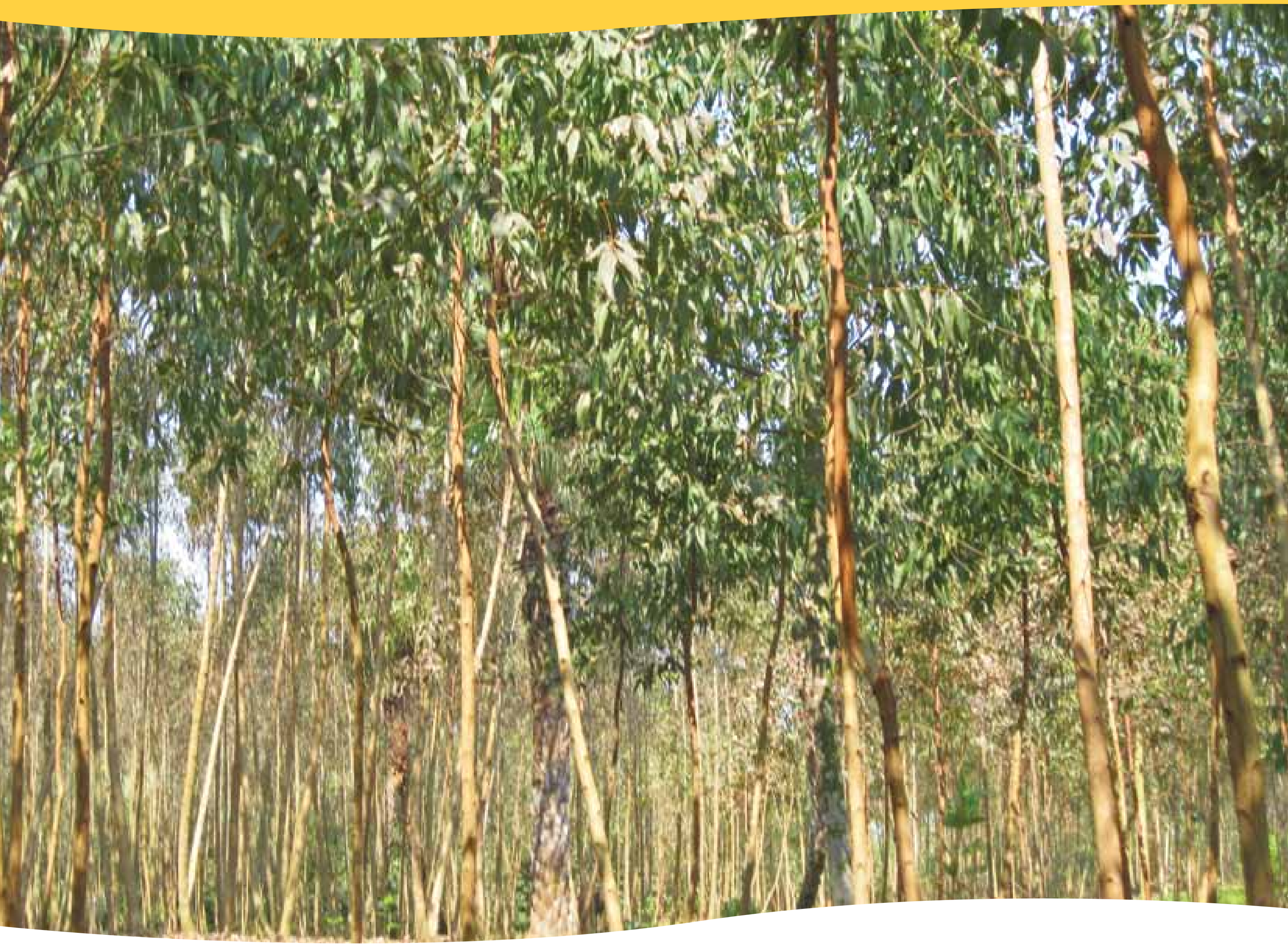

Eucalyptus urophylla S.T. Blake

Ecology and silviculture in Vietnam

Chaw Chaw Sein
Ralph Mitlöhner

CIFOR

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CIFOR, Bogor, Indonesia.

CIFOR
Jl. CIFOR, Situ Gede
Bogor Barat 16115
Indonesia

T +62 (251) 8622-622
F +62 (251) 8622-100
E cifor@cgiar.org

www.cifor.org

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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 Centre 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 *Eucalyptus urophylla* S.T. Blake 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 the research sites in smallholder industrial plantations in Binh Dinh and Phu Tho provinces, Vietnam.

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

The authors

Acknowledgements

We would like to express our deep gratitude to Christoph Kleinn, Sebastian Schnell and Nguyen The Dzung from the Institute of Forest Inventory and Remote Sensing, University of Göttingen, for their coordination of and contribution to field work and their scientific guidance. The administrative and scientific support of Kerstin Wydra, Centre for Tropical and Subtropical Agriculture and Forestry (CeTSAF) is gratefully acknowledged. We also thank our colleagues from the Institute of Tropical Silviculture and Forest Ecology, University of Göttingen, and the staff of the Silviculture Division at the Forest Science Institute of Vietnam for their great help in data collection. We thank the anonymous reviewers for their thoughtful comments, Ahmad Dermawan for his continuous support, Owen Elias for his careful editing and many others who have provided invaluable contributions to the development of this manuscript. This publication has been made possible through the financial support from the Advisory Service on Agriculture Research for Development (BMZ/BEAF), through the German agency for international cooperation, Gesellschaft für Internationale Zusammenarbeit (GIZ).

1. Introduction

The largest plantations of *Eucalyptus urophylla* S.T. Blake occur in Brazil. In recent years, the popularity of planting this species has increased markedly in humid and subhumid tropical climates. These regions include areas such as parts of Brazil, Indonesia and southern China (Eldridge *et al.* 1993). As the global population has increased and areas of native forest diminished, tree plantations and agroforestry have become an increasingly important source of timber, fuel-wood and raw materials for pulp and paper, particularly in developing countries. From these new forests, species of the genus *Eucalyptus* are widely used to provide wood products in regions where timber and other tree products are scarce. The total global area of *Eucalyptus* plantations in the year 2000 was nearly 18 million ha, mainly located in China, India, South Africa, South America and southeast Asia (FAO 2000).

