Aleurites moluccana (L.) Willd.

Ecology, silviculture and productivity

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Contents

List of figures and tables

Figures

Tables

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, '*Aleurites moluccana* (L.) Willd.: 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 *Aleurites moluccana* (L.) Willd. 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 by measuring some scattered trees grown in farmlands from our research site in Ranggang village, Takesung Subdistrict, Tanah Laut District, South Kalimantan. We also drew on some data for older trees available from websites and reports.

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.

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1. Introduction

Aleurites moluccana (L.) Willd., also known as candlenut, is one of the world's great domesticated multipurpose trees. It is native to the Indo-Malaysia region and was introduced throughout the Pacific islands in ancient times. In Indonesia, it has long been grown for both subsistence and commercial purposes, sustaining people's everyday lives, especially in the eastern part of the country. The species can be used for various purposes; the seeds provide material for lighting, cooking and pharmaceuticals, and the trunk is used for timber.

Aleurites moluccana is distributed across almost all islands in the Indonesian archipelago. Despite this wide distribution, and although the species is easy to grow, it has not been planted in large-scale plantations. It is extensively cultivated in home gardens, and in and around farms. The main *A. moluccana* cultivation areas in Indonesia are in the provinces of North Sumatra, West Sumatra, South Sumatra, Bengkulu, Lampung, West Java, West Kalimantan, South Kalimantan, East Kalimantan, Bali, South Sulawesi, Maluku and East Nusa Tenggara. The total cultivation area of *A. moluccana* in Indonesia has been reported to be 205 532 ha (Directorate of Perennial Crop Cultivation 2008). According to the 2003 agricultural census, as reported by the Ministry of Forestry and the National Statistics Agency (2004), the provinces with the highest number of *A. moluccana* trees planted by smallholders are East Nusa Tenggara and North Sumatra, with more than 2 million *A. moluccana* trees reportedly planted by households in each of these provinces.

2. Description of the species

2.1. Taxonomy

Botanical name: *Aleurites moluccana* (L.) Willd.

Family: Euphorbiaceae

Subfamily: Crotonoideae

Synonyms: *Aleurites javanica* Gand., *Aleurites remyi* Sherff, *Aleurites triloba* Forster & Forster f., *Camirium moluccanum* (L.) Ktze., *Croton moluccanus* L., *Jatropha moluccana* L.

Vernacular/common names:
Common names in Indonesia: Buwa kare, kembiri, kemili, kemiling, kereh, madang ijo, tanoan (Sumatra); kamere, kemiri, komere, midi, miri, muncang, pidekan (Java); keminting, kemiri (Kalimantan); berau, bontalo dudulaa, boyau, lana, saketa, wiau (Sulawesi); kemiri, kemwiri, kumiri, mi, nena, nyenga (Maluku); tenu (Nusa Tenggara); anoi (Papua) (Martawijaya *et al.* 1989).

Common names in other countries: candlenut, candleberry, varnish tree, Indian or Belgaum walnut (England); lauci, nggerenggere, sikeci, sikeli, sikethi, toto, tuitui, tutui, waiwai (Fiji); bancoulier, noyer de bancoul, noyer des Moluques, aleurites, noisette, noix, noyer, noyer des Indes (France); Kerzennussbaum, Lichtnussbaum (Germany); lumbang (Guam); kuikui (Hawaii); rama (Mangareva); ama (Marquesans); tahii, tahiri, tiairi, tiʻaʻiri, tutui (Mauretania); tuitui (Mangaia [Cook Islands], Futuna, Makatea, Niue, Tonga, Tubuai, Uvea); tutuʻi, tiʻaʻiri (Society Islands); tutui (Rimatara, Rurutu, Tahiti); raguar (Caroline Islands); sakan (Palau); sakan, shakan (Pohnpei); calumban, noz da India (Portugal); lama (Samoa); arbol lloron, avellano, avellano criollo, nogal de la India, nuez (Spain); kandeltri (Vanuatu); lerit, nwa, nwazet (Creole); ragaur (North Carolina) (Elevitch and Manner 2006).

