Acacia hybrid

Ecology and silviculture in Vietnam

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CIFOR

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Preface

Smallholders plant a wide range of tree species. In Vietnam, much of the planting involves the use of fast-growing trees geared towards the production of raw materials for the pulp and paper industry and woodchips. The Vietnamese government is carrying out a large scale reforestation programme with the aim of improving local livelihood security, environmental sustainability and industrial wood supply. Smallholders are involved in plantation timber production through various schemes.

In general, smallholder plantations are successful but farmers often lack the appropriate technical knowledge for efficient tree management. The harvesting of forest products is usually the primary management activity, with other practices being less frequently conducted. As a consequence, growth rates may be suboptimal. The productivity of smallholder plantations can be improved by enhancing smallholders' management knowledge and skills, including species selection (site matching), silvicultural management to produce high quality products, and pest and disease management.

This manual is one of a series of five, produced as part of the research project Strengthening Rural Institutions to Support Livelihood Security for Smallholders Involved in Industrial Tree-Planting Programmes in Vietnam and Indonesia, a scheme coordinated by the Center for International Forestry Research (CIFOR). This project is funded by the Advisory Service on Agriculture Research for Development (BMZ/BEAF), through the German agency for international cooperation, Gesellschaft für Internationale Zusammenarbeit (GIZ) for the period 2008–2011. This manual brings together a wealth of information on *Acacia* hybrid from a variety of different sources, with particular relevance to Vietnamese sites. However, in terms of growth and yield aspect, data for this species is limited, particularly from smallholder plantations. A concerted effort has been made to collect inventory data from research sites in smallholder industrial plantations in Binh Dinh Province, Vietnam.

We believe this manual offers valuable assistance to smallholders and organisations involved in implementing tree planting programmes.

The authors

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1. Introduction

Vietnam has over 400 000 ha of *Acacia* plantations, including over 220 000 hectares of clonal *Acacia* hybrid (*Acacia mangium* × *Acacia auriculiformis*). *Acacia* hybrid has been planted extensively in the southern provinces of Vietnam, and is becoming one of the main species for industrial plantations. *Acacia* hybrid plantations have the potential to provide several environmental benefits, with fast-growing *Acacia* plantations expected to reduce the pressure on native forests as a source of industrial raw materials. Acacias also have the valuable ability to fix atmospheric nitrogen. The capacity of *Acacia* hybrid to improve infertile soils could provide an economic benefit to subsequent rotations of *Acacia* or other crops in terms of lower fertiliser requirements (Kha 2001).

2. Description of the species

2.1 Taxonomy

Botanical name: *Acacia* hybrid
Family: Fabaceae
Subfamily: Mimosoideae
Common name in Vietnam: Keo lai

2.2 Morphological characteristics

The *Acacia* hybrid is a medium-sized tree that is similar in appearance to *Acacia mangium*. The tree is capable of reaching a height of 8–10 m and a diameter at breast height of 7.5–9.0 cm within 2 years.

The morphological traits of the hybrids (flower colour, pod aspect, leaf shape and size, bark aspect and wood density) are generally an even mixture between those of the *Acacia mangium* and *Acacia auriculiformis,* its pure parent species (Chiae 1993). However, the *Acacia* hybrid differs from *Acacia auriculiformis* and *Acacia mangium* in several ways. When *Acacia* hybrid is young, the bark is greenish white, similar to the bark of *Acacia auriculiformis*. As it ages, the bark turns greenish brown or brown, eventually becoming as smooth as the bark of *Acacia auriculiformis,* with slightly scaly, shallow furrows at the foot of the tree (Lapongan 1987, Rufeld 1987, Pinso and Nasi 1991, Kijkar 1992, Kha 1996).

The hybrid's branching behaviour differs from *Acacia mangium* and *Acacia auriculiformis* in that the tree has many small, light branches that can be easily pruned. Similarly, its main stem, though not as straight as that of *Acacia mangium*, is much straighter than the main stem of *Acacia auriculiformis*. Unlike the stem of *Acacia mangium*, that of the *Acacia* hybrid has no angles or ribs (Darus and Ghani 1989, Kijkar 1992). Its phyllode is about 4–6 cm wide and 15–20 cm long, with four veins similar to those of *Acacia mangium*, with the vein on the outer edge of the crescent difficult to see. Flowers come out in July and August and again in November and December. *Acacia* hybrid begins to set flowers at about 3 years. The flowers are creamy to whitish and arranged in a straight, or slightly bent, 8–10 cm spike. Since male flowers in the hybrid are usually situated towards

Figure 1. Seeds of *Acacia mangium*
Photo by Nguyen The Dzung

Figure 2. Seeds of *Acacia auriculiformis*
Photo by Nguyen The Dzung

Figure 3. *Acacia* hybrid seedlings
Photo by Sebastian Schnell

Figure 4. Three-year-old *Acacia* hybrid plantation in Binh Dinh Province, Vietnam
Photo by Sebastian Schnell

the bottom of the spike, less than 3% of the inflorescences produce fruits (Kijkar 1992). The pod (fruit) is usually very curly and twists like the pods of all *Acacia* species. The pods mature in about 3 months (Ibrahim 1993). A pod holds 5–9 seeds. The seed is about 0.3 × 0.4 cm, and about half of it is attached to the pod by a yellowish red funicle.