For nearly 20 years, *Eucalyptus* species have been important for plantations in Vietnam at elevations below 800 m, where they are grown to produce pulpwood and poles for construction. The total area of *Eucalyptus* plantations in Vietnam in 2001 was 348 000 ha, which represents about 30% of the country's total plantation area (MARD 2002). *Eucalyptus urophylla* was introduced to Vietnam in the 1980s (Tai 1994) and it has been widely planted since the early 1990s. It has performed well on sites with reasonably deep soils in central and northern Vietnam, and also in parts of the central highlands where elevation is below 900 m (Kha *et al.* 2003). The total area of *Eucalyptus urophylla* plantation, and its interspecific hybrids, was about 200 000 ha at the end of 2001. This is planted mainly in the provinces Phu Tho, Quang Ninh, Thai Nguyen, Vinh Phuc and Yen Bai in northern Vietnam (MARD 2002). The species is mainly used for pulpwood, fibreboard and mining timber. In Vietnam, the rotation age is 6–8 years for pulpwood.

In Vietnam, *Eucalyptus* have been planted on a large scale in many provinces in mountainous and coastal areas. They have played an important role in economic and social development, especially in providing income for people living in remote areas. *Eucalyptus* have been planted on such a large scale in Vietnam because they can grow well on degraded, unfertile soils, where it is very difficult to establish other tree species. Moreover, *Eucalyptus* plantations have a short rotation in Vietnam (5–7 years) and return on investments is relatively fast. The wood from forest plantations can be used for the production of goods for the large international and domestic markets (Kien *et al.* 2009).

2. Description of the species

2.1 Taxonomy

Botanical name: *Eucalyptus urophylla* S.T. Blake
Family: Myrtaceae
Subfamily: Myrtoideae
Vernacular/common names:
Bach dan Urophylla (Vietnam); Timor white gum, Timor mountain gum (United Kingdom); Popo, Ampupu (Indonesia); Palavao Preto (Portuguese), Eucalipto (Brazil) (Jøker 2004).

2.2 Morphological characteristics

Eucalyptus urophylla can reach heights of 45–55 m and is evergreen. In unfavourable environments it grows as a gnarled shrub, though its bole is usually straight. The bark varies depending on available moisture and altitude but is usually persistent, smooth and subfibrous, reddish brown to brown in colour, with shallow, close longitudinal fissures. Sometimes, however, it may appear rough, especially at the base of the trunk. Juvenile leaves are subopposite, whilst the stalks are broadly lanceolate and discolourous, and measure 10–15 cm × 5–8 cm. Lateral veins are just visible from 5–70° to the midrib. Adult leaves are phyllodinous, subopposite to alternate, long stalked (12–30 mm), broadly lanceolate and abruptly narrowed into a short tip or lanceolate. They taper into a long drip tip, 12–20 cm × 2–5 cm, at 40–50° to the midrib, and are dark green above and paler green on the underside. The inflorescence is an axillary, simple umbelliform; a condensed and reduced dichasium, called a conflorescence. Umbles are solitary and possess 5–8 flowers. The peduncle appears somewhat flattened and is generally 8–22 mm long, whilst the pedicel is angled and 4–10 mm long. Flowers are regular and bisexual. Flower buds are either ellipsoid or obvoid, shortly pointed to rotund, and measure 10–14 mm

Figure 1. *Eucalyptus urophylla* leaves
Photo by Chaw Chaw Sein

Figure 2. *Eucalyptus urophylla* seedlings
Photo by Nguyen The Dzung

× 6–10 mm. They can be divided into a calyx tube or bipanthium (lower part) and an operculum (upper part) which is shed at anthesis. The flower has numerous stamens. The fruit is a dry, thin-walled capsule enclosed in a woody hypanthium, with 3–5 included to partly exserted valves. The fruit is also obconical to cup shaped and measures 6–14 mm × 7–18 mm, in a disk-shape which appears almost folded or obliquely depressed. The seed is small, approximately semicircular and black. Germination is epigeal and the cotyledons are usually bilobed near to the centre. The first 5–7 pairs of leaves are opposite, though subsequent pairs are subopposite (PROSEA 1993).

2.3 Distribution

Eucalyptus urophylla naturally occurs on volcanically derived soils on seven islands in eastern Indonesia (Adonara, Alor, Flores, Lembata (Lomblem), Pantar, Timor and Wetar) at altitudes of 180–3000 masl (Pepe *et al*. 2004). The range extends about 500 km between longitudes 122°–127° E and latitudes 7° 30'–10° S. It was introduced to Java in 1890 and to Brazil in 1919. In 1966, it was introduced to Australia and since then to many other countries, notably Cameroon, China, Congo, French Guiana, Gabon, Ivory Coast, Madagascar, Malaysia and Papua New Guinea (PROSEA 1993).

2.4 Ecological range

Eucalyptus urophylla has the largest altitudinal range of any *Eucalyptus*, covering 1000–2960 masl in Timor, 70–800 masl in Wetar, and 300–1100

Figure 3. Two-year-old *Eucalyptus urophylla* plantation in Phu Tho Province, Vietnam
Photo by Sebastian Schnell

masl in Flores and the smaller islands to its east. It is frequently found as the dominant species in secondary montane forest. At lower altitudes and in drier, exposed locations, usually below 1500 masl, it is often replaced by *Eucalyptus alba*. The natural range of *Eucalyptus urophylla* is in the humid and subhumid climatic zones. At an altitude of about

400 m the mean maximum temperature of the hottest month is 27–30 °C, which may drop to 15–21 °C at 1900 masl. The mean maximum temperature of the coldest month is 8–12 °C. In Timor, many of the *Eucalyptus urophylla* forests occur at about 1000 m, where mist and frost are common. Annual rainfall in this area is 1300–2000 mm; the dry season lasts for 3–4 months. On other islands, drier conditions prevail, with rainfall of 600–1500 mm, and a dry season of 5–8 months (PROSEA 1993).

It may also be found on ridges and on loamy, lateritic and sometimes clayed soils. *Eucalyptus urophylla* occurs in open, often secondary, mountain forest and performs best on deep, moist, well-drained soils. It grows in the vegetal formations of dry deciduous forest and moist evergreen forest (Endo 1992). Because the species has no major edaphic requirements, it is appropriate for reforestation, both in flooded soils and in dry soils of low tropical lands.

2.5 Wood characteristics

The wood of *Eucalyptus urophylla* is light, medium weight or heavy. The heartwood is light- to reddish-brown, sometimes dark reddish brown on exposure. The sapwood is white, cream or light pinkish, is 20–60 mm thick, and is distinctly demarcated from the heartwood. The grain is straight to interlocked, and the texture moderately coarse to coarse. A ribbon figure is often present on quarter-sawn surfaces. The rate of shrinkage is moderate to high, 1.8–3.0% (-4.4%) radial and 3.4–7.0% (-8.9%) tangential from green to 12% moisture content. Care is needed during seasoning, especially with heavier timber, as backsaw boards tend to check, close spacing of stacking strips is important. The wood glues well, but pre-boring is advisable for screwing and nailing to prevent end splitting. It stains and paints well. It slices well if the wood has high moisture content, and the veneer often dries satisfactorily and has an attractive figure. The heartwood is usually resistant to preservative treatment and the sapwood is permeable. The chief constituent of *Eucalyptus* oil is eucalyptol. The oil has a camphor-like odour and a spicy, cooling taste. It is practically insoluble in water, but mixable with alcohol, chloroform, ether, glacial acetic acid and oils (PROSEA 1993).

