

# *Anthocephalus cadamba* Miq.

Ecology, silviculture and productivity

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## Preface

Smallholders in Indonesia have long been actively planting trees on private or community land. Various actors have encouraged this activity with the aim of improving local livelihood security, environmental sustainability and industrial wood supply. Such tree-planting efforts are generally successful, but they are often undertaken without technical assistance. Farmers often lack the necessary technical capacity and knowledge regarding proper management. The most common management activity is harvesting products, with other management practices less frequently implemented. As a result, the quality and quantity of products may not be fulfilling their potential. 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. There is thus a need for manuals on ecology and silvicultural management of the selected tree species planted by smallholders in Indonesia.

This manual, '*Anthocephalus cadamba* Miq.: ecology, silviculture and productivity', is one of a series of five manuals 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' coordinated by CIFOR. This project was funded by Germany's Advisory Service on Agriculture Research for Development (BMZ/BEAF), through the Gesellschaft für Internationale Zusammenarbeit (GIZ) for a 3-year period (2008–2010).

This manual gathers as much information as possible on *Anthocephalus cadamba* Miq. from available resources, with a focus on Indonesian sites. However, in terms of growth and yield (productivity), the availability of data for this species, particularly from smallholder plantations, is generally limited. Efforts have been made to collect inventory data from a research site in Asam Jaya village, Jorong Subdistrict, Tanah Laut District, South Kalimantan. Also, growth data for older stands provided by the Forestry Research and Development Agency was used.

The manual has been translated into Indonesian and modified slightly to meet smallholders' needs. The authors believe this manual will benefit smallholders and organisations involved in implementing tree-planting programmes.

Haruni Krisnawati, Maarit Kallio and  
Markku Kanninen

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# 1. Introduction

*Anthocephalus cadamba* Miq., also known as kadam, is a tropical tree species that is native to South Asia and Southeast Asia, including Indonesia. According to Slik (2006), *A. cadamba* has been planted on a large scale in Indonesia since the 1930s. It has been cultivated in Java (mostly in West Java and East Java provinces), Kalimantan (mostly in South Kalimantan and East Kalimantan provinces), Sumatra (across almost all provinces on the island), Sulawesi (across almost all provinces on the island), Sumbawa (West Nusa Tenggara) and Irian Jaya (Papua) (Martawijaya *et al.* 1989).

Because of its very fast growth, its ability to grow on a variety of soils, its favourable silvicultural characteristics and the absence of serious pests and diseases, *A. cadamba* has been used in Indonesia both for industrial plantations and for reforestation and afforestation. This species is also expected to become increasingly important for wood industries, particularly when supplies for plywood from natural forests decrease. Many plantations exist in the provinces of North Sumatra, Riau and Central Kalimantan. There has recently been an expansion of *A. cadamba* plantations by smallholders, particularly in Kalimantan and Java. In some parts of Java, *A. cadamba* is commonly planted to replace poor teak plantations after harvesting (Nair and Sumardi 2000).

## 2. Description of the species

### 2.1. Taxonomy

**Botanical name:** *Anthocephalus cadamba* Miq.

**Family:** Rubiaceae

**Subfamily:** Cinchonoideae

**Synonyms:** *Anthocephalus chinensis* (Lamk.) A. Rich. Ex. Walp., *Anthocephalus macrophyllus* (Roxb.) Havil., *Nauclea cadamba* (Roxb.), *Neolamarckia cadamba* (Roxb.) Bosser, *Sarcocephalus cadamba* (Roxb.) Kurz., *Anthocephalus indicus* A. Rich., *Anthocephalus morindaefolius* Korth.

**Vernacular/common names:**

Common names in Indonesia: Galupai, galupai bengkal, harapean, johan, kalampain, kelampai,

kelempi, kiuna, lampaian, pelapaian, selapaian, serebunaik (Sumatra); jabon, jabun, hanja, kelampeyan, kelampaian (Java); ilan, kelampayan, taloh, tawa telan, tuak, tuneh, tuwak (Kalimantan); bance, pute, loeraa, pontua, suge manai, sugi manai, pekaung, toa (Sulawesi); gumpayan, kelapan, mugawe, sencari (Nusa Tenggara); aparabire, masarambi (Papua) (Martawijaya *et al.* 1989).

Common names in other countries: Bangkal, kaatoan bangkal (Brunei); thkoow (Cambodia); kadam, cadamba, common burr-flower tree (England); koo-somz, sako (Laos); kelempayan, laran, selimpoh (Malaysia); mau-lettan-she, maukadon, yemau (Myanmar); labula (Papua New Guinea); kaatoan bangkal (Philippines); krathum, krathum-bok, taku (Thailand); c[aa]y g[as]o, c[af] tom, g[as]o tr[aws]ng (Vietnam) (Soerianegara and Lemmens 1993).