2.3 Distribution

Acacia is a large genus with over 1300 species widely distributed throughout the tropics and subtropics. Most species are found in the southern hemisphere and the main centre of diversity is located in Australia and the Pacific. Within the Indonesian region alone, 29 native or naturalised species occur, and several more have been introduced, mainly in the mountain regions of Java. Most of the timber-producing species are found in New Guinea. The *Acacia* hybrid grows in China, Indonesia, Malaysia, Thailand and Vietnam (Rufled 1987, Kijkar 1992, Kha 1996). In the late 1970s, natural hybridisation between *Acacia mangium* and *Acacia auriculiformis* was first reported in Sabah, Malaysia (FAO 1982). *Acacia mangium* was identified as the female parent and *Acacia auriculiformis* as the male parent of the natural *Acacia* hybrid (Le *et al*. 1993). *Acacia* hybrid is found where mean annual temperatures are 12–35°C, annual precipitation is 1200–1850 mm and elevation is 50–350 m (Vozzo 2002).

2.4 Ecological range

The species grows on sandy-loam or sandy-clay soil; however, it also thrives on lateritic crude soils (Somyos 2003). The planting sites in Vietnam are at 8°–22 °N, and an altitude of 5–500 m. With regards to climatic conditions, mean annual rainfall is 1500–2500 mm, and mean annual temperature is 23–28 °C. *Acacia* hybrid plantations are being established in the ecological range between latitude 17 °S, longitude 145.5 °E) in north Queensland, Australia, and near Kuala Lumpur (latitude 3 °N, longitude 102 °E) and Tawau (latitude 4 °N, longitude 118 °E) in Malaysia (Sedgley *et al.* 1992)

2.5 Wood characteristics

The wood density of the *Acacia* hybrid is the product of an equal input from the Acacia mangium and Acacia auriculiformis *Acacia* hybrid are similar to those of *A. mangium*, although the hybrid has a slightly higher wood density (0.455 g/cm^3) (Kha 1996).

The physical and mechanical properties of the hybrids, such as shrinkage, moisture absorption, slide and split resistance and the static bending and rupture strength, are a mixture of the properties displayed by the parents. The root system of the hybrids has been found to be deeper than either of the parents and therefore they are rarely blown down by strong winds (IUFRO 2000).

An important feature of *Acacia* hybrid is its higher pulping potential; the paper produced from it has better mechanical strength. Its pulling and folding strength is markedly superior to paper produced from *Acacia mangium* or *Acacia auriculiformis*. The folding resistance, before and after bleaching, of paper produced from *Acacia* hybrid is 790–1300 times, whereas that resistance for *Acacia mangium* is 305–440 times and for *Acacia auriculiformis* is 417–820 times. The cellulose content of *Acacia* hybrid wood is also markedly higher than that of *Eucalyptus urophylla*, *Eucalyptus camaldulensis* and some native tree species such as *Styrax tonkinensis* and *Manglietia glauca*. These properties make the wood of *Acacia* hybrid very suitable for paper production. *Acacia* hybrid has 2–4 times more rhizobium nodules (in weight and number) than its parent species. This improves the capability of *Acacia* hybrid for soil improvement (Kha 1996).

2.6 Uses

Acacia hybrid wood is used for construction, boat building, furniture and cabinet making and veneering. It also makes excellent particle board. The pulp is easy to bleach to a very bright colour and is excellent for paper making. The tree is also used for firewood, and is occasionally planted for erosion control, as a firebreak or for ornamentation. The leaves may also be used as forage for cattle (PROSEA 1993).

The establishment of *Acacia* hybrid plantations in rural areas creates employment opportunities for poor households, which had hitherto only been possible on large-scale forestry plantations. Higher wages than those provided by farms, as well as the opportunity for unskilled labourers to acquire new competencies, make such plantations an attractive enterprise. These new skills afford people new employment opportunities in the growing, harvesting, transport and processing sectors of wood production. The disadvantage is that this work can be largely seasonal and some of the processing jobs may be available to skilled labourers only, at least initially.

Acacia hybrid plantations have the potential to provide several environmental benefits. In parts of central Vietnam, fast-growing *Acacia* hybrids have been used to stabilise hill slopes, allowing agroforestry to be practiced on steep land, where previously cultivation would have caused excessive soil erosion. Whilst *Acacia* hybrid is beneficial for this application, they are unsuitable as windbreaks because the trees tend to snap in high winds. The plantation of *Acacia* hybrid also has a role to play in reducing greenhouse gases, if the wood is not harvested for pulp or firewood. *Acacia* hybrid is gaining favour over eucalyptus for commercial pulpwood production as it is faster growing, less susceptible to disease and more adaptable to poor soil types (ACIAR 2004).