Figure 4. Wood of *Eucalyptus urophylla*
Photo by Nguyen The Dzung

Fibres are relatively short (about 1.0 mm in length). The wood is very suitable for producing bleached chemical pulp, with an average pulp yield of 49.5%. The wood of *Eucalyptus urophylla* is less dense than most *Eucalyptus*, the basic density is 540–570 g/m^3 (RISE 2009).

The most important traits for increased pulpwood production are volume and basic density (Borralho *et al.* 1993). In research in Vietnam, Pinyopusarerk *et al.* (2006) observed that for most growers, high density wood is the most valuable, as it is sold on a weight basis. Wood is often sold on a stacked-volume basis in the field, but by green-weight at the pulp or chip mill. Thus the target for growers is big, healthy, straight trees with higher density wood. An average wood basic density of 500–550 kg/m^3 is considered desirable for pulpwood plantations.

2.6 Uses

Eucalyptus urophylla wood is primarily used for pulp production, fuelwood and for charcoal. The wood's other primary use is for boards, though it is also used for electrical transmission poles, long-lasting posts and pilings, light and heavy construction, cabinet-making, carpentry and for plywood and agglomerate boards. It is useful in protecting river banks and providing shade and is a honey-producing species with good properties (PROSEA 1993). The bark has a tannin content of over 10%, but it is not used commercially. The leaves yield pale-yellow oil, the major components of which are paecymene (76%), alpha-pinene (7%) and gamma terpenene (4%).

Figure 5. One-year-old coppice rotation of *Eucalyptus urophylla* in Phu Tho Province, Vietnam
Photo by Sebastian Schnell

The essential oil is a good source of paracymene, which possesses disinfectant properties and is used in soap making and in the perfume industry (Orwa *et al.* 2009).

3. Seed production

3.1 Seed collection

Eucalyptus urophylla first begin to flower when they are 2–3 years old, with seeds being produced abundantly by the age of 4. Flowering occurs during the dry season and within 6 months the seeds reach maturity. The major pollinators of the flowers are insects, birds and mammals, and to a lesser extent, wind. The fruits occur in rosettes of 5–7. The seeds can be judged mature when the fruits become hard and brown and begin to open. Prior to opening, the fruits should be cut from the branches by hand and placed in paper or cloth sacks. To avoid the formation of fungi, the seeds must be kept well ventilated and should not be exposed to high temperatures.

3.2 Seed preparation and storage

The fruit is a typical *Eucalyptus* capsule: cup-shaped and made up of 3–5 valves. It has a double operculum (lid) and the outer operculum is shed early. On average there are 400 000–700 000 seeds/kg; with 1000 viable seeds weighing 1.4–2.5 g.. The ripe seeds can be kept viable for 5–20 years if they are stored in a sealed container and kept at low humidity (8–10%) and a temperature of 3–5 °C in order to protect against insects and fungi.

3.3 Seed viability

Most *Eucalyptus* seeds germinate well without pre-germination treatment, but some species require cold and humid stratification to break latency. This treatment consists of moistening the seed and placing it in a cold room (3–5 °C) for 2–10 weeks. The appropriate temperature for germination is 20 °C. Complete germination occurs in 10–21 days, depending on the species (Vozzo 2002). The seed is usually relatively easy to germinate.

4. Propagation and planting

4.1 Sowing

Seeds can be scattered or planted in furrows prepared with friable, porous or light-textured organic matter, which allows for adequate drainage. Usually, 25–50 g of seed is mixed with an equal quantity of fine sand and is broadcast sown over each levelled nursery bed before being covered with a thin layer of fine sand. Beds are watered with a watering can fitted with a fine rose and are normally covered with bamboo slats during the day time until the seedlings have attained a height of 5–6 cm and are suitable for pricking out.

The potting mixture consists of 7 parts of soil, 2 parts of fine sand and 1 part of compost or organic manure. Although tolerant of chemically poor soils, the species must be planted in loose textured soils. It does not tolerate very clayey soils with a shallow phreatic layer and shows much improved growth in soils that remain wet during the dry season.

Seeds germinate in approximately 20 days and the seedlings can be transferred to planting tubes when they have 2–3 leaf pairs. Seedlings are container raised and pricked out into 22×10 cm perforated, clear, polythene bags. Seedlings 5–6 cm high are pricked out and, in the initial stages, shaded. Regular watering is carried out and, when they are 25–30 cm in height, usually after 3–4 months, the seedlings are ready for planting in the field. Hardening off should be done about 2 weeks before planting into the field by reducing watering and removing shade.

Provenance selection is very important, with low-altitude provenances usually giving the highest yields (NAS 1983). According to Whitesell *et al.* (1992), previous work in Hawaii suggested that desirable criteria for selection of the species should include:

- fast growth and good stem form for the provision of high biomass production over a range of site conditions;
- the ability to be asexually reproduced using vegetative propagation methods;
- a superior ability for coppicing;
- resistance to serious disease or insect attacks;
- suitability for other uses besides biomass, for example pulp, lumber or chemicals.

4.2 Clonal technology

Clonal technology can be used to improve the productivity and quality of produce of new plantations. Candidate trees with phenotypical characteristics (straight bole; fast growth; weak branches; disease-free, small crown; self-pruning capacity) should be selected for propagation. Propagules should be prepared from stem cuttings of 30–35-day-old coppice shoots or pollards that are 30–35 days old.

Early in the morning, the juvenile shoots of *Eucalyptus urophylla* are brought to the processing unit to avoid desiccation. The cuttings are washed with mild detergent and pure water. Then the cuttings are cut into 10 cm lengths, with two internodes, and half of each leaf is cut off to reduce the transpiration of water. These cuttings are kept in 2% fungicide solution for 10 minutes and later a fresh cut is made at the lower end. The lower end of the cutting is given a quick dip in the root hormone IBA at 4500 ppm and transplanted in coco-peat for rooting. Transplanted cuttings are placed in low cost mist chambers without delay.

