Acacia mangium Willd.

Ecology and silviculture in Vietnam

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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 mangium* Willd from several 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 Phu Tho 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

Acacia mangium Willd is an important multipurpose tree for the tropical lowlands. It is one of the most widespread of the fast-growing tree species which are used in plantation forestry programmes throughout Asia, the Pacific and the humid tropics. It has also become naturalised in Brazil, Puerto Rico and many other areas. Due to its rapid growth and tolerance of very poor soils, *Acacia mangium* is playing an increasingly important role in efforts to sustain a commercial supply of tree products whilst reducing pressure on natural forest ecosystems. Fast-growing *Acacia* plantations provide industrial wood for Vietnam's wood-processing, pulp and paper industries and woodchip exports, as well as household fuelwood supplies in rural areas. Currently, 80% of the total requirement of Vietnam's wood-processing industries must be imported. *Acacia* plantations are nitrogen fixing and the leaves provide an effective litter layer, making the species a favoured plantation genus in Vietnam. Vietnamese plantations are predominantly cultivated on small forest farms. The *Acacia* species grown in Vietnam originate from northern Australia, Indonesia and Papua New Guinea. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has collaborated with Vietnam's Forest Science Institute for over two decades in a research and support capacity aimed at improving the silvicultural practices involved in the introduction and breeding of *Acacia* (Kha 1996).

2. Description of the species

2.1 Taxonomy

Botanical name: *Acacia mangium* Willd
Family: Fabaceae
Subfamily: Mimosoideae
Synonyms: *Mangium montanum, Racosperma mangium*
Vernacular/common names:
Arr (Papua New Guinea), Black wattle (Australia, UK and USA), Brown salwood (Australia, UK and USA), Kayu safoda (Peninsular Malaysia), Keo tai tuong (Vietnam), Kra Thin Tepa (Thailand), Mangge hutan (Indonesia), Tongke hutan (Indonesia) (Turnbull 1986).

2.2 Morphological characteristics

Acacia mangium is a fast growing, nitrogen fixing, evergreen with phyllodes that serve as leaves (NFTA 1987). It is a medium-sized to fairly large tree measuring up to 35 m tall. Its bole is branchless for up to 15 m, and can measure up to 90 cm in diameter. The bark's surface is fissured near the base and of a greyish brown to dark brown colour, whereas the inner bark is a paler shade of brown. Branchlets are observed to be acutely triangular, the phyllodes straight, or straight along one side and curved along the other. These branchlets measure up to 25.0 × 3.5–9.0 cm and are 2–5 times as long as wide, with 4 or 5 main longitudinal veins, the secondary veins finely anatomising. Flowers possess five merous and have a corolla 1.2–1.5 mm long. The pods of the tree are broad, linear and irregularly

Figure 1. *Acacia mangium* seed
Photo by Nguyen The Dzung

Figure 2. *Acacia mangium* seedlings
Photo by Sebastian Schnell

Figure 3. *Acacia mangium* flowering branch
Photo by Nguyen The Dzung

Figure 4. *Acacia mangium* tree habitat
Photo by Chaw Chaw Sein

coiled, measuring up to 10 × 0.3–0.5 cm when ripe. These pods are membranous to slightly woody and inconspicuously veined (PROSEA 1995).

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. *Acacia* is found, sometimes dominant, in primary and secondary forest, forest margins, savannah, grassland and savannah woodland, on poorly drained floodplains and along fringes of mangrove forest, where it is sometimes associated with *Melaleuca* and *Rhizophora* spp. Its altitudinal range is up to 200 masl in Malaysia, attaining 500–800 m in Australia. 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. *Acacia mangium* occurs on the Aru Islands, Papua, West Papua, Sula Islands, Seram, Western Province of Papua New Guinea and north-eastern Queensland, Australia. It is also planted elsewhere, in the Malaysian region, especially in Sabah and Peninsular Malaysia (PROSEA 1995).

Acacia from the southwest of Western Province, Papua New Guinea, and from the adjacent Western Papua display the fastest growth, followed by those originating from the Claudie River in far north Queensland (16–18° S). *Acacia* from the Indonesian island of Ceram, and from Piru in western Papua grow most slowly (Hardwood and Williams 1992, Turvey 1996, Nirsatmanto *et al.* 2003).

Acacia mangium is found in areas of high rainfall in northern Australia, New Guinea and some adjacent islands. The prevailing climate in these areas is usually strongly seasonal, with rainfall of less than 50 mm/month in June–October, in contrast to the average annual rainfall of 1450–1900 mm in southern New Guinea, and 2100 mm in northern Queensland (PROSEA 1995).