3. Propagation and planting

3.1 Clonal selection techniques and propagation methods

The clonal selection techniques and propagation methods developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) were adopted by the Vietnamese hybrid selection programme, which began in 1992. The steps involved in selecting, testing and commercialising hybrids are summarised in Figure 5. The hybrid specimens (or clones) must undergo extensive screening before being selected for commercial release. An initial round of selection is conducted based on the best performing hybrids observed growing in the field. There is, however, no guarantee that these superior traits will be retained in trees propagated by cutting. This is because both genetics and the environment exert a profound influence over performance. To ensure the selected clones are indeed superior to their parents, the clones grown under a variety of environmental conditions or 'zones' and their performance is tested (ACIAR 2004).

3.2 Clonal propagation

Low-cost mist chambers consist of pits dug in compact soil, generally 12 m long, 1.3 m wide and 27 cm deep. The pit is lined on all sides using a single layer of bricks arranged vertically. A 7 cm-thick layer of sand and pebbles is laid on the bottom. Then, 6 cm of water is poured into the pit, or alternatively the water is poured into channels (15 cm wide and 23 cm deep) on all four sides. The hydro pit is covered with polythene sheet, mounted on a semicircular bamboo or cast iron frame. The water vapour collected on the inner surface of the polythene sheet

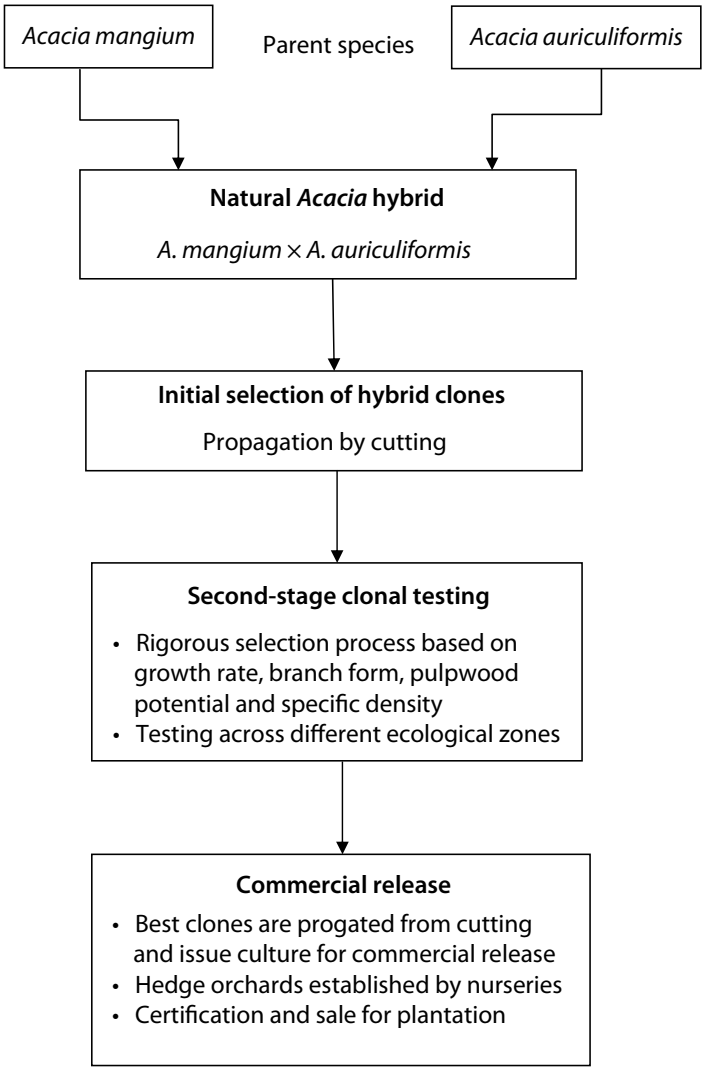

Figure 5. *Acacia* hybrid selection process
Source: Modified from ACIAR (2004)

will reduce the temperature and the drops formed will fall on the leaf laminae and continue to keep their surfaces wet.

Under favourable conditions (i.e. 80% humidity and 25–30 °C) roots develop in 20–25 days. The species should be propagated by root-cuttings (macro-cutting) or by tissue culture, as both methods have proven very successful. Cuttings from pre-juvenile plants usually root well (more than 92%). Coppicing shoots from tree stumps or from pre-juvenile shoots originating in hedge orchards should be treated with a rooting hormone and kept under controlled conditions. Relative humidity should remain above 80% and temperature below 30 °C. Tissue culture techniques have also been successfully developed using aseptic emerging seedlings as multiplication materials (WCPM 2005).

The rooted ramets are transferred to a shade house for acclimatisation and hardening. Twelve days later they are transferred to an open nursery and are nursed until they attain planting height, which occurs after about 2–3 months. The clonal identity of each plant is preserved to assess the field performance of each specimen. Clonal technology for production of outstanding, high yielding, disease resistant planting stock of *Acacia* hybrid is in the process of being perfected and is being adopted on a large scale for mass propagation.