Low cost mist chambers are constructed from pits covered in polythene. Pits measuring 12 m long, 1.3 m wide, and 27 cm deep, are dug in compact soil. The pits are lined on all sides with a single layer of bricks arranged vertically. A 7 cm layer of sand and

Figure 6. Three-year-old *Eucalyptus urophylla* plantation in Phu Tho Province, Vietnam
Photo by Sebastian Schnell

pebbles is put at 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, fitted over semi-circular bamboo or cast iron frames to form a tunnel. The fog collected on the inner surface of the polythene sheet will reduce the temperature and the drops will fall on the leaf laminae and keep the surface wet.

Under favourable conditions of 80% humidity and 25–30 °C, roots should develop in 20–25 days. The rooted ramets are transferred to a shade house for adaptation and hardening. After 12 days the ramets should be transferred to an open nursery and nursed for 2–3 months until they reach planting height. The clonal identity of each clone should be maintained to assess field performance. Clonal technology for production of outstanding, high yielding, disease resistant planting stock of *Eucalyptus urophylla* is in the process of being perfected and is being adopted on a large scale for mass propagation (WCPM 2005).

Table 1. Growth in diameter and height of *Eucalyptus urophylla* in sample plots in Binh Dinh Province, Vietnam (age classes 1–5 years)

Number of plots	Statistic	Number of trees/ha	d (cm)	H (m)	Diameter increment (cm/year)	Height increment (m/year)
57	Minimum	884	1.9	2.0	1.0	1.4
57	Maximum	4456	9.6	13.6	4.1	4.7
57	Mean	2253	5.7	7.5	2.5	3.3
57	Standard deviation	629	2.5	3.6	0.7	0.7

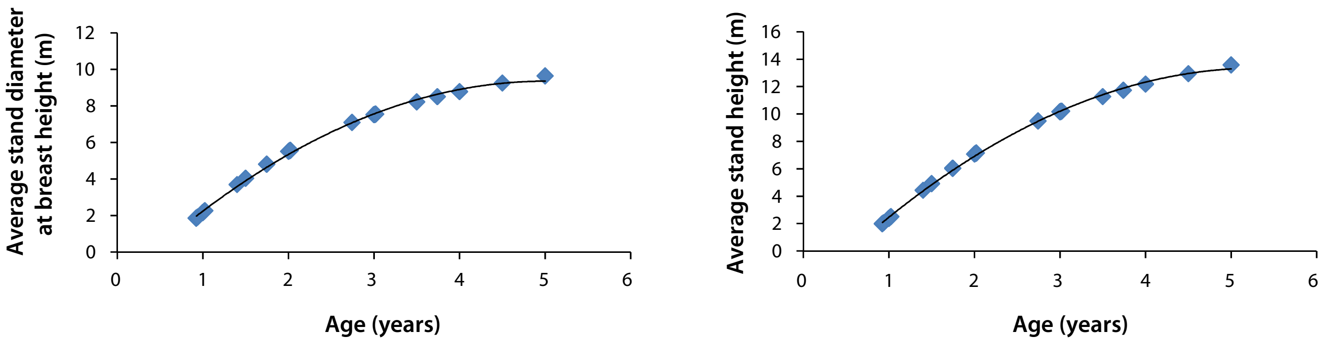

Figure 7. Growth in diameter and height of *Eucalyptus urophylla* in different age classes in sample plots Binh Dinh Province, Vietnam (Michailow's growth function)

4.3 Preparation of planting site

Amongst countries that have highly productive *Eucalyptus* plantations, the benefits of optimal soil preparation practices are well recognised. Intensive cultivation practices, including the burning of plant residues, ploughing and harrowing, have given way to minimum cultivation techniques that involve disturbing the soil only to the extent necessary. This enables the retention of organic residues and makes the use of herbicides to control invasive weeds more effective (Evans and Turnbull 2004).

Intensive mechanical site preparation is often avoided in Vietnam, since it is expensive and damaging to the environment. If existing ground vegetation and litter is too depleted, this can result in accelerated erosion of the soil and loss of nutrients.

This area is marked with a line, the planting lines in hilly terrain run parallel to the contour. A small patch, about 1 m in diameter, is marked out about a month before planting. The space around each planting hole is clean weeded. Planting holes are dug 25 cm in diameter and 45 cm deep.

The most effective method to control the weeds (especially *Imperata cylindrica*) is to use a glyphosate herbicide. Blanket spraying should be conducted at 4 L/ha, and strip spraying at 2 L/ha, with mixture of 250 ml of herbicide in 60 L of water.

4.4 Planting

Planting should be done early in the rainy season or, at the latest, 1 or 2 months before the end of the rainy season. It is important that seedlings have sufficient time before the beginning of the dry season to create a good wood system that will help them endure any extended dry period (RISE 2009).

An initial growing space per tree should be set at 2.5 × 2.5 m. If larger tree sizes, longer rotation ages, or higher yields per hectare at harvest are desired, then a policy of wider spacing could be adopted. When mixed with other species such as teak (*Tectona grandis*), the usual spacing practice for *Eucalyptus* is 2.5 × 2.5 m. When *Eucalyptus* is mixed with *Acacia auriculiformis* in the dry and intermediate zones, a spacing of 2 × 2 m is maintained, as both species are grown as short rotation fuelwood crops and additional spacing is not necessary. In the dry zone, when *Eucalyptus* is planted under the 'Taungya' system, the spacing adopted is 2.5 × 2.5 m to accommodate inter-row cultivation of food crops (Bandaratillake 1996).

5. Plantation maintenance

5.1 Weeding

Eucalyptus urophylla is extremely susceptible to competition in the early stages and must be kept weed free for 6–12 months (RISE 2009). Post-planting weed control is required twice in the first 6 months and must be done carefully with manual backpack sprayers (Whitesell *et al.* 1992). Alternatively, weeds can be controlled by hand-pulling, hoeing or disc-cultivating. Clean tending near the young trees themselves by hand-pulling is not a difficult operation when the soil is in good condition. The weeds can be controlled by disc-harrowing between the rows. It is important to remove weeds before they seed and thereby multiply the problem (FAO 1979).

Frequent weeding, up to three times per year, is necessary until the canopy closes 3–5 years after planting. If weeding is not conducted efficiently a complete failure of the plantation may occur (Orwa *et al.* 2009).

In Vietnam, the traditional way of controlling weeds in *Eucalyptus urophylla* plantation is by mix planting with cassava when the plantation is young.