2.4 Ecological range

Acacia mangium occurs naturally in the humid tropical lowlands of Queensland, which is the species' southern limit (18° 5' S); its northern limit is 0° 5' S in Papua ((Das 1984). It has been successfully used in reclamation of soils mined for bauxite, gold, copper, charcoal, iron and tin, especially in tropical Asia, Australia and Brazil (Ang and Ho 2002, Ferrari *et al.* 2004, Maiti 2006). It can be planted in hard compact soils, savannah areas, dry ridge tops and slopes of hills, moist foothills and infertile dry soils. On poor sites in Sabah, Malaysia, *Acacia mangium* notably outperformed other species tested. On disturbed or burned sites, on degraded oxisols (laterite) underlain with volcanic rock, on soils so worn out that shifting cultivation had been abandoned, and on hill slopes infested with weeds, *Acacia mangium* has grown vigorously (Anon 1983). Ahmad and Ang (1993) noted that *Acacia mangium* is suitable for reclaiming compacted sites, including decking and primary logging roads in logged-over forests. Midgley and Vivekanandan (1986) reported that *Acacia mangium* has the ability to tolerate extended drought, as proven by agroforestry trials in Sri Lanka. According to Haishui and Zengjiang (1993), large-scale plantations of the species are being established successfully in Southern China: below latitude 23.5° N, with an annual mean temperature of 20 °C (maximum 38 °C, minimum 5 °C) and annual rainfall of 1500 mm mainly occurring in March–July, on the mainland (June–October on Hainan Island).

Acacia mangium plantations are being established in Sri Lanka in the lowland wet zone and highlands with remarkable success (Vivekanandan 1993). The species is found to be promising for planting in acid sulphate soil in southern Vietnam, where the soil pH is low (3.2–3.5) and the ground remains waterlogged in the rainy season (Kha 1993). Pinyopusarerk *et al.* (1993) stated that *Acacia mangium* grows well under the latitudinal range of 0° 1'–1° 8' S, altitudinal range of 0–800 m and rainfall range of 1000–3000 mm in sandy loam soil exhibiting an acid-alkaline reaction.

In southern Sumatra, Indonesia, *Acacia mangium* plantations managed by Musi Hutan Persada are geographically located at 103° 10'–104° 25' E and 3° 5'–5° 28' S. The area has a lowland humid environment with an average daily temperature of 29 °C. The annual rainfall in the last 80 years has been 1890–3330 mm, mostly in January–May with a dry spell in October–December. However, during the dry spell there may be some light rain. The relative humidity varies from 56% in the dry season to 81% in the rainy season (Hardiyanto 1998). The plantations are established on *alang-alang* (*Imperata cylindrica*) grassland, scrubland and logged-over secondary forest areas. Both the grassland and shrubland were created by long-term shifting cultivation, using fire for site preparation. The terrain is mostly flat to undulating (0–8%) although some areas are quite rolling (8–15%).

In Colombia, the yearly rainfall in the planted areas is 2000–2500 mm. Rainfall is seasonal and unimodal, with 3–4 ecologically dry months (with less than 60 mm). Normally, water is scarce in December–March. Monthly temperatures are high and uniform all year round. The mean annual temperature is 26.6–27.7 °C (Diez 1992).

2.5 Wood characteristics

Acacia mangium is a medium weight hardwood. The heartwood is pale olive-brown, grey brown to pink, darkening to a reddish brown or dark red, and often attractively streaked. The sapwood is yellowish white, cream or straw coloured and distinctly demarcated from the heartwood. Heartwood formation varies significantly with provenance. Like the wood of other fast-growing tree species, the wood from wattle plantations has the potential disadvantages of small diameter, knottiness, low density and little strength. Other species are usually preferred for production purposes because *Acacia mangium* has a large proportion of reaction wood, greater incidence of spiral growth, greater growth stress and a greater proportion of juvenile wood. *Acacia mangium* has a density of 560–1000 kg/m^3 at 15% moisture content. The grain is straight to shallowly interlocking with an even, fine to medium texture. Wood of *Acacia mangium* tested in Australia at 11% moisture content showed a modulus of rupture of 106 N/mm^2, shear rate of 8.0–10.5 N/mm^2 and compression parallel to grain of 60 N/mm^2.