### 2.2. Botany

*Anthocephalus cadamba* is a large tree with a broad umbrella-shaped crown and straight cylindrical bole (Figure 1). The branches are characteristically arranged in tiers. The tree may reach a height of 45 m with a stem diameter of 100–160 cm and sometimes it has a small buttress up to 2 m high. The bark (Figure 2) is grey, smooth and very light in young trees, but rough and longitudinally fissured in old trees. The branches spread horizontally and drop at the tip. The leaves (Figure 3) are glossy green, opposite, simple sessile to petiolate, ovate to elliptical (15–50 cm long by 8–25 cm wide). In young fertilised trees, the leaves are much larger, subordinate at base and acuminate at apex; the stipules are interpetiolar, narrowly triangular and deciduous. The fruitlets are numerous, somewhat fleshy, with their upper parts containing 4 hollow or solid structures. The fruit (Figure 4) occurs in small, fleshy capsules packed closely together to form a fleshy yellow-orange infructescence containing approximately 8000 seeds. The seeds somewhat are trigonal or irregular shaped, not winged (Soerianegara and Lemmens 1993).

### 2.3. Distribution

*Anthocephalus cadamba* grows naturally in Australia, China, India, Indonesia, Malaysia, Papua New Guinea, Philippines, Singapore and Vietnam. It is



Figure 1. Four-year-old *A. cadamba* trees showing the species' characteristic shape, planted by a smallholder in South Kalimantan



Figure 2. The grey and smooth stem bark of young *A. cadamba* trees



Figure 3. Glossy green leaves of *A. cadamba*



Figure 4. *A. cadamba* fruits

a favoured plantation species inside and outside its native range. It has been planted as an ornamental and plantation tree and has been successfully introduced into Costa Rica, Puerto Rico, South Africa, Surinam, Taiwan, Venezuela and other tropical and subtropical countries (Orwa *et al.* 2009).

## 2.4. Ecological range

*Anthocephalus cadamba* is a typical pioneer species that grows best on deep, moist, alluvial sites, and often in secondary forests along riverbanks and in the transitional zone between swampy, permanently flooded and periodically flooded areas. Sometimes

large individuals can be found in primary rainforests. It grows on a variety of soils but is more abundant and dominant on well-accelerated fertile soils. It does not grow well on leached and poorly aerated soils, even when their physical conditions are good (Soerianegara and Lemmens 1993).

Light is the most important condition for *A. cadamba*'s growth. In its natural habitat, the maximum temperature varies from 32 to 42 °C and the minimum temperature varies from 3 to 15.5 °C. *Anthocephalus cadamba* is sensitive to frost. The mean annual rainfall for growing ranges from 1500 to 5000 mm. However, some *A. cadamba* may also grow locally on much drier sites with as little as 200 mm annual rainfall (e.g. in central parts of South Sulawesi). The range of the altitude for growing is between 300 and 800 m above sea level. In the equator region it is found from just above sea level up to an elevation of 1000 m (Martawijaya *et al.* 1989).

**2.5. Wood characteristics**

*Anthocephalus cadamba* is lightweight hardwood. The heartwood is white with a yellow tinge darkening to creamy yellow on exposure, and not clearly differentiated from sapwood (Martawijaya *et al.* 1989). The wood has a fine to medium texture, straight grain and low lustre and has no characteristic odour

or taste (Figure 5). The wood density is in the range 290–560 kg/m<sup>3</sup> at 15% moisture content (Table 1). The wood is easy to work with hand and machine tools, cuts cleanly, gives a very good surface and is easy to nail. It is very easy to preserve using either open-tank or pressure-vacuum systems. It can also be easily impregnated with synthetic resins to increase its density and compressive strength. However, the wood is rated as non-durable. Graveyard tests in Indonesia show that the average life of wood in contact with the ground is less than 1.5 years. The timber air-dries rapidly with little or no degradation. To prevent blue stain, the wood has to be worked up soon after cutting, or it should be treated within 48 hours or be submerged in water (Soerianegara and Lemmens 1993).

**2.6. Uses**

The wood is suitable for multiple end uses, such as plywood, light construction materials, flooring, beams and rafters, boxes and crates, tea-chests, packing cases, shuttering, ceiling boards, toys, wooden shoes, bobbins, yokes, carvings, matches, chopsticks and pencils (Soerianegara and Lemmens 1993). It is also suitable for dug-outs or canoes and inexpensive furniture if properly seasoned. The pulp is sometimes mixed with other, generally long-fibred material to produce medium quality paper.