5.2 Fertilising

The fertiliser requirements of *Eucalyptus urophylla* depends on the soil type in the area of tree planting. In the Philippines, the first application is with BFI fertiliser (200 g of nitrogen/phosphorus/potassium [NPK], 200 g Phoscal plus, 20 g Boron and 5 g zinc sulphate for each tree). The second application (200 g Phoscal plus, 100 g urea and 60 g potassium chloride) is then conducted 2 months leter (RISE 2009). In *Eucalyptus urophylla* plantations in southern China, Patrik (2007) recommended that at least 150 kg nitrogen, 115 kg phosphorus and 115 kg potassium per hectare, per year should be broadcast to achieve highest stem volume production. There was a significant difference between fertilisation once and twice per year with this mixture. The highest stem volume growth was observed when fertiliser was applied twice a year (34.4 m^3).

5.3 Refilling

Refilling is essential in areas where trees cultivated for timber or large poles have been harvested. This is because the stools will have been cut at various stages and regrowth will have been suppressed by the shade from remaining trees. The first refilling should be conducted in the rainy season, 1 month after planting (to replace dead seedlings), with the second

Table 2. Growth in diameter and height of *Eucalyptus urophylla* in sample plots in Phu Tho Province, Vietnam (age classes 1–6 years)

Number of plots	Statistic	Number of trees/ha	Diameter (cm)	Height (m)	Diameter increment (cm/yr)	Height increment (m/yr)
110	Minimum	486	3.5	4.5	1.0	1.3
110	Maximum	5856	7.5	11.5	4.6	5.0
110	Mean	2603	6.0	8.7	2.0	2.9
110	Standard deviation	1171	1.0	1.8	0.8	0.9

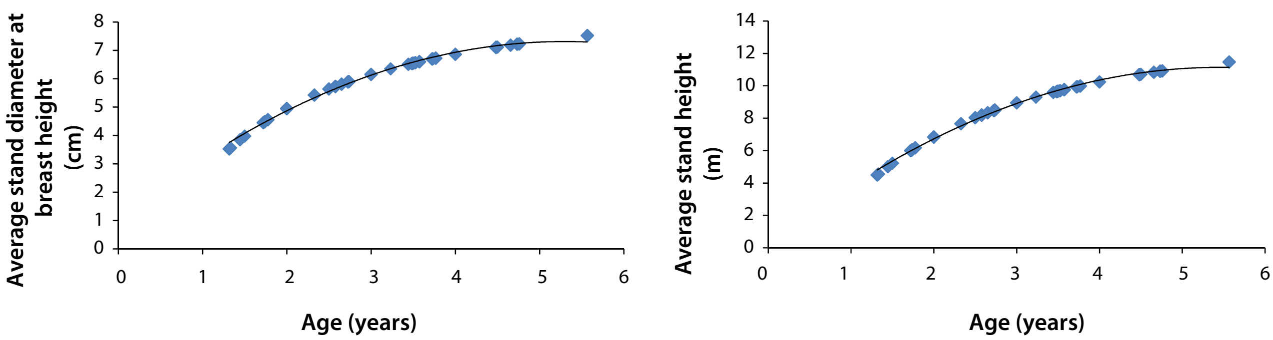

Figure 8. Growth in diameter and height of *Eucalyptus urophylla* in different age classes in sample plots in Phu Tho Province, Vietnam (Michailow's growth function)

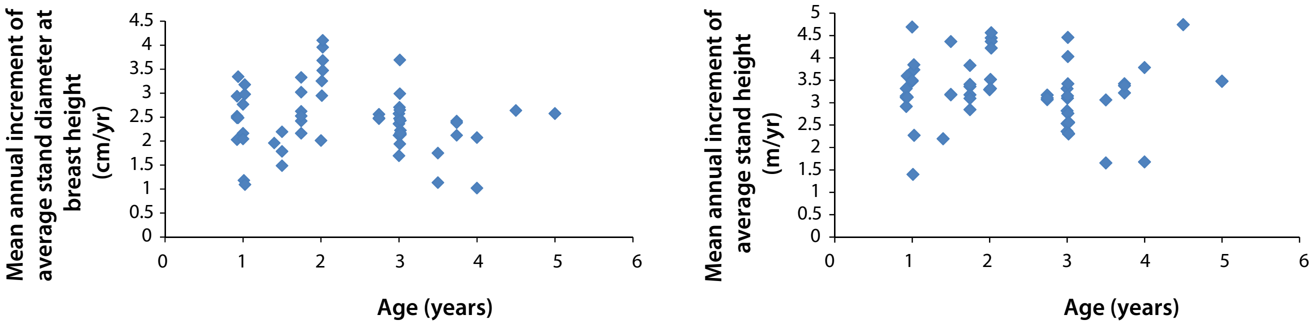

Figure 9. The average annual increase in diameter and height of *Eucalyptus urophylla* in different age classes in sample plots in Binh Dinh Province, Vietnam

Table 3. Productivity of *Eucalyptus urophylla* 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/yr)
57	Minimum	884	0.5	0.5
57	Maximum	4456	209.0	61.2
57	Mean	2253	40.6	13.6
57	Standard deviation	629	50.0	12.3

being carried out at the end of the second year. If the survival rate on large-scale plantations is less than 70%, further refilling will be necessary.

5.4 Coppice system

When the trees are felled, new stems often sprout from the stumps to produce another crop of trees. This new crop is called the 'coppice crop' to distinguish it from the 'seedling crop'. Coppice crops play an important role in ensuring the profitably of *Eucalyptus* plantations, as replanting costs are reduced and coppice stems grow faster than seedlings, providing a shorter rotation and quicker returns. Several successive coppice crops are possible, however achieving a stable coppice crop depends on planting the suitable species in the right environment and harvesting in the correct manner (Orwa *et al.* 2009).

The first (seedling) crop is felled at age 7–10 years in most *Eucalyptus* coppice plantations. Felling is the most important operation in relation to the survival of the plantation through successive coppicing of the stumps, which can be repeated for 3 or 4 more rotations. The period of felling, type of equipment and techniques used are all important. Felling should not be done in dry periods and heavy frosts, which can loosen the bark from the stumps. The early growing period, after the heavy frosts, is probably the best time in cold areas, as the shoots will be established before the next winter. Felling tools are also important. With experience in Australia and South Africa, better results have been shown in coppicing from the use of chainsaws rather than axes. Using an axe increases the risk of loosening the bark on the stump. Alternatively, bow-saws and two-man crosscut saws have sometimes been reported to give better results than chainsaws.

Attention must also be paid to the felling level. If the stump is too high the chances of survival are lower. If the cut is at ground level the bark may loosen. A stump height of 10–12 cm is recommended, and should provide an adequate number of coppice shoots. The cut should be as smooth as possible and slanted so as to facilitate water run-off. The accumulation of water on the stump increases the risk of fungus attack. Lop and top should be removed from the stumps after felling so that the young coppice can develop without interference (FAO 1979).