3.3 Preparation of planting site

Land covered in grasses or light brush is cleared by bulldozers in flat or slightly undulating terrain. Land is cleared manually in steeper terrain and where residual secondary vegetation needs to be removed. The slashed vegetation is usually cleared though burning, despite the fact that this has been illegal in Indonesia and Vietnam since 1995, whereas chemical treatments are applied in areas affected by *Imperata cylindrica.* Most site preparation is designed to disturb topsoil minimally, which is quite different from site preparation for estate crops.

3.4 Planting

Clonal plants or rooted cuttings are planted in contour lines on slopes, and in straight lines on flat terrain. A 30 × 20 × 30 – 40 cm deep planting hole is used for each plant. The most suitable stocking for pulpwood plantations in Vietnam is between 1111 trees/ha (initial spacing of 3 × 3 m) and 1666 trees/ha (3 × 2 m) (CARD 2005). Spacing of the seedlings in the plantation is adjusted depending on the intended uses of the trees and the fertility of the site. Since the species displays poor natural pruning tendencies, the trees are planted close together to deter epicormic branches from occurring. In mono-specific stands, a spacing of 2 × 2 m or 2.5 × 2.5 m is common. However, if saw log production (large diameter stems) is the objective, wider spacing (3.0–3.5 m between rows and between plants) is employed. In agroforestry situations, spacing within rows and between rows must take into account the effect of shade and root competition on the yield of associated crops.

Figure 6. One-year-old *Acacia* hybrid plantation in Binh Dinh Province, Vietnam
Photo by Sebastian Schnell

In Vietnam, planting takes place twice a year, in February and August, during the rainy season, when the soil is wet, so that the seedlings can become established before the dry season starts. As soon as the land has been prepared it is marked with lines, and each planting point is marked with a stick.

Figure 7. Three-year-old *Acacia* hybrid plantation in Binh Dinh Province, Vietnam
Photo by Sebastian Schnell

4. Plantation maintenance

4.1 Weeding

Weeding is an important practice in industrial plantation and helps meet production requirements as well as quality control standards. In order to prevent trees suffering any serious slowing in growth, weeding should be timed to coincide with when the trees are least susceptible to damage. Particular care should be taken to remove climbers, creepers and vines in the first year. *Acacia* hybrid has been found to be very sensitive to herbicides (PROSEA 2011).

Generally, the greater the area weeded around a tree, the less the competition the tree is subjected to and therefore the better it grows. Typically, spot weeding is less effective than strip weeding, whereas clean weeding is optimum. Lowery *et al*. (1993) concluded from a review of weed control in tropical forest plantations that complete weeding in most cases results in the best growth and survival, but partial weeding in strips along the tree rows may be a good compromise between making soil resources available to the tree and nutrient conservation. Adherence to the general principle of 'the more weed control the better' can only be entertained when cost, the risk of soil erosion, and the possibility of reducing biodiversity are also taken into account.

Weed control conducted by manual weeding or by herbicide application has been shown to improve stand productivity. A minimum of weeding twice a year during the first 2 years of plantation growth is encouraged. After that, on more productive sites, weed growth is suppressed by the development of the tree canopy, whereas on poorer sites weed control is necessary for a longer time.

4.2 Fertilising

Fertiliser is used during the growing season to improve the health and appearance of trees. In Vietnam, the most commonly used fertilisers are nitrogen/phosphorus/potassium (NPK) mixtures, urea, superphosphate, potassium, calcium, decomposed manure, and a micro-organism-enriched fertiliser (consisting of a mixture of organic matter, micro-organisms and added nutrients). Generally, fertiliser is applied at the time of planting

and 6 months after planting. The highest dose used in Vietnam has been 25.0 g nitrogen, 25.0 g phosphorus, 20.7 g potassium and 100 g micro-organism-enriched fertiliser per seedling, applied to *Acacia* at planting (CARD 2005). Fertiliser is most effective when applied just before a good rainfall. In Vietnam, Hai *et al.* (2005) reported that adding up to 20 g of phosphorus fertiliser at planting was adequate to give a noticeable response in early height growth and has already sustained a full rotation of *Acacia* hybrid growth.

In an experiment with *Acacia* hybrid in three different ecological regions of Vietnam, Son *et al.* (2006) found that the best growth increments in Binh Duong Province occurred when a mixture of 200 g NPK (containing 28 g nitrogen, 8 g phosphorus and 10 g potassium) and 100 g of micro-organism-enriched fertiliser was applied per tree. The annual volume increment was 36.7 m^3/ha/year at age 6 years, compared to 28.8 m^3/ha/year in the control (no fertiliser) treatment.

4.3 Refilling

The first refilling is usually done in the rainy season, 1 month after planting, to replace the dead rooted cuttings or clonal plants. The second is carried out at the end of the second year. If the survival rate is less than 70% further refilling is necessary for large scale plantations.