**Table 1. Wood density of *A. cadamba***

|  | Wood density (kg/m <sup>3</sup> ) |        |      | Moisture content (%) | References                      |
|--|-----------------------------------|--------|------|----------------------|---------------------------------|
|  | Low                               | Medium | High |                      |                                 |
|  | 290                               | 420    | 560  | 15                   | Oey (1964)                      |
|  | 290                               | 465    | 560  | 15                   | Soerianegara and Lemmens (1993) |
|  | 370                               | –      | 465  | 15                   | Soerianegara and Lemmens (1993) |
|  | –                                 | 310    | –    | 12                   | Soerianegara and Lemmens (1993) |



**Figure 5. Wood characteristic of *A. cadamba***



The tree is also suitable for ornamental use and shade along roadsides and villages as well as for shelter for other crops in agroforestry systems. It is also used in reforestation and afforestation programmes. It can help improve some of the physical and chemical properties of the soil under its canopy due to its large amounts of leaf and non-leaf litter, which increase the level of soil organic carbon, cation exchange capacity, available plant nutrients and exchangeable bases (Orwa *et al.* 2009).

An extract of the leaves can serve as a gargle and the fresh leaves are used as fodder for cattle or sometimes as plates and serviettes. The dried bark is used to relieve fever and as a tonic. A yellow dye, obtained from the bark of the roots, can serve as tannin or dyestuff (Soerianegara and Lemmens 1993).

### 3. Seed production

#### 3.1. Seed collection

Seed production of *A. cadamba* under plantation conditions usually begins by the age of 5 years. The tree starts flowering at the age of 4 years. The flowering period commonly lasts 2–5 months. In Indonesia, flowering starts in April–August, sometimes March–November, and the fruits mature in June–August (Martawijaya *et al.* 1989). In other countries, flowering and fruiting periods commence later (Table 2).

The seeds are mature when the fruit has changed colour to dark brown. The fruits are harvested from the tree by climbing or from covers on the ground after shaking the branches.

#### 3.2. Seed preparation

Special techniques are required to extract the minute seeds from the fleshy multiple fruits. Successful extraction of seeds from ripe fruits involves air-

drying, crushing and sieving (Soerianegara and Lemmens 1993). The fruits are soaked in an open area until rotten, ground by hand into a thick slurry, air-dried and passed through a series of sieves. This procedure improves the germination rate up to 98%. In Indonesia, the fruits are cut into small pieces and dried in the sun. Once dried, the fruits are gently crushed and cleared using a fine sieve. According to Soerianegara and Lemmens (1993), the weight of 1 million air-dried seeds is about 38–56 g.

#### 3.3. Seed storage and viability

Seeds should be stored in dry, airtight containers. Properly stored seeds can remain viable for up to 2 years, and up to 6 months at an ambient temperature (Jøker 2000). According to Martawijaya *et al.* (1989), dried seeds stored in airtight containers in a moist room will retain viability for about 1 year. The germination rate of fresh seeds is variable, but generally low at about 25%. When seeds are stored in cool, airtight boxes for about 2.5 months, a much higher germination rate (up to 95%) can be obtained.

## 4. Propagation and planting

#### 4.1. Sowing

Because of their small size, the seeds are mixed with fine sand (1:10) and sown in seedbeds (Jøker 2000). Alternatively, a salt or pepper pot can be used for sowing. The seedbeds should be protected from heavy rain and not watered too much as damping-off can be a problem. To prevent damping-off disease, seedlings should be placed in well-ventilated conditions. A mild fungicidal spray may also be used to prevent the damping-off (Soerianegara and Lemmens 1993). Direct sowing is not very successful because of the small size of the seeds and their sensitivity to drought, excessive moisture and direct sun.

**Table 2. Flowering and fruiting periods of *A. cadamba* in selected countries**

| Country     | Flowering      | Fruiting           |
|-------------|----------------|--------------------|
| India       | May–June       | January–February   |
| Indonesia   | April–August   | June–August        |
| Laos        |                | October–December   |
| Philippines | April–May      | September–February |
| Malaysia    | June–September | September–February |
| Sri Lanka   |                | September          |



Figure 6. *Anthocephalus cadamba* seedlings



Figure 7. 5×5 m *A. cadamba* lines intercropped with rubber trees in smallholder plantations in South Kalimantan

#### 4.2. Preparation for planting out

Germination usually takes places 2–3 weeks after sowing. When the seedlings are 8–12 weeks old, they can be transplanted to nursery beds or polythene/ plastic bags. It is recommended to use a medium that is enriched with organic matter. After 6–7 months, when the seedlings are about 30–40 cm tall, they are ready to be transplanted into the field (Figure 6). Under good care, seedlings can sometimes be planted out when they are 10–15 cm tall. According to Soerianegara and Lemmens (1993), planting seedlings of about 1 cm in diameter that have been topped give satisfactory results.