2.2. Botany

Aleurites moluccana is a medium-sized tree with a large spreading crown (Figure 1) that can reach 20 m in height and 0.9 m trunk diameter (diameter at breast height; DBH), although it typically grows to 10–15 m in open areas. Crooked trunks and irregular, wide, spreading or pendulous side branches are typical. In narrow valleys, *A. moluccana* usually has a branchless trunk and achieves its greatest height. The bark is grey-brown in colour, and fairly smooth with fine vertical lines (Figure 2). It has very distinctive leaves, which are 3- to 5-nerved from the base, alternate and simple, with entire, wavy margins. The leaf blades are 10–20 cm long with 2 glands at the junction of the leaf base and petiole that secrete a sweetish sap (Figure 3). Younger leaves are usually simple and deltoid to ovate in shape. The upper surface of young leaves is whitish with a silvery gloss, becoming dark green with age. The underside is rusty stellate-pubescent when young (having a hairy glossy indument) (Elevitch and Manner 2006).

The flower is monoecious, that is, it has both male and female flowers on the same tree. The flowers are greenish-white and fragrant and are arranged in a

Figure 1. Three-year-old *A. moluccana* trees showing its characteristic ornamental shape

Figure 2. Stem bark of *A. moluccana* (Photo: © Craig Elevitch)

Figure 3. Wavy leaves and infloresc ence of *A. moluccana*

Figure 4. Whitish corolla of *A. moluccana* flowers

Figure 5. Fruits of *A. moluccana*

10–15 cm terminal panicled cyme, with many small male flowers surrounding the female flower. The corolla is whitish with 5 free petals, dingy white to creamy in colour, oblong in shape and up to 1.3 cm in length (Figure 4). The fruit is green to brownish in colour and is a laterally compressed, ovoid to globose indehiscent drupe 5–6 cm long by 5–7 cm wide (Figure 5). Each fruit usually contains 2 or 3 seeds, but 1 seed may be found in male fruit. These seeds are edible when roasted. The seeds are contained within a hard, black, rough shell that is elliptical in shape and about 2.5–3.5 cm long (Elevitch and Manner 2006).

2.3. Distribution

Aleurites moluccana has a large geographical distribution. This species is native to Indo-Malaysia (including Brunei, Cambodia, China, Cook Islands, Fiji, French Polynesia, Indonesia, Kiribati, Laos, Malaysia, Marshall Islands, Myanmar, New Caledonia, Norfolk Island, Papua New Guinea, Philippines, Samoa, Solomon Islands, Thailand, Tonga, Vanuatu and Vietnam). The tree has also been successfully introduced in Antigua and Barbuda, Bahamas, Bangladesh, Barbados, Brazil, Cuba, Dominican Republic, Grenada, Guadeloupe, Haiti, India, Jamaica, Japan, Kenya, Martinique, Montserrat, Netherlands Antilles, Puerto Rico, Sri Lanka, St Kitts and Nevis, St Lucia, St Vincent and the Grenadines, Trinidad and Tobago, Uganda, United States of America and Virgin Islands (US) (Elevitch and Manner 2006).

2.4. Ecological range

Climatically, *A. moluccana* is extensively found in areas associated with the tropical monsoon climate, which have rather dry conditions in the dry season. It thrives in moist tropical regions up to 1200 m above sea level. Near the equator, the tree is reported to grow at elevations of up to 2000 m, although it is more likely that it has an upper limit of about 1200 m (Elevitch and Manner 2006). In Indonesia, the species is found at elevations of 0–800 m on flat to undulating terrains (Directorate of Industrial Plantation Forests 1990). *Aleurites moluccana* is known for its ability to grow well on slopes, even steep gullies.

Aleurites moluccana grows in areas with a mean annual rainfall ranging from 640 to 4290 mm with a mean of 1940 mm (Duke 1983). The mean annual temperature for growing is between 18 °C and 28 °C. The mean maximum temperature of the hottest month is 26–30 °C and the mean minimum temperature of the coldest month is 8–13 °C. In Indonesia, *A. moluccana* also grows locally on drier sites with as little as 200 mm annual rainfall in South Sulawesi and East Nusa Tenggara and even in moist sites in West Java (Ginoga *et al.* 1989).