4.4 Pruning

The purpose of pruning is to encourage trees to develop a straight stem and more valuable, knot-free trunks. High density plantations will have lower pruning costs than lower density plantations. The greater the initial distance in the tree spacing, the more artificial pruning will be necessary to produce a clear bole. The closer the spacing of trees in a higher density plantation, the more they will be forced into an upright growth habit. The resultant lack of light will increase natural pruning of the lowest branches.

Table 1. Growth in diameter and height of *Acacia* hybrid in different age classes in sample plots in Binh Dinh Province, Vietnam

Number of plots	Statistic	Number of trees/ha	Diameter (cm)	Height (m)	Diameter increment (cm/year)	Height increment (m/year)
89	Minimum	909	2.0	3.1	1.2	1.7
89	Maximum	4456	11.5	15.6	4.5	5.5
89	Mean	2166	7.7	10.6	2.6	3.6
89	Standard deviation	640	2.7	3.5	0.7	1.0

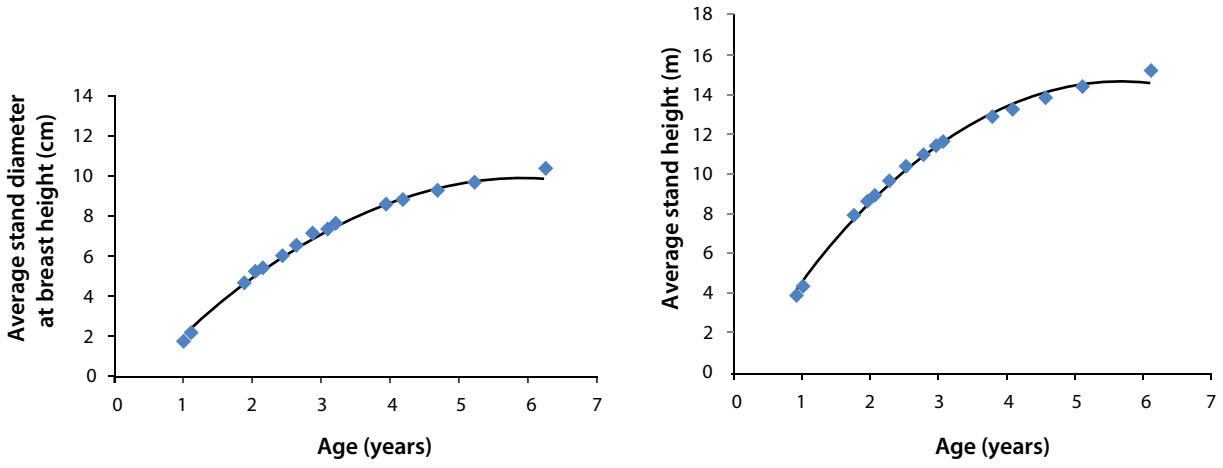

Figure 8. Growth in diameter and height of *Acacia* hybrid in different age classes in sample plots in Binh Dinh Province, Vietnam (Michailow's growth function)

Pruning some branches increases the growth rate of the remaining branches (Ramos *et al.* 1998). In contrast, careless pruning can significantly reduce growth, introduce disease and reduce timber value. When the trees reach 2 years of age, pruning in late winter can begin to develop a single stem. Pruning should be done with great care in order to avoid damage to the branch collar and the branch bark bridge, which can lead to disease. Pruning tools should always be cleaned and sharpened to ensure a clean, smooth cut.

Two common management options are stocking and form pruning. Higher initial stocking densities reduce the incidence of large branches (Neilsen and Gerrand 1999) but may lead to a reduction in the average growth of individual trees. Unlike lift pruning, form pruning selectively removes branches throughout the crown and can be used to reduce average branch size before subsequent lift pruning (Pinkard 2002). It can also be used to correct potential deviation of stems from a pathway of vertical growth (Nicholas and Gifford 1995, Medhurst *et al.* 2003).

In a review of pruning research on *Acacia* hybrid, Dung *et al.* (2005) concluded that only height growth was significantly different between pruning and no pruning treatments, as 3 years after treatment, the pruned trees were observed to be taller. It is possible that pruned branches in the lower, shaded part of the crown were unable to survive owing to their inability to photosynthesise sufficiently. In Vietnam, CARD (2005) recommended that a first pruning for *Acacia* plantations should be undertaken at the time of canopy closure and before crown lift has started. Trees selected for pruning are determined by their form, the characteristics of the branches and diameter at breast height. The number of trees pruned is determined by the distribution of log sizes required at harvest. No more than 30% of the green crown length should be removed when the selected trees are lift pruned. Form pruning may be required before canopy closure occurs to increase the numbers of trees that meet the requirements for lift pruning.

4.5 Thinning

Thinning is the selective process of removing or harvesting some trees to allow the remaining trees to maintain a steady growth rate. Thinning also provides the opportunity to selectively remove poorly formed trees and species of lower value, which are sometimes referred to as 'wolf trees'. If growth and survival vary significantly, thinning may be necessary only in areas where the trees are very dense. Monitoring the growth rate of the tree is important because the goal of thinning is to maintain steady growth. Thinning is usually conducted when the plantation is 3, 5 and 7 years old.