The rates of shrinkage are fairly low to moderate: 1.0–1.45% radial and 2.3–4.2% tangential, from green 12% moisture content. When seasoned with care, end splitting and surface checking are not significant during drying. Boards 25 mm thick take about 3 months to air dry. The timber kiln dries rapidly but marked collapse may occur in early stages of seasoning, though this can be combated through reconditioning.

Acacia mangium wood is easy to work with all tools. It planes easily to a smooth, lustrous surface using cutting angles of 15–25° and finishes well with sharp tools. It drills quite easily, provided the base is supported to prevent end-chipping and it turns well under low to moderate pressures. The nailing and screwing properties are satisfactory and the wood takes a good polish.

Figure 5. Bark of a 7-year-old *Acacia mangium* tree
Photo by Nguyen The Dzung

Acacia mangium wood is usually durable when exposed to the weather, but is not durable in contact with the ground. It is mostly resistant to termite attack via a root fungus but not entirely. The heartwood is moderately resistant to preservative treatment, but the sapwood is permeable. The pulping properties are excellent and comparable to those of commercial *Eucalyptus*. In tests in Australia using the sulphate process, wood chips of *Acacia mangium* from a 9-year-old plantation required only moderate amounts of alkali to yield in excess of 50% of screened pulp with paper making properties. Pulp yields were even higher (up to 75%) with the neutral sulphides semi-chemical process, and the pulp was readily bleached to brightness levels acceptable for use in fine papers. The energy value of *Acacia mangium* wood is 20 100–20 500 kJ/kg (PROSEA 1995).

2.6 Uses

The timber of *Acacia mangium* species is incredibly multifunctional and can be used for furniture and cabinet making, light to heavy construction, mouldings, poles, posts, panelling, mining timbers, boat building, carts, joinery, turnery, tool handles, agricultural implements, matches, splints, particle boards, hard board and veneer, as well as for plywood, pulp and paper. The wood is tough and resilient and particularly suitable for axe handles and sports equipment. The pulp is suitable for the manufacture of linear boards, bags, wrapping papers and multiwall sacks. The wood makes a good fuel-wood and good charcoal as it has a high energy value. The sawdust provides a good medium for the production of shiitake mushrooms. Other non-timber uses include honey production, adhesives and as an ornamental and shade tree for roadsides or other urban forestry (PROSEA 1995).

Since *Acacia mangium* can grow on marginal soils, many farmers choose to plant this species to improve the soil fertility of fallowed fields or pastures. Since trees with diameters of 7 cm are fire resistant, *Acacia mangium* plantations can be used as fire breaks. The trees are also planted as windbreaks, for shade, soil protection and as ornamentals. The leaves and pods of some species are used for animal fodder. The germinated seeds can be cooked and eaten in the same manner as a vegetable.

3. Seed production

3.1 Seed collection

The small flowers are grouped in spikes up to 10 cm long and occur singly or in pairs in the leaf axils near the branch tips. The trees flower annually, usually at the end of the rainy season or the early part of the dry season, and the fruits ripen 5–7 months after flowering. *Acacia mangium* starts to flower and produces seeds 18–20 months after planting. Flowering occurs in Australia in May, with fruits maturing in late October–December. Fruits ripen in Indonesia in July, in Papua New Guinea in September (Turnbull 1986), and in Central America in February–April (Francis 2003). The seeds are dispersed when small birds consume the oily funicle, or they eventually fall to the ground under the mother trees. Individual trees in an *Acacia mangium* plantation produced 1 kg of seed per year (Francis 2003). The fruits may be harvested by clipping them with pruning poles when they become dark brown and begin to crack open. Although they are best harvested before the fruits are fully open, the pods with hanging seeds remain available on the trees for several weeks (Bowen *et al.* 1981).

3.2 Seed preparation

The seed coat is very hard when ripe. Therefore pre-germination treatments should be carried out to promote prompt, uniform, and high levels of germination. Before planting, seeds should be placed in boiling water for 30 seconds and then cooled by soaking in cold water for 2 hours; alternatively they can be manually scarified. Germination, reported at 60–80% (after pre-germination treatments), may begin after 1 day and continue for 10–15 days (Francis 2003).

3.3 Seed storage and viability

The viability of *Acacia mangium* seeds tends to increase over the course of the fruiting season, whilst the seed size decreases (Bowen and Eusebio 1981). After air drying, small amounts of seed may be separated by hand. Mechanical separation involves hammer milling the pods followed by shaking, blowing and screening. Seed cleaning is difficult because the stringy funicles tangle with debris and screens. Cleaned seeds average 80 000–110 000 per kg (Francis 2003). Storage with moisture content of 4–12% at 3–5 °C in sealed containers is recommended, although seed stored at ambient temperatures will retain its viability for up to 2 years (Bowen and Eusebio 1981).