#### 4.3. Planting

The planting distance of *A. cadamba* in the field is usually around 3–4×3–4 m (Soerianegara and Lemmens 1993). However, Martawijaya *et al.* (1989) reported that spacing of 3×2 m is also used. A wider spacing of 4–5×4–5 m is commonly applied by smallholders in our study village in South Kalimantan; some of their plantations have been intercropped with fruit, food crops and rubber (Figure 7). In other sites in South Kalimantan, *A. cadamba* plantations have been intercropped with upland rice. Planting *Leucaena leucocephala* between the lines of *A. cadamba* has also been reported to have promising results (Soerianegara and Lemmens 1993). *Anthocephalus cadamba* has also proved to be an excellent shade tree for dipterocarp line planting.

### 5. Plantation maintenance

#### 5.1. Weeding

*Anthocephalus cadamba* is generally considered a light-demander, requiring high light availability for seedling growth. The seedlings are highly susceptible to weeds. Therefore, after planting, the area around the young seedlings needs to be weeded of competing vegetation, especially of climbers and plants causing shade. Smallholders in Indonesia commonly practise both manual and chemical weed controls. Weeding should be done several times during the first few years after planting until the trees approach canopy closure. The interval between 2 successive weedings is usually 3 months during the first year, and 6 months after the first year (Soerianegara and Lemmens 1993).

#### 5.2. Fertilising

To attain optimal growth in infertile sites, fertilisers are required. Application of fertilisers at the planting time is the most widely used practice. However, some of the smallholders in our study village in South Kalimantan fertilised the trees more than once during the first 2 years of the plantation growth. Urea and Triple Super Phosphate (TSP) were the most widely used fertilisers. According to Soerianegara and Lemmens (1993), applying urea fertiliser of about 15 g per plant in a ring around the seedling results in much faster growth.



**Figure 8.** Four-year-old *A. cadamba* trees showing natural pruning in smallholder plantation in South Kalimantan

### 5.3. Replanting

Replanting is often done twice during the rotation. The first replanting normally takes place in the rainy season at 1 month after planting to replace the dead seedlings and the second replanting at the end of the second year.

### 5.4. Pruning

Pruning is usually done to produce knot-free timber. It also gives easier access to timber stands and reduces damage caused by fire. However, pruning in *A. cadamba* plantations is unnecessary as the species shows natural pruning (Figure 8), with dead branches falling off (Soerianegara and Lemmens 1993).

### 5.5. Thinning

Thinning is practised to encourage crown development, which results in bole diameter increment, and to remove inferior trees and favoured vigorous trees. Thinning in *A. cadamba* plantations can be done easily as the trees have straight stems without defects and very regular small crowns. It should be done early and frequently, depending on the site quality and spacing, starting 2–4 years after planting. The number of thinnings required also varies depending on initial density, ranging from 1 to 3 thinnings in a rotation. Krisnawati *et al.* (2010) developed thinning scenarios for *A. cadamba* plantations, and found that for plantations with a 15-year rotation and a spacing of 3×2 m, 3 thinnings

conducted at 2, 4 and 8 years of age are sufficient to obtain a high timber volume; for plantations with 3×3 m spacing, thinnings should be conducted at 2, 4 and 7 years of age with a 13-year rotation. In a wider spacing (e.g. 4×4 m), 1 thinning at 3–4 years of age is suitable with a rotation of 10–15 years.