In plantations for pulpwood production, thinning can be carried out to achieve a final stock of 600–700 stems/ha from the 1,250 trees/ha planted. The trees are thinned after 18 months, with the entire plantation being clear-cut after 6–8 years. In plantations producing high quality logs, the initial number of trees is generally thinned, reducing the stem number from 900/ha to 100–200/ha, in 2 or 3 thinning operations. The first thinning is done when the trees are 9 m tall, that is, before 2 years of age, with the total rotation for the production of sawn timber being about 15–20 years.

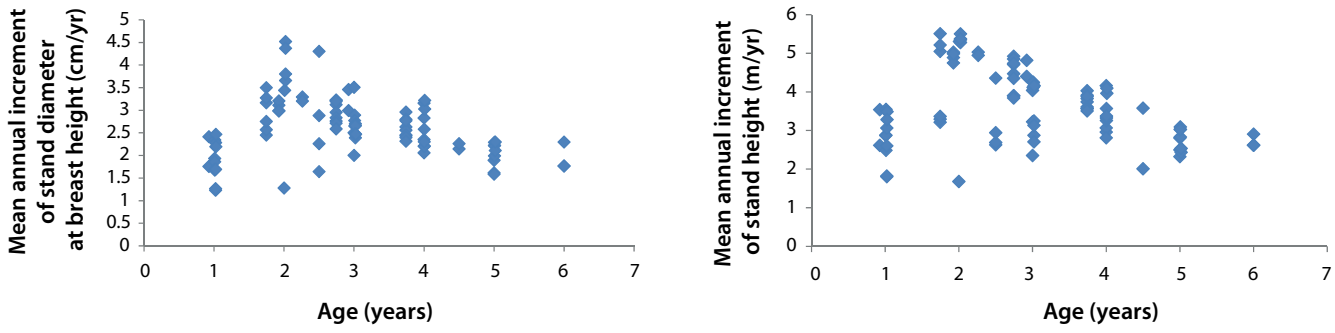

Figure 9. The average annual increase in diameter and height of *Acacia* hybrid in different age classes in sample plots in Binh Dinh Province, Vietnam

4.6 Control of pests and diseases

The major pests associated with *Acacia* hybrid cause direct damage to seedlings, branches and stems, as well as wilting caused by root damage. Damage does not result in death, but may deform or suppress tree growth. Most disease agents of *Acacia* hybrid are associated with or caused by fungi. Common afflictions include damping-off, heart rot, powdery mildew, stem galls, dieback, leaf spots and root rot. *Acacia* hybrid is particularly susceptible to heart rot. In Malaysia, the incidence of heart rot has been frequently observed in *Acacia mangium* but it has never been reported in *Acacia* hybrid (Lee 2002). Insect attacks can be controlled using insecticidal spot treatment (Old *et al.* 2000). Major disturbances, pests and disease were not found in the *Acacia* hybrid plantations in Binh Dinh Province, Vietnam, although a few plantations were attacked by termites. In these instances, farmers used pesticides to combat the problem.

Heart rot is the only disease of tropical *Acacia* that has been the subject of sustained research during the last decade (Lee *et al.* 1988, 1996, Lee and Maziah 1993).

Damping-off affects many host species including *Acacia* spp. and is caused by *Fusarium solani, Phytophthora* spp., *Pythium* spp. and *Rhizoctonia solani* (Lee 1985, Liang 1987, Maziah 1990). Damping-off probably occurs wherever tropical *Acacia* are nursery-grown on a large scale. Damping-off can be managed efficiently by following suitable nursery practices. Seedlings grown in either polypots or in root trainers are less vulnerable to disease, as several common damping-off pathogens do not readily spread from one container to another. Proper management of the nursery, including good hygiene and good quality water supply, are needed to decrease disease incidence. If disease occurs, it can be prohibited by reducing watering of beds to a bare minimum and by regulating shading. Chemical treatment can become essential to control outbreaks of damping-off. Depending upon the pathogen(s) involved, drenching with carbendazim, captan or mancozeb, applied in place of normal watering, has been found to be very effective. After treatment, control of watering to prevent excessive soil moisture helps to check further spread of the disease (Old *et al.* 2000).

Table 2. Productivity of *Acacia* hybrid in sample plots in Binh Dinh Province, Vietnam

Number of plots	Statistic	Number of trees/ha	Stem volume (m^3/ha)	Volume increment (m^3/ha/year)
89	Minimum	909	0.2	0.2
89	Maximum	4456	183.1	40.5
89	Mean	2166	69.4	20.9
89	Standard deviation	640	44.7	11.6