5.5 Pruning

Pruning is undertaken to maximise the amount of clear wood produced by a tree. Pruning achieves this by removing branches early, containing branch related defects to a central knotty core and allowing subsequent growth to be defect free (Shepherd 1986). Pruning should be done carefully to avoiding 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.

Pruning encourages a more uniform crop of logs, which can help to reduce the processing costs and result in a higher price. Before pruning it is imperative that growers draw up a management regime that aims to produce logs of a certain specification for a particular market. If this planning is not implemented then increased returns from pruning may not be realised.

Only a percentage of trees should be pruned. Selection of the crop trees is required, as not all trees in a stand will be of sufficient form and vigour to produce logs to specification. The targeted specifications for logs should be based on a maximum allowable knotty core diameter (Koehler 1984 , Stackpole *et al.* 1999). For instance, to produce 90% clear wood volume from a 6 m log would need a centre diameter at harvest of 50 cm and a knotty core diameter of 15 cm (Gerrand *et al.* 1997).

Forest managers should time pruning to coincide with canopy closure, to reduce the impact of pruning on tree growth. After canopy closure the lower branches become shaded and will develop minimally and contribute little carbon to the tree. Pruning before canopy closure will remove branches that are still contributing carbon to the tree and will be more likely to reduce tree growth rates (Kelvin 2003). The branch size of individual trees is also an important factor in determining the timing of pruning. In low stocked plantings, failure to prune before branches become too large can be detrimental to wood quality. Large branches will not only take a longer time to block but also increase the risk of decay (FAO 1979).

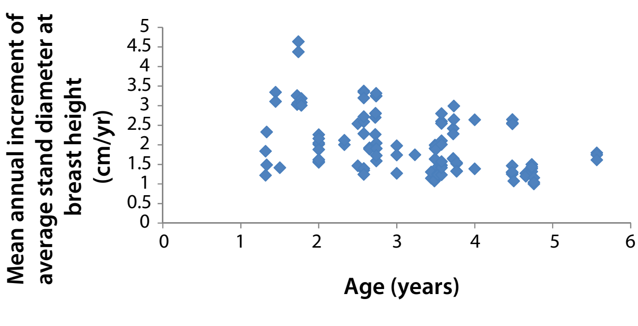

Figure 10. The average annual increase in diameter and height of *Eucalyptus urophylla* in different age classes in sample plots in Phu Tho Province, Vietnam

Pruning is a value adding activity, but it is labour intensive. Scheduling of pruning activities will thus vary depending on the scale of operation and the labour management regimes in place. Large-scale industrial plantations will require more sophisticated scheduling, which will typically involve predictions of stand development, to optimise both time of pruning and labour use (Pinkard and Beadle 2000).

5.6 Thinning

Thinning artificially reduces the number of trees growing in a stand. It is generally carried out several times and starts a few years after canopy closure. Thinning can be made at different intensities and in different ways. The two main approaches to thinning are (1) systematic, mechanical or line thinning, and (2) selective thinning. In systematic thinning, trees are thinned following an objective and systematic procedure in which individual tree quality is not considered. Removal of every third row of trees is an example, and only intensity is varied. In selective thinning, trees are thinned or left depending on the subjective judgment of the person making the thinning; both intensity and the kind of tree favoured can be varied. Selective thinning is particularly important in species with generally poor form, so that the best stems can be favoured. The two main methods of selective thinning are low thinning and crown thinning, and they determine which kinds of trees are removed (Evans and Turnbull 2004).

Thinning practices can seriously affect the level of green pruning, also called 'Summer pruning', that is needed in a stand. Thinning of the stand will increase the amount of light reaching the lower canopy and hence the supply of carbon to the tree to support growth. Thus, if a stand is thinned and pruned, green pruning may have a greater effect on subsequent tree growth rates (Medhurst and Beadle 2000). Regular

Table 4. Productivity of *Eucalyptus urophylla* in sample plots in Phu Tho Province, Vietnam

Number of trees	Statistic	Number of plots (number of trees per hectare)	Stem volume (m^3/ha)	volume increment (m^3/ha/yr)
110	Minimum	486	0.4	0.2
110	Maximum	5856	116.8	31.3
110	Mean	2603	39.2	12.4
110	Standard deviation	1171	25.6	7.1

thinning should be conducted when the plantation is 3, 5 and 7 years old.

The secret to maximising the yield of big trees is to implement thinning at exactly the right point in time. Large, straight trees are cultivated by regularly thinning out the crop, leaving the best trees to grow to a bigger size. However, if close to markets, the production of firewood and poles could be an important source of early income for the grower. Depending on the initial spacing, a selective thinning removing every second or third line can be carried out. Thinning conducted at a later stage would be more selective and leave behind the best, evenly spaced trees.

5.7 Control of pests and diseases

Though termite attacks are relatively common in *Eucalyptus* plantations in the dry zone, they are significantly scarcer in the wet zone. Depending on the intensity of the termite attack, insecticides are applied either at the time of planting or the moment an attack is discovered. Generally, when the incidence of attack is high, soil in the polythene tubes is dipped in a 0.5% Aldrin solution before planting. This is an effective method of controlling termite attack until the seedlings are established in the field (Bandaratillake 1996).

Seedlings of *Eucalyptus urophylla* are susceptible to attack by stem borers such as *Zeuzera coffeae*. In the Solomon Islands, die-back attributed to the coreid insect *Amblypelta cocophaga* has been observed in 3–4-month-old plantings. Damping-off of seedlings occurs in cases of high humidity. Root fungi such as *Botryodiplodia* spp., *Fusarium* spp. and *Helminthosporium* spp. are also a severe problem (Orwa *et al*. 2009).

In the tropics and subtropics, *Cryphonectria cubensis* is a widespread and significant pathogen of plantation *Eucalyptus*. The main damage to trees caused by *Cryphonectria cubensis* is the development of large basal cankers which can kill trees during the first 2–3 years of growth. On older trees, extensive perennial cankers develop several metres in length up the bole of the tree. Under favourable climatic conditions, with susceptible species or clones, up to 50% of stems in plantations have been killed (Alfenas *et al*. 1983). Cankers are characterised by death of phloem, cambium and sapwood with partial girdling of trees. The economic effects of *Cryphonectria cubensis* canker are reduced growth rate (Camargo *et al*. 1991), reduced coppicing (Hodges and Reis 1976), and increased mortality (Boerboom and Maas 1970, Wood yield is significantly reduced when cankers extended to more than 25% of the commercially useful stem length (Ferrari *et al*. 1984).