Aleurites moluccana can grow on a variety of soils, including red loams, stony clay ground, sand and limestone. The tree requires free drainage. It grows on lightly acidic to alkaline soils with a pH of 5–8. It is also quite drought tolerant and can even grow well on relatively poor sites if it is well established with enough soil moisture available, particularly during establishment. It flourishes in moist environments. The tree prefers full sun and can grow as a pioneer species in open areas with suitable rainfall. It can grow in a modest amount of shade, up to 25% (Elevitch and Manner 2006).

2.5. Wood characteristics

The wood of *A. moluccana* is straw coloured and very plain. Although it is very light and soft, it is fairly tough. The species gravity is about 0.31 (Oey 1964). The wood density is in the range of 230–490 kg/m^3 at 15% moisture content (Table 1). It is relatively non-resistant to decay or insect attack. *Aleurites moluccana* wood has been used for unpainted draining boards because the wood retains its whitish colour for a long time. The wood is easy to work with hand and machine tools, cuts cleanly and gives a very good surface.

2.6. Uses

The traditional uses of *A. moluccana* are extensive. Almost all parts of the tree, including the leaves, fruits, bark, wood, roots, sap and flowers, are useful for traditional medicine, lighting, building materials, dyes, food, decorations and many other uses (Heyne 1987). The tree is toxic and caution should be exercised when using its different parts for medical purposes or for consumption. In Java, the bark is used for bloody diarrhoea (dysentery). In Japan, the bark has been used on tumours. In Sumatra, pounded seeds, burnt with charcoal, are applied around the navel for costiveness. In Malaysia, the

Table 1. Wood density of *A. moluccana*

Wood density (kg/m^3)			Moisture content	References
Low	Medium	High	(%)	
230	330	490	15	Anonymous (1981)
230	310	440	15	Martawijaya *et al.* (1989)

pulped kernels or boiled leaves are used in poultices for headache, fevers, ulcers, swollen joints and gonorrhoea. In Hawaii, the flowers and the sap at the top of the husk (when just removed from the branch) have been used to treat candidiasis in children (Scott and Craig 2000). The nut is often used for cooking in Indonesian and Malaysian cuisine. In Java, it is also used to make a thick sauce that is eaten with vegetables and rice.

Oil extracted from the seed is an irritant and laxative, and sometimes used like castor oil. It can be made into soap. Chewed seeds are used as a soap substitute. It is also useful for conditioning the hair. Refined *A. moluccana* oil is widely sold in the cosmetics industry and may currently be *A. moluccana*'s primary commercial product. After removal of the oil, the remaining seed cake can be used for fertiliser (Elevitch and Manner 2006).

In agricultural systems, *A. moluccana* trees can be integrated into windbreaks and borders, and used for shade, soil stabilisation and improved fallow. In urban areas, the trees make attractive shade trees or visual screens with their large leaves and white flowers.

The tree is rarely used for timber as it is not resistant to decay or insect attack. However, in some countries, including China, Malaysia and Indonesia, *A. moluccana* timber has been used for making items such as shelving, boxes, cabinets, packing cases, chopsticks and matches. In Bali, some traditional wooden handicrafts are carved from selected *A. moluccana* wood. A study conducted in a forest product laboratory in Indonesia suggested that the wood is also suitable for pulp and veneers (Martawijaya *et al.* 1989). In Hawaii, the trunk is sometimes used to make small canoes for fishing (Elevitch and Manner 2006).

3. Seed production

3.1. Seed collection

Flowering and fruiting begin when the trees are 3–4 years old. The tree typically flowers in September–October. However, the flowering period can vary between countries, e.g. in Australia the flowering period is from January to March (http://www.sgapqld.org.au/bushtucker11.html); in Sri Lanka flowering commences in April to May; and in Uganda, the tree can flower several times a year. In several places in Hawaii, flowering and fruiting can take place almost continuously, and frequently, flowers and fruits at all stages of ripeness occur in a tree simultaneously (Elevitch and Manner 2006).

The seeds are mature when the fruit has changed colour to yellowish-brown. Mature fruits can be picked from the tree, collected by shaking the tree or collected from the ground. The best time for collecting mature fruits or seeds is during the peak seed maturation season. In Indonesia, this season is in November–December. When seeds are collected from the ground, the collection should be done frequently (1–2 times a week) during the peak seed maturation season in order to avoid losing the seed viability due to soil moisture and microorganisms (Mulawarwan *et al. 20*03). In addition, the ground should be cleared before the seed collection season and, when feasible, tarps placed under the seed trees to facilitate the collection.

