ACIAR Satellite trial was used to illustrate the same issues as at Dong Ha. An adjacent young stand was used by Mr Lam to demonstrate tip- and lift-pruning practices. At the ACIAR Core Thinning trial Mr Lam selected plots from each treatment to show participants how the trees had responded to the #1 thinning two years previously and how the crowns had responded and then recovered from a strong wind event three months after thinning. A plot which was to be used for the #3 thinning at age 5.8 years (May 2012) was used to illustrate tree selection based on removal of first trees of poor form and then small trees, at the same time maximising evenness of spacing. The ACIAR Core Fertiliser trial which was established in May 2010 showed that significant responses to both thinning and P fertiliser can occur on sites that have received only small amounts of fertiliser at planting, and in a stand where thinning was delayed until age 3.8 years. In the stand thinned to 600 stems/ha with or without 50 kgP or 50 kgP + basal fertiliser, the significant responses to treatment were very apparent, as was individual tree crown development.

Participants also visited a grafted *A. mangium* seed orchard (CSO), a second- generation *A. mangium* seed orchard (SSO), and a clonal trial of *Eucalyptus* hybrid. The purposes were to introduce participants to programs designed to provide good genetic material for sawn-timber plantations, and to illustrate differences between stock originating from SSOs, CSOs, and elite clones.