4. Propagation and planting

4.1 Sowing

Seeds are sowed in germination trays or beds, and when seedlings have about three leaves they are packed into plastic nursery bags where they grow to a plantable size (Turnbull 1986). Seeds are sometimes sowed directly into 1–2 litre nursery bags, a method which requires pricking to one plant per bag after seedlings emerge. The appropriate height for transplanting is 25–40 cm, which is reached when the seedlings have been in the nursery for 9–16 weeks. Although *Acacia mangium* seedlings usually auto-inoculate with *Rhizobium* symbiotic nitrogen fixers, artificial inoculation in the nursery is recommended (Von Carlowitz *et al.* 1991). Bare-root planting and direct seeding into prepared seed spots has been used, but, owing to the relatively low survival rate, these methods are generally not favoured. Seedlings are ready to be planted out in about 16 weeks (Turnbull 1986).

Plants can also be propagated vegetatively through single-node stem cuttings 4–5 cm long and 0.5–1.5 cm in diameter, leaving 0.5–1.0 cm phyllodes, a commonly used method in Vietnam. The application of indolebutyric acid or rooting powder enables 65–75% rooting and is reported to be slow. Air-layering gives promising results (PROSEA 2011).

4.2 Preparation of planting site

In Vietnam, preparation of the planting site, through tilling the land and excavating planting holes, is carried out at different times in various regions. In some regions, smallholders plant twice per year. In the north, plantations are established in February–August; with February and August being the two main months for planting. On sites covered by grasses or light brush, the area can be cleared by bulldozer, if it is not too hilly. On steeper terrain, where residual secondary vegetation needs to be cleared, manual labour is necessary as the slopes are often incapable of supporting heavy machinery. Though illegal, the slashed vegetation is usually burned as part of site preparation. In contrast to site preparation for estate crops, most site preparation of this nature is designed to disturb topsoil minimally.

4.3 Planting

In Vietnam, planting holes are dug about 1 month before planting and two-thirds of the hole is filled with a mixture of top soil. The hole is normally 30 cm deep, 20 cm wide at the base and 30–40 cm square at the top. The most suitable stocking for pulpwood plantations 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 is used (3.0–3.5

m between rows and between plants). 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.

In Vietnam, planting takes place in 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.

5. Plantation maintenance

5.1 Weeding

Weeding is important in industrial plantations as it helps meet production requirements and 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. Generally, the greater the area weeded around the tree, the less 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 exposing soil to 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. However, *Acacia mangium* has been found very sensitive to herbicides (PROSEA 2011). A minimum of weeding twice a year during the first 2 years of plantation growth is encouraged. After that, on the more productive sites, weed growth is suppressed by the development of the upper stories of the tree canopy, whereas on poorer sites weed control is necessary for a longer time.

Figure 6. Four-year-old *Acacia mangium* plantation in Phu Tho Province, Vietnam

Photo by Sebastian Schnell

5.2 Fertilising

Fertiliser application can replenish the nutrient supply to maintain or even increase productivity. 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 *Acacias* at planting (CARD 2005). Fibre research in Riau, Indonesia indicates that application of balanced nitrogen/phosphorus/potassium (NPK) fertilisers, and good harvest-residue management, lead to increased height and diameter at breast height of 3-year-old *Acacia mangium* in the second rotation, compared with the first rotation at the same age (Siregar *et al.* 2008). In Malaysia, Wan *et al.* (1989) concluded that the soils are low in nutrients, especially phosphorus. A number of fertiliser trials have been carried out to determine the best schedule for fertilisers. In Bengkoka (Sabah, Malaysia), 90–100 g of Christmas Island rock phosphate (CIRP) is applied at the time of planting, followed by 45 g of NPK mixture 2 months later, at the time of first weeding. Further application of fertiliser may be needed, according to Udarbe and Hepburn (1987). In Dingmen, China, a regime of 100 kg/ha nitrogen, 50 kg/ha phosphorus, and 50 kg/ha potassium was applied to an *Acacia mangium* plantation resulting in 179% increased production volume at age 2.6 years (Simpson 1992).

5.3 Refilling

The first refilling is usually done in the rainy season, 1 month after planting, to replace the dead plants, 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.

5.4 Singling and pruning

The purpose of pruning is to encourage trees to develop a straight stem and more valuable, knot-free trunk. 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.