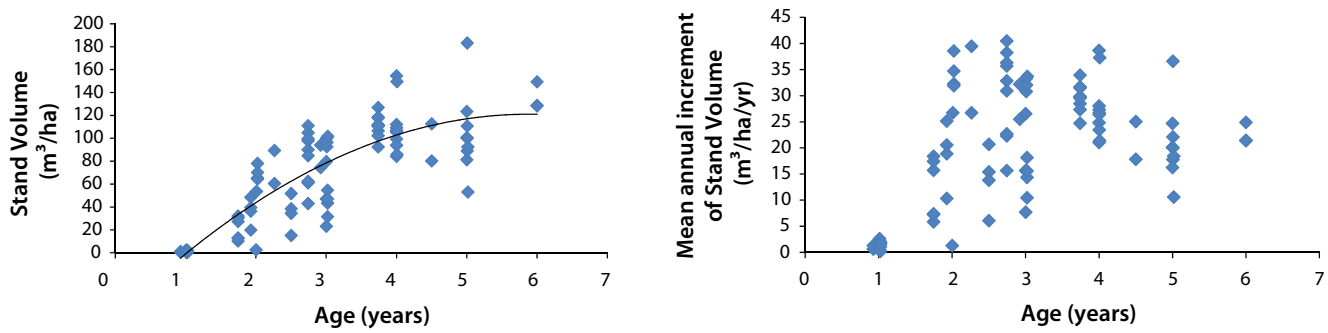

Figure 10. Average stand volume and average annual increase in volume of *Acacia* hybrid in different age classes in sample plots in Binh Dinh Province, Vietnam

Leaf spot may be serious when plants are of low vigour or when planted in high-humidity sites with poor air circulation. Overcrowding and poor soil conditions can also indirectly increase host susceptibility to the disease. The most effective means of control and management of the disease are proper cultural practices. Selective pruning and thinning can be carried out to improve air circulation and penetration of sunlight, thereby reducing disease incidence (Old *et al*. 2000).

On *Acacia*, powdery mildew is found on the phyllodes, mainly of plants in the nursery and also in the lower crown of young trees in the field. Chemical treatments are not usually necessary unless damage is severe. Sulphur dusting or application of fungicides such as benomyl, chlorothalonil, triadimefon, maneb and zineb gives efficient control (Old *et al*. 2000). Josiah and Allen-Reid (1991) indicated that the disease can be controlled by placing diseased seedlings in direct sunlight for an extended period.

5. Growth and yield

5.1 Growth in diameter and height

Height and diameter are important inventory measures for estimating tree volume. In the study area in Binh Dinh Province, Vietnam, samples were collected from 89 plots of *Acacia* hybrid representing different age classes (1–6 years). Michailow's growth function was used to estimate the diameter and height of the stand:

$$H = a * \exp\left(\frac{-b}{age}\right) \qquad D = a * \exp\left(\frac{-b}{age}\right)$$

Table 1 presents growth in diameter and height of samples from 89 *Acacia* hybrid plots.

The annual growth in diameter and height from 1–5 years of age is nearly identical. These plantations were evaluated to determine the mean annual increments. They achieved a minimum increase in diameter of 2.0 cm and a height of 3.1 m at 1 year of age, and a maximum increase in diameter of 11.5 cm and height of 15.6 m at 6 years of age.

Figure 9 illustrates average annual increases in diameter and height with regards to age. The average annual increases in diameter of *Acacia* hybrid are from 1.2 cm/year to 4.5 cm/year, with an average of 2.6 cm/year. The average annual increases in height are from 1.7 m/year to 5.5 m/year, with an average of 3.6 m/year.

5.2 Productivity

In order to estimate the stand volume, single stem volume must be estimated first. To estimate stem volume for *Acacia* hybrid, the data used previously for assessing the relationship between height and diameter were analysed. The total volume of each *Acacia* hybrid sample tree was calculated using the following model developed by the Forest Science Institute of Vietnam (MARD 2001):

$$V = 10^{-4}.\frac{\pi}{4}.D^2.H.0.490$$

In this study, the rotation of *Acacia* hybrid is 6 years for pulp and paper production. Chapman-Richards' generalisation of Bertalanffy's growth model (Richards 1959) was used to estimate the stand volume:

$$V = a.[1-\exp(-b.age)]^c$$

Table 2 presents productivity in 89 *Acacia* hybrid sample plots.

The samples yielded minimum increases in volume of 0.2 m^3 at 1 year of age and 183.1 m^3 at 6 years of age, giving an average of 69.4 m^3 for these plantations.

Table 3. Aboveground biomass of *Acacia* hybrid in sample plots in Binh Dinh Province, Vietnam

Number of plots	Statistic	Number of trees/ha	Total aboveground biomass (tonnes/ha)
89	Minimum	909	1.6
89	Maximum	4456	186.1
89	Mean	2166	86.7
89	Standard Deviation	640	50.1

Figure 10 illustrates the average annual increases in volume with regard to age. The average annual increases in volume of *Acacia* hybrid are from 0.2 m^3/year to 40.5 m^3/year, with an average of 20.9 m^3/year for every variable.