The first fruits produced are often the first to fall. These early fruits are often not fully mature and may contain poor-quality seeds. Later in the season immature fruits frequently fall together with mature fruits. In this case, care should be taken to collect only mature fruits or seeds from the ground (Mulawarwan *et al. 20*03; Elevitch and Manner 2006).

3.2. Seed preparation

To extract the seeds, the fruits are pressed or lightly beaten, and then washed and dried. If the fruits are fresh, they are allowed to decay a few days in a moist area, which makes it easier to peel off the thick, leathery outer husk. This exposes the hard shell that encloses the seed. There are about 100–120 seeds per kg with the husk removed and shells on. Typically, germination is about 80% over the course of several months. To improve the germination rate, bad seeds can be floated off in water (Elevitch and Manner 2006).

3.3. Seed storage and viability

The seeds can be stored for several months after drying to 10–12% moisture content. Often seeds lying on the ground under trees are viable and can be used successfully (Elevitch and Manner 2006). The seeds

can grow in moderate shade, but full sun also works and may accelerate germination. Seeds collected from the ground might be infected by soil pests or diseases so a separate container should be used for storage; also, they should not be mixed with seeds collected directly from the tree.

4. Propagation and planting

4.1. Sowing

Propagation of *A. moluccana* seedlings is easily done by seed. The seeds are usually sown in a seedbed with a spacing of 5×5 cm. The seeds are pressed gently into the soil and then covered by a layer of dried leaves or grass up to 3–10 cm thick. The grass is then burnt for about 3 minutes. Immediately after burning and whilst seeds are still hot, they are thrown into cold water, which makes the hard shells crack. This kind of treatment can result in a germination rate of more than 85% for good seeds. The germination usually occurs 15–20 days after sowing. Untreated seeds may stay in a seedbed for as long as 38–150 days before germination (Rosman and Djauhariya 2006).

4.2. Preparation for planting out

Because *A. moluccana* germinants have a large, thick taproot, it is recommended that seedlings are grown in 2–4 litre (1/2–1 gallon) root-training containers. Use a well-drained potting medium such as 50% peat moss, 25% perlite and 25% vermiculite, amended with a little compost, dolomite lime, gypsum and 14–14–14 slow-release fertiliser. Potting media can also be inoculated with mycorrhizal fungi from a reputable commercial source, particularly if the trees will be planted in degraded soils (Elevitch and Manner 2006).

Untreated seeds germinate in about 4 months. Placing the seeds in a moist medium and in warm sunlight may hasten and improve germination. Cracking the seed coat (shell) and soaking overnight in water may also hasten germination. Fungi growing on the seed coat may become a problem for germinating seeds, so treating the seeds with a fungicide prior to sowing may be helpful in reducing fungal problems. According to Elevitch and Manner (2006), seedlings can be transplanted into the field after about 3–4 months when they have attained a height of about 25 cm and stem diameter of 12 mm. Seedlings may also be transplanted into the field after about 6 months' germination when they have reached a height of about 60 cm and stem diameter of 80 mm with healthy and green leaves (Wahid 1991).

4.3. Planting

The best time for planting is in the beginning of the rainy season. The land needs to be cleared from weeds. Planting spacing depends on the production purpose. It has been reported that, in Hawaii, 200–300 seedlings are planted per hectare for producing oil seeds (Elevitch and Manner 2006). In Indonesia, various planting spacings have been reported. The spacings of 8×8 m and 6×6 m have been recommended for *A. moluccana* trees in agroforestry systems (intercropped with other tree species or annual crops). For pure *A. moluccana* stands, spacings of 4×4 m and 3×3 m are recommended (Dali and Gintings 1993). Spacings of 10×10 m and 4×4 m have also been recommended for oil seed production and pulpwood production, respectively (Directorate of Perennial Crop Cultivation 2008).

As a windbreak in an agricultural system, *A. moluccana* can be planted with a spacing of 3×4 m. In Tonga and Hawaii, *A. moluccana* has been planted densely in double rows, with 2×2 m or 3×3 m spacing, as a living fence or as a boundary marker (Elevitch and Manner 2006).