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. Usually, pruning is done twice; the second time, branches are pruned off further up the trunk, often to a height of 6 m. Pruning off branches with a diameter of 2 cm or more makes the trees susceptible to infections, especially heart rot (Srivastava 1993). 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.

Acacia mangium has a strong tendency to produce multiple leaders from the base; as single stems are preferred for harvesting, 'singling' (conversion of multi-stemmed to single-stemmed trees) is undertaken routinely at about age 4–6 months. Pruning is unnecessary for pulpwood; however, persistent branches are pruned off in plantations where the objective is to produce high quality saw or veneer logs. This has led to the development of lift-pruning regimes, with the intention of converting the bottom log to clear or knot-free wood (Mead and Speechly 1991, Weinland and Zuhaidi 1991). The preferred practice is green pruning, which removes live rather than dead branches. Dead branches are associated with a high percentage of discoloration and decay in unpruned *Acacia mangium* (Ito and Nanis 1994).

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) or to correct potential deviation of stems from a pathway of vertical growth (Nicholas and Gifford 1995, Medhurst *et al.* 2003).

In *Acacia mangium* plantations in Indonesia, Beadle *et al.* (2007) observed no significant differences in diameter increment between the two pruning treatments. The removal of either 25% of leaf area (form pruning) or 25% crown length from below (lift

Table 1. Growth in diameter and height of *Acacia mangium* in different age classes in sample plots in Phu Tho Province, Vietnam

Number of plots	Statistic	Number of trees/ha	d (cm)	H (m)	Diameter increment (cm/year)	Height increment (m/year)
104	Minimum	508	2.7	2.8	1.3	1.5
104	Maximum	2663	13.9	15.3	4.8	4.9
104	Mean	1267	9.7	10.5	2.5	2.8
104	Standard deviation	434	3.1	3.5	0.6	0.7

pruning) would not be considered severe pruning treatments. In Peninsular Malaysia, according to Majid and Paudyal (1992), significant reductions in diameter growth were only observed after crown length removal from below exceeded 40% in an experiment in an *Acacia mangium* plantation. Mead and Speechly (1991) reported that *Acacia mangium* has around 50 branches in the lower 6 m of the stem. Hence pruning from below removes a greater proportion of the leaf area than represented by the crown length (Pinkard and Beadle 1998) because the branches in this section of the stem are, on average, larger and the internode length is smaller than on branches higher in the crown. Form pruning, however, removes branches higher in the crown that are more photosynthetically active per unit leaf area than those lower in the crown. Significant differences in growth from these two treatments were therefore not anticipated.

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 started. Trees are selected for pruning according to 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.

5.5 Thinning

Many reforestation projects in southeast Asia traditionally prioritised the planting of forests with little regard for the tending of the stands after establishment, thereby leaving them unmanaged for long periods. *Acacia mangium*, which is planted widely in southeast Asia, has the potential to produce both pulpwood and lumber (Groome 1991). However, in order to produce large volume trees, thinning is required (Kato 1999).

In tropical tree plantations, thinning is usually conducted from a relatively early stage of stand development (Lamprecht 1989, Evans and Turnbull 2004). Plantations need to be conscientiously managed to enhance stand quality and promote wood production. Tending operations such as thinning are typically used to increase production of usable-sized trees (Zeide 2001). Thinning could also provide an intermediate financial return from the removed trees (Evans and Turnbull 2004). In plantations of fast growing, exotic species, thinning is unnecessary for biomass production; whereas, production of higher quality, large-diameter timber usually necessitates at least one thinning (Lamprecht 1989). In this case, thinning would be 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 1250 trees/ha planted. Trees are thinned after 18 months. These plantations are clear felled after 6–8 years. In plantations producing high quality logs, the initial number of trees is generally thinned, reducing them from 900/ha to 100–200/