5.3 Biomass estimation

Biomass may be a more important measure of yield than yield volume. To estimate stand biomass, the biomass of a single tree must be estimated first. To estimate biomass for *Acacia* hybrid, the previous height data were used. Total biomass of each *Acacia* hybrid sample tree was calculated using the following model developed by the Forest Science Institute of Vietnam (MARD 2009):

$$B = 0.2230(h)^{2.1661}$$

The following model developed by Heriansyah *et al.* (2007) was used to estimate stand biomass:

$$B_i = a.(d_i^2.H_i)^b$$

Table 3 presents biomass estimates from 89 *Acacia* hybrid sample plots.

Figure 11 illustrates aboveground biomass, with regard to age. It is estimated that the specimens attained minimum increases in aboveground biomass of 1.6 tonnes at 1 year of age and maximum increases of 186.1 tonnes at 6 years of age, giving an average of 86.7 tonnes/ha for these plantations.

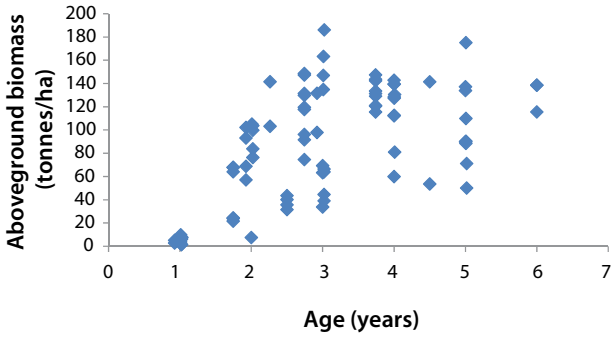

Figure 11. Aboveground biomass of *Acacia* hybrid in different age classes in sample plots in Binh Dinh Province, Vietnam

Table 4. *Acacia* hybrid schedule of activity for smallholder industrial plantations in Binh Dinh Province, Vietnam

Year	Operations	Activities
E–1	1. Seedlings	Vegetative propagation by rooted cuttings or by tissue culture
	2. Raise plants in nursery	Bare rooted or container plants
		Cutting (vegetative propagation) [alternatively]
	3. Prepare site	Slash and logging debris removed
		Holes excavated (30 × 20 × 30–40 cm)
E Planting	1. Spacing	Close spacing (2 × 2 m, 2.0 × 2.5 m, 2.5 × 2.5 m) is used to produce pulpwood
		Contour lines on slopes and straight lines on flat terrain
	2. Planting system	Fertiliser should be applied at planting time and 6 months after planting
	3. Fertilising	
E+1 Tending	1. Weeding	Weed control by manual weeding or herbicide application. Minimum of weeding twice a year during the first 2 years of plantation growth is encouraged
		1 month after planting for the first time, end of the second year for the second time
	2. Refilling	
E+2	Pruning	When the trees reach 2 years of age, pruning in late winter can encourage development of a single stem
		Done carefully to avoid injury to the tree or damage to the branch collar
E+3	Thinning	Poorly formed trees and species of lower value selectively removed
		Regular thinning is conducted when the plantation is 3, 5 and 7 years old
		If final product is pulpwood, thinning is not necessary
E+4 years and longer	Harvesting	The tree reaches the size or quality of timber which fetches a good price
		The rotation for pulpwood is mostly 5 or 6 years

E = Year of plantation establishment

5.4 Rotation

According to ACIAR (2004), companies commonly harvest *Acacia* hybrid for pulpwood at 5 years, whereas traditional species are typically harvested at 7 years. In some southern provinces of Vietnam, smallholders are growing hybrids under a 'low input' regime and are harvesting after only 3 years, mainly because they cannot afford to have funds tied up in forestry for longer than this. In Vietnam, according to Hai *et al.* (2005), if plantations are established on good soils with good genetic stock and appropriate site management (including weed control and appropriate application of fertiliser), thinning *Acacia* plantations down to 600 stems/ha at age 2.5–3.0 years could provide an initial harvest of pulpwood. This would enable the retained trees to produce a crop of small saw logs on rotations as short as 5–6 years.

6. Schedule of activity

Table 4 presents a suggested schedule of operations and activities for smallholder industrial plantations of *Acacia* hybrid in Vietnam.

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This manual summarises information on the ecology and silviculture of the species *Acacia* hybrid, with an emphasis on Vietnam. It also encompasses growth and yield data from published sources, as well as collected from sites under smallholder industrial plantations in Binh Dinh Province, Vietnam. This manual is 1 of 5 that guide smallholder tree planting of five selected tree species in Vietnam. The other four species are: *Acacia mangium* Willd, *Cinnamomum parthenoxylon* (Jack) Meisn, *Erythrophloeum fordii* Oliver and *Eucalyptus urophylla* S.T. Blake.

The Government of Vietnam is carrying out a large scale 'reforestation' programme, with the aim of improving local livelihood security, environmental sustainability and industrial wood supply. Smallholders are involved in plantation timber production through various schemes. Generally, these reforestation efforts have been effective, even though smallholders often lack the appropriate technical knowledge and management skills. Consequently, the quality and quantity of wood products may be suboptimal. The productivity of smallholder plantations can be improved by enhancing smallholders' management knowledge and skills, including species selection (site matching), silvicultural management to produce high quality products, and pest and disease management.

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