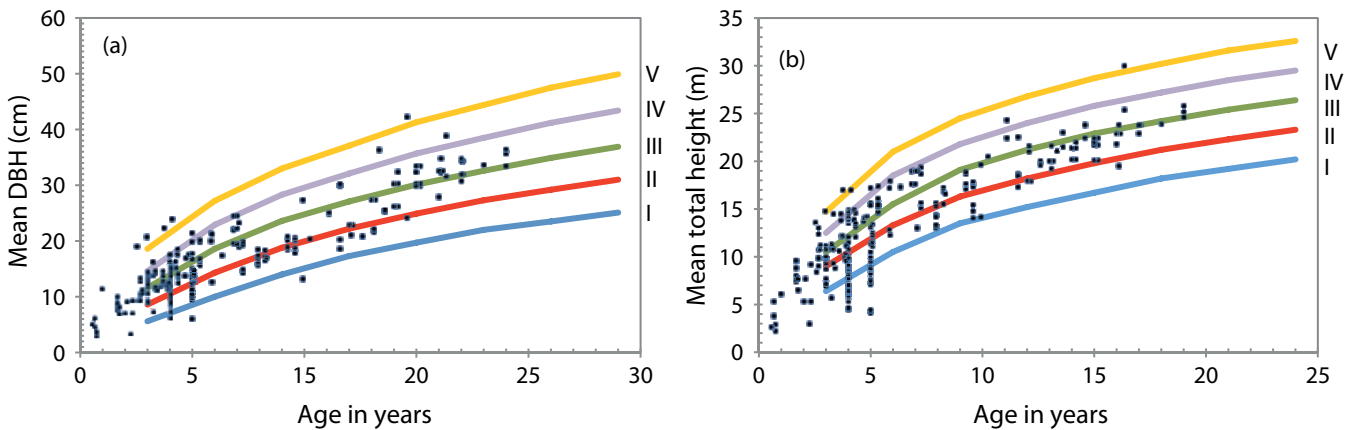
### 5.6. Control of pests and diseases

No serious diseases have been reported on *A. cadamba* in Indonesia. The fungus *Gloeosporium anthocephali* may cause partial or complete defoliation and dieback (Soerianegara and Lemmens 1993). A variety of insects often eat the leaves. Ngatiman and Tangketasik (1987) recorded some unidentified insects (presumably caterpillars) in plantations in East Kalimantan. Suratmo (1987) refers to *Margaronia* sp. (Lepidoptera, Pyralidae) as a defoliator of *A. cadamba*. Selander (1990) reported heavy defoliation of experimental plantations of *A. cadamba* in South Kalimantan by an unidentified caterpillar. Even though *A. cadamba* trees with severely perforated leaves are very common, they usually recover well (Soerianegara and Lemmens 1993). Intari and Natawiria (1973) reported white grubs (larvae of some groups of beetles) eating the roots and damaging 1–2-year-old trees planted under the *taungya* system in Java. Insecticides can be sprayed to control pests and fungicides sprayed to protect against fungi attacks.

## 6. Growth and yield

The ability to predict the growth and yield potential of *A. cadamba* plantations is of considerable importance for plantation planning. Several sources have reported that *A. cadamba* grows fast (e.g. Soerianegara and Lemmens 1993, Orwa *et al.* 2009), but extremely few reliable experimental data on which to base such predictions are available. The information on growth and yield presented here is based on preliminary data of young *A. cadamba* stands (up to 5 years old) collected from 92 temporary sample plots established in smallholder plantations in South Kalimantan. For older stands, information was taken from 26 permanent sample plots distributed across several sites in Java (collected by the Forest Research Institute of Bogor) and preliminary reports by Sudarmo (1957) and Suharlan *et al.* (1975).





**Figure 9.** The relationships between age and diameter (a) and age and height (b) of *A. cadamba* trees taken from measurement of temporary plots in South Kalimantan and permanent plots in Java (points: mean values of the plot; lines: value taken from the yield table (Sudarmo 1957; Suharlan *et al.* 1975)). Roman numerals indicate site quality class with a low number indicating poor site quality.

### 6.1. Growth rates

The relationships between mean diameter and age and between mean height and age have rarely been reported for *A. cadamba* plantations. However, measurements of temporary sample plots collected from smallholder plantations in South Kalimantan can be used to depict the development of diameter and height, particularly for young stands. For older stands, information obtained from growth data of permanent plots in Java was used.

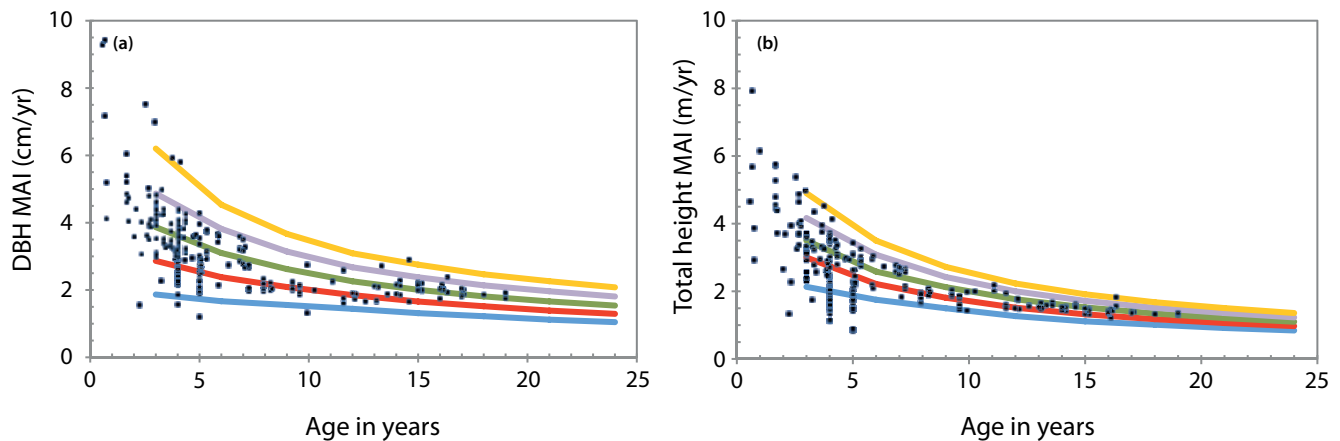
In *A. cadamba* trees grown in small farms in South Kalimantan, the mean diameter ranged from approximately 6.0 to 16.4 cm with a maximum diameter of 25.3 cm for trees younger than 5 years old. The mean height of the same stands ranges from 4.1 to 14.6 m with a maximum value of 17.1 m. In another site in South Kalimantan, an average diameter of up to 23.9 cm and a mean height of up to 17 m were recorded for *A. cadamba* trees up to 4 years old growing in an experimental plot (<http://www.papadaanfoundation.com/tabel-pertumbuhan>). These differences in the development of diameter and height were expected as the trees growing in the experimental plot were well maintained and only a few selected trees were measured, whereas some of the trees planted by smallholders had not been carefully maintained.