6. Growth and yield

6.1 Growth in diameter and height

Height and diameter are important inventory measures for estimating tree volume. Samples were collected from smallholder *Eucalyptus urophylla* plots in the study areas in Vietnam. In Binh Dinh Province, samples were collected from 57 plots representing age classes of 1–5 years and in Phu Tho Province, from 110 plots representing age classes of 1–6 years. Michailow's growth function was used to estimate the diameter and height of the stand:

6.1.1 Growth in diameter and height in Binh Dinh Province

Table 1 presents growth in diameter and height of samples from 57 *Eucalyptus urophylla* plots in Binh Dinh Province, Vietnam.

In Binh Dinh Province, 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 (MAI). They achieved a minimum increase in diameter of 1.9 cm and a height of 2.0 m at 1 year of age and a maximum increase in diameter of 9.6 cm and height of 13.6 m at 5 years of age.

6.1.2 Growth in diameter and height in Phu Tho Province

Table 2 presents growth in diameter and height of samples from 110 *Eucalyptus urophylla* plots in Phu Tho Province, Vietnam.

In Phu Tho Province, the annual growth in diameter and height from 1 to 5 years of age is nearly identical. These plantations were evaluated to determine MAI. They achieved a minimum increase in diameter of 3.5 cm and height of 4.5 m at 1 year of age and maximum increase in diameter of 7.5 cm and height of 11.5 m at 6 years of age.

Figure 9 illustrates average annual increases in diameter and height with regard to the age of *Eucalyptus urophylla* in Binh Dinh Province. The average annual increases in diameter are from 1.0 cm/year to 4.1 cm/year, with an average of 2.5 cm/year. The average annual increases in height are from 1.4 m/year to 4.7 m/year, with an average of 3.3m/year.

Figure 10 illustrates the average annual increases in diameter and height with regards to age of *Eucalyptus urophylla* in Phu Tho Province. The average annual increases in diameter are from 1.0 cm/year to 4.6 cm/year, with an average of 2.0 cm/yr. The average annual increases in height are from 1.3 m/year to 5.0 m/year, with an average of 2.9 m/year.

6.2 Productivity

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

$$V = 0.3256\ (d^2h)^{0.9106}$$

Table 5. Aboveground biomass of *Eucalyptus urophylla* in sample plots in Binh Dinh Province, Vietnam

Number of trees	Statistic	Number of plots (number of trees per hectare)	Total aboveground biomass (tonnes/ha)
57	Minimum	884	1.4
57	Maximum	4456	194.7
57	Mean	2253	44.0
57	Standard deviation	629	40.4

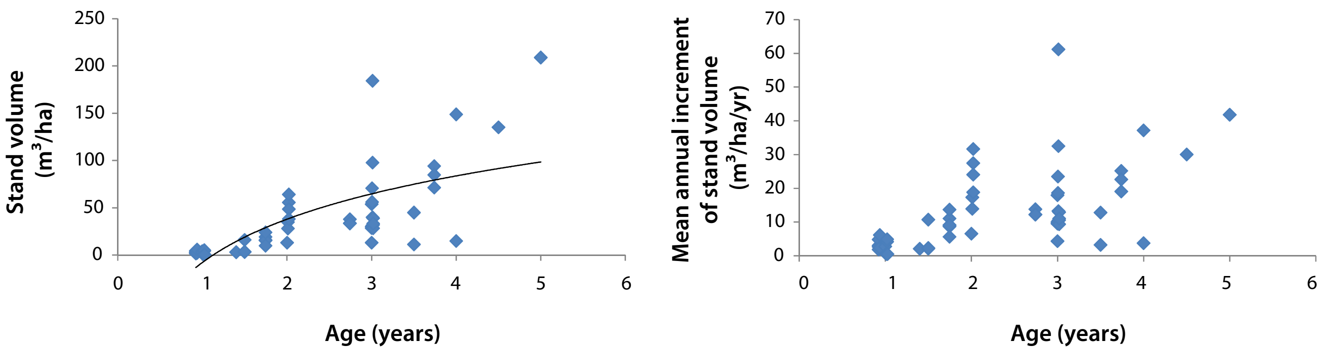

Figure 11. Average stand volume and average annual increase in volume of *Eucalyptus urophylla* in sample plots in Binh Dinh Province, Vietnam

In this study, the rotation of *Eucalyptus urophylla* is 5–6 years for pulp and paper production. Chapman-Richards' generalisation of Bertalanffy's growth model (Richards 1959) was used to estimate the stand volume:

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

6.2.1 Productivity in Binh Dinh Province

Table 3 presents productivity in 57 *Eucalyptus urophylla* sample plots in Binh Dinh Province.

The samples yielded minimum increases in volume of 0.5 m^3 at 1 year of age and 209.0 m^3 at 5 years of age, giving an average of 40.6 m^3/ year in volume for these plantations.

6.2.2 Productivity in Phu Tho Province

Table 4 presents productivity in 110 *Eucalyptus urophylla* sample plots in Phu Tho Province.

The samples yielded minimum increases in volume of 0.4 m^3 at 1 year of age and 116.8 m^3 at 6 years of age, giving an average of 39.2 m^3/year in volume for these plantations.

Figure 11 illustrates the average annual increases in volume with regard to age in *Eucalyptus urophylla* in Binh Dinh Province. The average annual increases in volume are from 0.5 m^3/year to 61.2 m^3/year, with an average of 13.6 m^3/year for every variable.

Figure 12 illustrates the average annual increases in volume with regard to age in *Eucalyptus urophylla* in Phu Tho Province. The average annual increases in volume are from 0.2 m^3/year to 31.3 m^3/year, with an average of 12.4 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 *Eucalyptus urophylla*, the previous height data were used. Total biomass of each *Eucalyptus urophylla* sample tree was calculated using the following model developed by the Forest Science Institute of Vietnam (MARD 2009):

$$B = 0.4803(h)^{1.7773}$$

Table 6. Aboveground biomass of *Eucalyptus urophylla* in sample plots in Phu Tho Province, Vietnam

Number of trees	Statistic	Number of plots (number of trees per hectare)	Total aboveground biomass (tonnes/ha)
110	Minimum	486	1.1
110	Maximum	5856	142.2
110	Mean	2603	56.2
110	Standard Deviation	1171	27.5