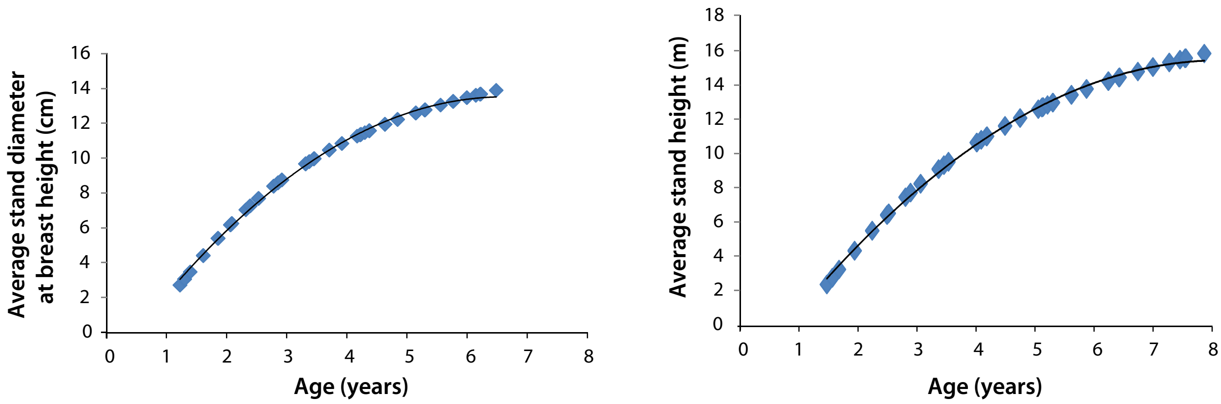

Figure 7. Growth in diameter and height of *Acacia mangium* in different age classes in sample plots in Phu Tho Province, Vietnam (Michailow's growth function)

ha in 2–3 thinning operations. The first thinning is done when trees are 9 m tall, that is, before 2 years of age. The rotation is 15–20 years. In Papua New Guinea, plantations grown on a 7–8 year rotation for pulpwood and are not thinned (PROSEA 1995).

In a 12-year-old *Acacia mangium* plantation in Kemasul Forest Reserve, Peninsular Malaysia, Zuhaidi and Mohd (1997) observed that an annual diameter increment for the whole stand ranged from 0.7 cm (unthinned) to 1.8 cm (heavy thinning) for the whole 12-year period. Likewise, the periodic annual diameter increment ranged from 1.1 cm (unthinned) to 2.4 cm (heavy thinning) for the potential final crop of 200 trees. The highest total volume increment (was observed in the moderately thinned plots (211.77 m^3) and the lowest in the unthinned plots (199.55 m^3). However, no significant effect was observed from the thinning interventions on live crown ratios, which ranged from 18% (unthinned) to 30% (heavy thinning). Generally, *Acacia mangium* responded favourably to thinning, with improvement in growth rates. But, in a rotation period of 15 years, the initial target of 3 cm/year annual increment is not assured.

5.6 Control of diseases

Damping-off is one the most serious diseases which can afflict the nursery. Caused by a wide variety of fungi, this ailment can thankfully be overcome with the use of fungicide. The young plants of *Acacia mangium* are also susceptible to other common diseases in their nurseries, the most serious of which is heart rot. This disease invades through branch wounds (e.g. those caused by pruning) and is also known as white rot, as the affected wood becomes whitish, spongy or fibrous and is surrounded by a dark stain. Its presence is indicated by dead or broken branches, wounds and cankers.

The major pests associated with *Acacia mangium* 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 (Hutacharern 1993). Heart rot, root rot and phyllode rust are the main threats (Old *et al.* 2000), with heart rot by far the most widespread, having been observed in most countries in which *Acacia mangium* has been planted, including Malaysia (Mahmud *et al.* 1993, Zakaria *et al.* 1994, Ito and Nanis 1994, Ito 2002), Bangladesh, Papua New Guinea, Thailand, Vietnam (Basak 1997), India (Mehotra *et al.* 1996) and Indonesia (Old *et al.* 2000). Heart rot is usually associated with older trees, but it occurs from the age of 2 years in *Acacia mangium* because of the early formation of heartwood. Heart rot can dramatically decrease timber volume and quality (Lee 2002).

In Peninsular Malaysia, a volume loss of up to 17.5% of the merchantable timber of *Acacia mangium* has been reported as a result of heart rot (Lee *et al.* 1988, Zakaria *et al.* 1994). In Sabah, up to 18.1% of merchantable volume was affected by decay (Mahmud *et al.* 1993). Heart rot presents little problem for the pulpwood industry (Gales 2002), because the fungi that cause heart rot preferentially remove lignin, which must be removed by chemical treatment for pulp production. In Peninsular Malaysia, heart rot incidence in *Acacia mangium* has been reported in 57% of 2-year-old trees and 98% of 8-year-old trees (Zakaria *et al.* 1994). In Sabah, the