The mean diameter range for trees older than 10 years growing in several plantation sites in Java is 18.6–42.3 cm with a mean value of 29.3 cm. In West Java, *A.*

*cadamba* trees in a 10.5-year-old stand were reported to have an average height of 22 m and an average diameter of 40.5 cm (Soerianegara and Lemmens 1993). In North Sumatra, 16-year-old *A. cadamba* trees growing in an arboretum of a forest research area with a spacing of 2×2 m were reported to have a mean diameter of 49 cm (with a maximum diameter of 70 cm) and a mean height of 21 m ([http://www.jifpro.or.jp/Database/Database\\_on\\_Artificial\\_Forests/Indonesia.html](http://www.jifpro.or.jp/Database/Database_on_Artificial_Forests/Indonesia.html)).

The relationships between the mean diameter and age and between the height and age of *A. cadamba*, taken from measurements of temporary plots in South Kalimantan and permanent plots in Java, are shown in Figure 9. In general, diameter at breast height (DBH) increases fairly rapidly up to 8–18 cm in trees younger than 5 years old. However, the growth rates slow noticeably after 10 years, and the diameter begins to level off after 15 years. The mean height was recorded as 19.6 m for trees younger than 10 years old and ranged from 17.3 to 30 m after 10 years. The wide variations in mean diameter and height are probably due to differences in site quality and owners' management practices. For example, we found *A. cadamba* trees grow slowly, particularly in height, in some stands in South Kalimantan with dense ground vegetation and poor site quality.

As shown in Figure 10, young *A. cadamba* trees up to 5 years old can grow 1.2–11.6 cm/year in diameter and 0.8–7.9 m/year in height. However, the growth rates of both diameter and height in Java



**Figure 10.** Mean annual increment (MAI) in diameter (a) and height (b) of *A. cadamba* trees taken from measurement of temporary plots in South Kalimantan and permanent plots in Java (points: MAI values of the plot, lines: value taken from the stand yield table (Sudarmo 1957; Suharlan *et al.* 1975)). Different colours indicate different site quality classes with a lower curve indicating poorer site quality.

**Table 3.** Parameter estimates, standard errors and related fit statistics of the height–diameter model for *A. cadamba* trees

| Parameter             | Estimate  | SE     | <i>t</i> | <i>Pr</i> ≥   <i>t</i> | RMSE   | <i>R</i> <sup>2</sup> <sub>adj</sub> |
|-----------------------|-----------|--------|----------|------------------------|--------|--------------------------------------|
| <i>b</i> <sub>0</sub> | 15.239580 | 2.2976 | 6.63     | < 0.0001               | 1.6369 | 0.5292                               |
| <i>b</i> <sub>1</sub> | 2.929555  | 0.2346 | 12.49    | < 0.0001               |        |                                      |
| <i>b</i> <sub>2</sub> | 0.100718  | 0.0202 | 4.99     | < 0.0001               |        |                                      |

are higher than those in South Kalimantan. In South Kalimantan, diameter growth is only 1.2–4.8 cm per year and height growth is only 0.8–3.7 m per year. In general, growth rates slow to about 2 cm/year in diameter and 3 m/year in height until the 10<sup>th</sup> year. Thereafter the growth is significantly slower.

## 6.2. Height–diameter relationship

The height and diameter are essential inventory measures for estimating tree volume. Measurement of tree height is, however, difficult and costly. Consequently, height is measured for only a subset of trees in the plots. Quantifying the relationship between tree height and diameter is therefore necessary to predict the heights of the remaining trees.