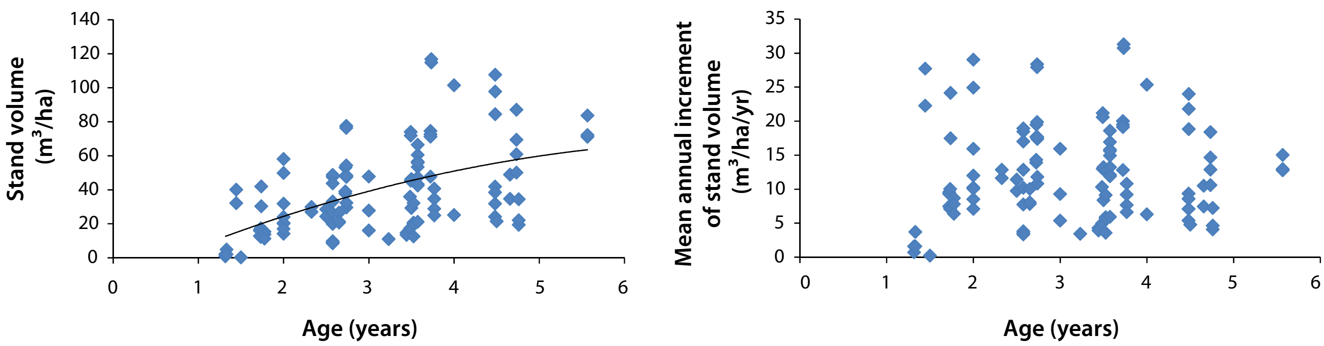

Figure 12. Average stand volume and the average annual increase in volume of *Eucalyptus urophylla* in different age classes in sample plots in Phu Tho Province, Vietnam

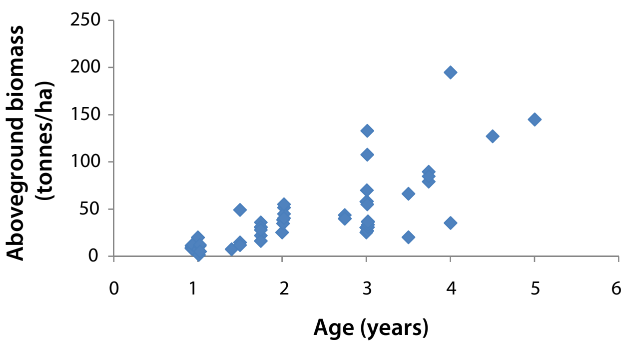

Figure 13. Aboveground biomass of *Eucalyptus urophylla* in different age classes in sample plots in Binh Dinh Province, Vietnam

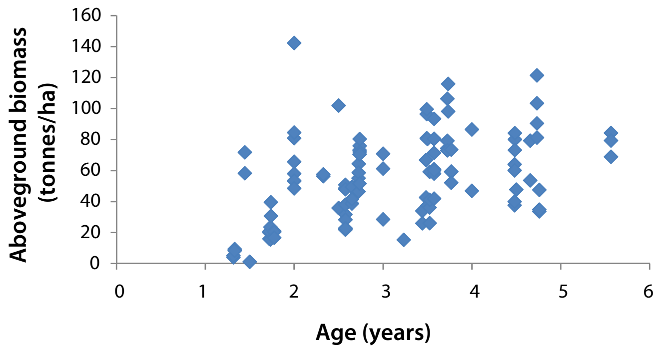

Figure 14. Aboveground biomass of *Eucalyptus urophylla* in different age classes in sample plots in Phu Tho Province, Vietnam

Table 7. *Eucalyptus urophylla* schedule of activity for smallholder industrial plantations in Binh Dinh and Phu Tho provinces, Vietnam

Year	Operations	Activities
E–1	1. Obtain seeds	From seed production areas and mother (plus) trees
	2. Seedlings	Vegetative propagation by rooted cuttings or by tissue culture
		Bare rooted or container plants
	3. Raise plants in nursery	Cutting (vegetative propagation) [alternatively]
	4. Prepare site or coppice from last rotation stumps	Slash and logging debris removed
		Holes excavated (30×20×30–40 cm)
		New stems often sprout from the stumps to produce another crop after the first crop is felled
E Planting	1. Spacing	Close spacing (2.0x2.0 m, 2.0x2.5 m, and 2.5x2.5 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	1. Weeding	Weed control by manual weeding or herbicide application
Tending	2. Refilling	1 month after planting for the first time, end of the second year for the second time
E+2	Pruning	Rarely need pruning
		Done carefully to avoid damage to the tree or to the branch collar
E+3	Thinning	Start a few years after canopy closure
		Regular thinning is conducted when the plantation is 3, 5 and 7 years old
E+4 years and longer	Harvesting	After felling of the first crop rotation, coppice harvesting is preferable because replanting costs are reduced and coppice stems grow faster than seedlings
		The rotation may be as short as 3–5 years for small-sized pulpwood
		The tree reaches the size or quality of timber which fetches a good price

E = Year of plantation establishment

The following model developed by Baker *et al.* (2003) was used to estimate stand biomass:

$$B_i = a.d_i^b$$

6.3.1 Biomass estimation in Binh Dinh Province

Table 5 presents biomass estimates from 57 *Eucalyptus urophylla* sample plots in Binh Dinh Province.

Figure 13 illustrates aboveground biomass with regard to age. It is estimated that the specimens attained minimum increases in aboveground biomass of 1.4 tonnes at 1 year of age and maximum increases of 194.7 tonnes at 5 years of age, giving an average of 44.0 tonnes/ha for these plantations.

6.3.2 Biomass estimation in Phu Tho Province

Table 6 presents biomass estimates from 110 *Eucalyptus urophylla* sample plots in Phu Tho Province.

Figure 14 illustrates aboveground biomass with regard to age. It is estimated that the specimens attained minimum increases in aboveground biomass of 1.1 tonnes at 1 year of age and maximum increases of 142.2 tonnes at 6 years of age, giving an average of 56.2 tonnes/ha for these plantations.

6.4 Rotation

Eucalyptus urophylla has good coppicing properties and can be expected to produce at least three coppice rotations after the initial seedling rotation (Orwa *et al.* 2009). The rotation may be as short as 3–5 years for small-sized pulpwood, but is generally 8–10 years. In Israel, a successful plantation of 5 successive 10-year coppice rotations has been achieved, but in general 2–3 coppice rotations of 10–12 years are feasible. In northern Vietnam, plantations of *Eucalyptus urophylla* are managed on short rotations of 6–8 years supplying raw material for pulp mills in the region and small quantities of larger logs for small sawmills (Kien *et al.* 2009).

7. Schedule of activity

Table 7 presents a suggested schedule of operations and activities for smallholder industrial plantations of *Eucalyptus urophylla* in Vietnam.

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This manual summarises information on the ecology and silviculture of the species *Eucalyptus urophylla* S.T. Blake, 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 and Phu Tho provinces, 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 hybrid*, *Acacia mangium* Willd, *Cinnamomum parthenoxylon* (Jack) Meisn and *Erythrophloeum fordii* Oliver.

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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