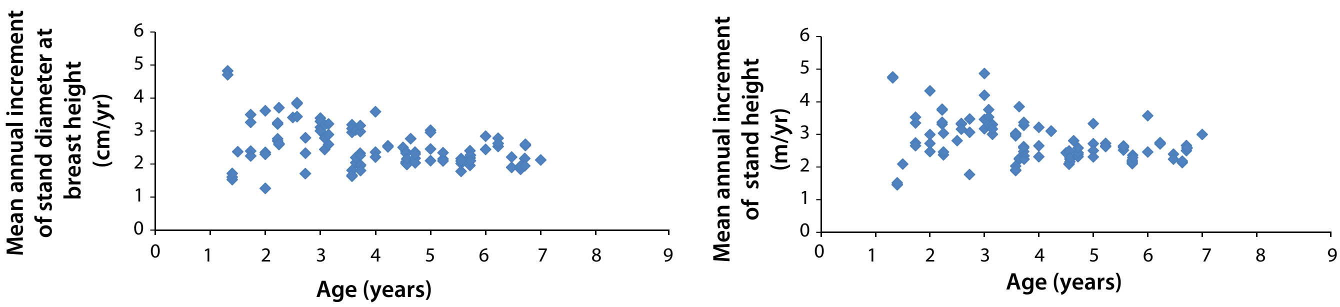

Figure 8. The average annual increase in diameter and height of *Acacia mangium* in different age classes in sample plots in Phu Tho Province, Vietnam

average incidence of heart rot was 35.5% amongst 6-year-old trees (Mahmud *et al.* 1993) and was a maximum of 50% in a different study of 9-year-old trees (Ito and Nanis 1994). In Bangladesh, heart rot incidence ranged from 49% to 58% in different regions (Basak 1997).

6 Growth and yield

6.1 Growth in diameter and height

Height and diameter are important inventory measures for estimating tree volume. In the study area in Phu Tho Province, Vietnam, samples were collected from 104 *Acacia mangium* plots representing different age classes (1–7 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 104 *Acacia mangium* plots.

The annual growth in diameter and height from 1 to 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 2.7 cm and height of 2.8 m at 1 year of age and a maximum increase in diameter of 13.9 cm and height of 15.3 m at 7 years of age.

Figure 8 illustrates average annual increases in diameter and height with regards to age. The average annual increases in diameter of *Acacia mangium* are from 1.3 cm/year to 4.8 cm/year, with an average of 2.5 cm/year. The average annual increases in height are from 1.5 m/year to 4.9 m/year, with an average of 2.8 m/year.

6.2 Productivity

In order to estimate stand volume, single stem volume must be estimated first. To estimate stem volume for *Acacia mangium*, the data used previously for assessing the relationship between height and diameter were analysed. The total volume of each *Acacia mangium* 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 mangium* is 5–7 years for pulp and paper production. Chapman-

Table 2. Productivity of *Acacia mangium* in sample plots in Phu Tho Province, Vietnam

Number of Plots	Statistic	Number of trees/ha	Stem volume (m^3/ha)	Volume increment (m^3/ha/yr)
104	Minimum	508	0.8	0.5
104	Maximum	2 663	197.4	41.6
104	Mean	267	60.7	13.9
104	Standard deviation	434	42.4	7.1

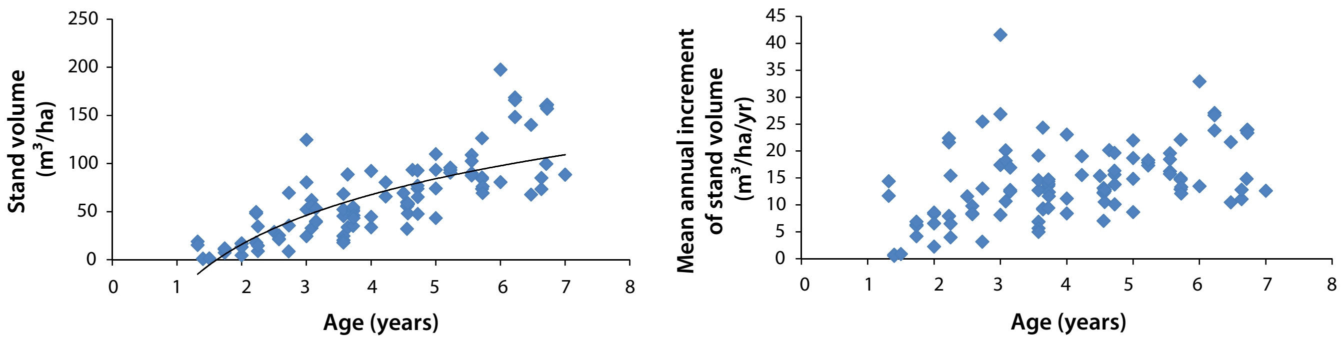

Figure 9. Average stand volume and average annual increase in volume of *Acacia mangium* in different age classes in sample plots in Phu Tho Province, Vietnam

Richards' generalisation (1959) of Bertalanffy's growth model was used to estimate stand volume:

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

Table 2 presents productivity in 104 *Acacia mangium* sample plots.