Very little information is available on the height–diameter relationship for *A. cadamba* stands. Using our inventory data of 797 *A. cadamba* trees collected from smallholder plantations in South Kalimantan, whose diameter at breast height (*D*) and total tree height (*H*) were measured, the relationship between total tree height and DBH was investigated for the

species. Six non-linear models were tested: Chapman–Richards, Curtis, exponential, Gompertz, Korf and Patterson. Of these, the Gompertz model fits the data best. The functional form of the selected model was:

$$H = 1.3 + b_0 \exp(-b_1 \exp(-b_2 D))$$

The results of fitting the selected model, including non-linear least squares estimates of the parameters, the standard error, *t*-statistic, *p*-value, the root mean squared error (RMSE) and the adjusted coefficient of determination, are presented in Table 3.

As shown in Figure 10, height increases at a decreasing rate as the DBH increases. It should be noted that using the model, all trees with the same diameter in any stand will have the same predicted height regardless of the stand in which they are growing. For example, the predicted height for *A. cadamba* trees with a diameter of 15 cm is 9.3 m. In fact, the height range for trees with a diameter of 15 cm is 5–13 m (Figure 11). This result is not surprising as the data used for estimating the height–diameter relationship were collected from plots with a wide



range of stand conditions. This is supported by a relatively low proportion of total variation in observed values of tree height, accounting for only 52.9%. The value of *RMSE* was also quite high at about 1.64 m – more than usually expected for height–diameter relationship models. To improve height predictions, it is advisable to include additional stand variables such as site quality, stand age and/or stand density, which may affect the height–diameter relationship.

### 6.3. Stem volume equation

Estimation of single stem volume is a necessary first step in order to estimate the stand volume. However, no published information was available on stem volume model for *A. cadamba* plantations. To obtain information on stem volume estimation for *A. cadamba*, the same data used for developing the height–diameter relationship were analysed. The total volume of each *A. cadamba* sample tree was calculated using both measured DBH and total tree height as well as a common form factor of 0.47, obtained from data of *A. cadamba* grown in a plantation in Java. A constant form factor equation (Clutter *et al.* 1983, Husch *et al.* 2003), which relates the total volume (*V*) with diameter (*D*) and height (*H*) together, was selected to estimate total stem volume:

$$V = a D^2 H \quad \text{where } a = 0.0000369$$

The development of total wood volume of *A. cadamba* trees obtained from the volume equation is presented in Figure 12. An improved model is

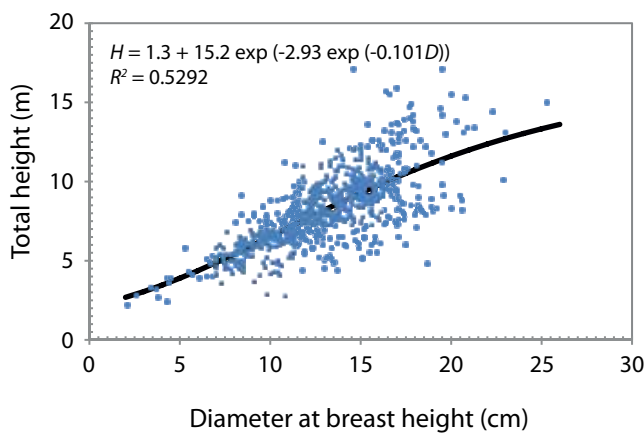


Figure 11. The relationship between height and diameter of *A. cadamba* developed using measurement data from smallholder plantations in South Kalimantan (points: measured values, solid line: model)

required to cover a wide range of age and tree sizes. Sample trees should also be sectioned to obtain more accurate predictions.

### 6.4. Productivity

If stand density (stocking) is known, the calculated mean diameter can be used to predict basal area and volume for a stand of a given age in order to give an idea of productivity. A tree of 50 cm in diameter produces about 2.5–3 m<sup>3</sup> wood. Soerianegara and Lemmens (1993) reported that in a 30-year rotation in Indonesia, the stand attained a mean height of 38 m and average diameter of 65 cm, producing 350 m<sup>3</sup>/ha in the final harvest. Total wood production including thinning amounted to 23 m<sup>3</sup>/ha per year. These data refer to wood volume to a limit of 7 cm in diameter.

A report by Sudarmo (1957) indicated that *A. cadamba* plantations growing in several sites in Java generally reach a maximum volume mean annual increment (MAI) of 20 m<sup>3</sup>/ha/year by the age of 9 years in good-quality sites, producing up to 183 m<sup>3</sup>/ha over the rotation. In medium-quality sites, the volume MAI of 16 m<sup>3</sup>/ha/year can be attained in 9 years producing up to 145 m<sup>3</sup>/ha. In poor-quality sites, the total volume production in 9-year-old stands is about 105 m<sup>3</sup>/ha and a maximum volume MAI of 15 m<sup>3</sup>/ha/year may not be achieved for 9 years and even up to 24 years (Figure 13). At 24 years of age, the maximum volume MAI could reach only 13 m<sup>3</sup>/ha/year.