The samples yielded minimum increases in volume of 0.8 m^3 at 1 year of age and 197.4 m^3 at 7 years of age, giving an average of 60.7 m^3 /year in volume for these plantations.

Figure 9 illustrates the average annual increases in volume with regard to age. The average annual increases in volume of *Acacia mangium* are from 0.5 m^3/year to 41.6 m^3/year, with an average of 13.9 m^3/year for every variable.

6.3 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 mangium*, the previous height data were used. Total biomass of each *Acacia mangium* 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:

Table 3 presents biomass estimates from 104 *Acacia mangium* sample plots.

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

Figure 10 illustrates aboveground biomass with regard to age. It is estimated that the specimens attained minimum increases in aboveground biomass of 1.3 tonnes at 1 year of age and maximum increases of 190.3 tonnes at 7 years of age, giving an average of 50.0 tonnes/ha for these plantations.

6.4 Rotation

The time of harvest depends on local markets and local climate conditions. Harvesting can also take place early if drought, pests or disease threaten. Plantations are usually harvested when the trees reach the right size or quality of timber to get a good price. In former times, farmers would harvest when they needed money and fuelwood, but nowadays most plantations are grown for industrial raw material. In Vietnam, the rotation varies from 5 to 7 years depending on the aims and means of the cultivator. According to ACIAR (2006), *Acacia mangium* plantations are established at around 1000 stems/ha and are clear felled at age 6–7 years, when managed for pulpwood. For sawn timber the rotation is 15–20 years (PROSEA 1995).

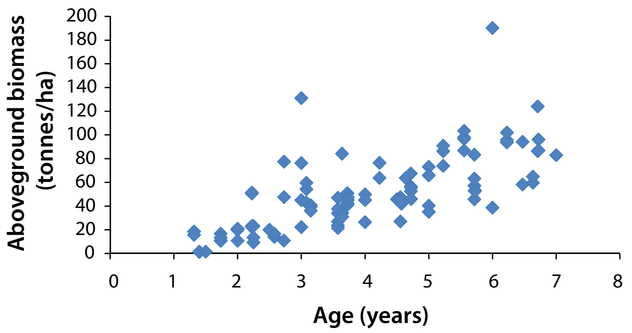

Figure 10. Aboveground biomass of *Acacia mangium* in different age classes in sample plots in Phu Tho Province, Vietnam

Table 3. Aboveground biomass of *Acacia mangium* in sample plots in Phu Tho Province, Vietnam

Number of plots	Statistic	Number of trees/ha	Aboveground biomass (tonnes/ha)
104	Minimum	508	1.3
104	Maximum	2 663	190.3
104	Mean	1267	50.0
104	Standard deviation	434	31.8

B (total)= total aboveground biomass

Table 4. *Acacia mangium* schedule of activity for smallholder industrial plantations in Phu Tho Province, Vietnam

Year	Operations	Activities
E[a]–1	1) Obtain seeds	From seed production areas and mother (plus) trees
	2) Seedlings	Vegetative propagation by rooted cuttings or by tissue culture
	3) Raise plants in nursery	Cutting (vegetative propagation) [alternatively]
	4) Prepare site	Slash and logging debris removed
		Holes excavated (30 x 20 x 30 – 40 cm)
E (Planting)	1) Spacing	Close spacing (2.0 x 2.0 m, 2.0 x 2.5 m and 2.5 x 2.5 m) is used to produce pulpwood
	2) Planting system	Contour lines on slopes and straight lines on flat terrain
	3) Fertilising	Fertiliser should be applied at planting time and 6 months after planting
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
	2) Refilling	1 month after planting for the first time, end of the second year for the second time
E+2	Pruning	Stocking and form pruning
		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 or 5	Harvesting	The tree reaches the size or quality of timber which fetches a good price
		The rotation for pulpwood varies from 5 to 7 years

a E = the year of plantation establishment

7. Schedule of activity

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

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This manual summarises information on the ecology and silviculture of the species *Acacia mangium* Willd, 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 Phu Tho Province, Vietnam. This manual is 1 of 5 that guide smallholder tree planting of 5 selected tree species in Vietnam. The other 4 species are: *Acacia* hybrid, *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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