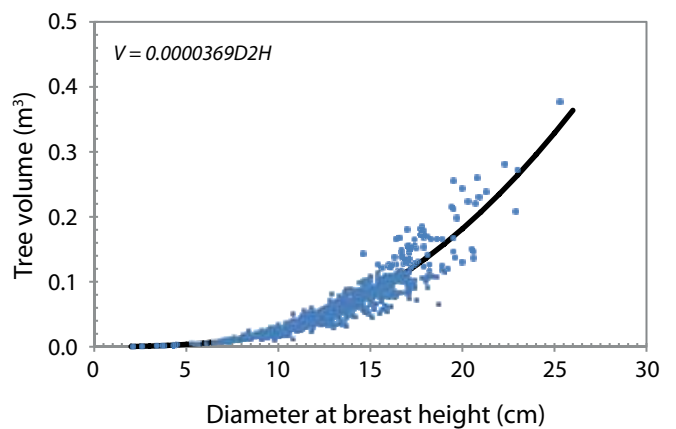
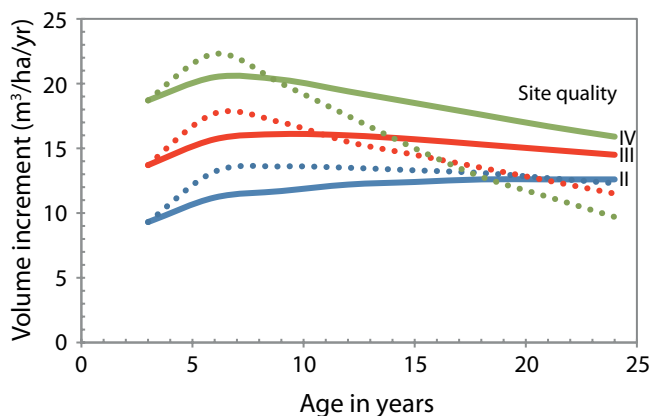


Figure 12. Total stem volume estimation of *A. cadamba* developed using measurement data from smallholder plantations in South Kalimantan (points: measured values, solid line: model)



**Figure 13.** Volume MAI (solid lines) and CAI (dashed lines) against age by site quality for *A. cadamba* plantations. Graphs were drawn from a preliminary yield table by Sudarmo (1957), which reported only 3 site-classes, II, III and IV, with a low class number indicating poor site quality.

## 6.5. Rotation

The rotation period (harvesting time) depends upon the production purpose. For pulpwood and matches, harvesting can start 4–5 years after planting. For example, a match factory in North Sumatra is growing *A. cadamba* on a 4-year rotation under optimal management, which includes fertilisation (Soerianegara and Lemmens 1993). For wood production, felling of trees can start approximately from the age of 10 years. In the Philippines, economic rotations applied in plantations are 5 years for pulpwood and 7 years for the combination of pulpwood and sawn timber (Soerianegara and Lemmens 1993).

Rotation length may be guided by the time taken for stands to reach their maximum MAI in volume. In Indonesia, Sudarmo (1957) predicted that *A. cadamba* plantations will reach their maximum MAI of volume sometime between 9 and 24 years, depending on site quality (Figure 13). These values refer to wood volume, including stems with a diameter of 7 cm and more. Krisnawati *et al.* (2010) developed management scenarios for this plantation species and found that optimum rotation varied from 10 to 20 years depending on initial stand density and site quality. In state-owned plantations in Java, according to a decree by the director of Perum Perhutani (Decree No. 378/Kpts/Dir/1992; Perum Perhutani 1995), the economic rotation for *A. cadamba* is set at around 20 years.

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This manual gathers information on the ecology and silviculture of *Anthocephalus cadamba* Miq., with a focus on Indonesia. It also includes growth and yield data from published sources, collected from smallholders' farms in the research sites in South Kalimantan province, and collected previously by the Forestry Research and Development Agency of Indonesia. The manual is one of the five manuals produced to guide smallholder tree planting of five selected tree species in Indonesia. The other four species are: *Acacia mangium* Willd.; *Aleurites moluccana* (L.) Willd.; *Paraserianthes falcataria* (L.) Nielsen; and *Swietenia macrophylla* King. Smallholders in Indonesia have planted trees on private or community land for long time. Various actors have encouraged this activity to improve local livelihoods, environmental sustainability and industrial wood supply. Since farmers often lack technical capacity and management know-how, the quality and quantity of products may not be optimal. Productivity of smallholder plantations can be improved by enhancing smallholders' management knowledge and skills, including species selection based on site matching, silvicultural management to produce high-quality products, and pest and disease management.

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