5. Plantation maintenance

5.1. Weeding

Early weeding is recommended for *A. moluccana* as it is vulnerable, especially to light competition (Directorate of Industrial Plantation Forests 1990). Weeding should be done 4 times a year (or every 3 months) during the first year after planting. For the first 1–3 years after planting, weeding should be done every 6 months until the trees are approaching canopy closure (Dali and Gintings 1993). Weeding can be done along the row of the main species (line weeding) or in an area of 1 m in diameter around the seedling (ring weeding). Once the trees are established, they require little care. Nevertheless, weeding around mature trees can make fruit harvesting (seed collection) easier, as seeds are more visible on the cleared ground (Rosman and Djauhariya 2006).

5.2. Fertilising

Even though *A. moluccana* can grow on marginal sites, regular fertilising is required to produce more seeds. Both organic (animal waste) and inorganic (chemical) fertilisers can be applied. Organic fertilising should be done once a year, with a dose of 2 kg/tree for young trees. For mature trees whose seeds have been harvested several times, 10–30 kg/tree of organic fertiliser should be given (Directorate of Perennial Crop Cultivation 2008).

If inorganic fertiliser is used, the dose depends on the age of the trees. It should be done twice a year: at the beginning and at the end of the rainy season. The annual doses are as follows: 20 g urea + 10 g SP36 + 10 g KCl per tree (for 1-year-old trees); 100–250 g urea + 80–75 g SP36 + 20–100 g KCl per tree (for 2–6-year-old trees); 500 g urea + 250 g KCl per tree (for trees more than 7 years old) (Directorate of Perennial Crop Cultivation 2008).

5.3. Replanting

Replanting is almost always recommended, normally 1 month after planting during the rainy season.

5.4. Pruning

Aleurites moluccana trees regrow well after pruning. Only light, broken and dead branches are usually pruned. Pruning for *A. moluccana* is usually conducted for the following purposes: (1) to make harvesting easier during the peak seed maturation season; (2) to control pests and diseases; (3) to cut down climbers; (4) to encourage new shoot growth; and (5) to accelerate the flowering and fruiting period by controlling the C/N ratio, as the medium value of C/N ratio could stimulate flowering. The best time for pruning is at the beginning of the rainy season because the tree requires more water to produce new shoots (Directorate of Perennial Crop Cultivation 2008).

5.5. Thinning

Thinning is not necessary for *A. moluccana* stands if only oil seed and/or pulpwood will be produced. If the trees are also intended for sawn timber production, thinning is done depending on the density and the growth rate.

5.6. Control of pests and diseases

Pests or diseases rarely seriously affect *A. moluccana*, and there are no pests of economic importance (Siemonsma 1999). However, minor pests have been noted to attack *A. moluccana* trees in Indonesia (Directorate of Perennial Crop Cultivation 2008). Spider mites (from the Tetranychidae family), molluscs and caterpillars sometimes eat the leaves. Stem borers, usually longhorn beetles (from the Cerambicyadae family) sometimes attack the trunk. Signs of the pest infestation include round exit holes up to 2 cm in size, a sawdust-like material composed of tree shavings and insect waste, and oozing sap. Termites (woodworm) sometimes attack the roots; this can be recognised from black spots at the root surface and the base of the trunk. Larva *Dacus* sp. and pod borers may attack the fruits and seeds. One of the diseases known to attack *A. moluccana* is *hawar daun cendawan*, which causes leaves to fall and premature fruit drop. In general, however, these pests and diseases do little damage to *A. moluccana*. There is no standard method of control. Spraying pesticides and fungicides may be useful for controlling pest and fungi attacks (Directorate of Perennial Crop Cultivation 2008).

6. Growth and yield

The ability to predict the growth and yield potential of *A. moluccana* plantations is of considerable importance for plantation planning. Elevitch and Manner (2006) said that *A. moluccana* trees can grow quickly; however, little information on the growth and productivity of the species is available. The information on growth and yield presented here is based on preliminary data of young *A. moluccana* trees (3–5 years old) collected from only a few scattered trees grown by smallholders in South Kalimantan. For older stands, information was taken from the Japan International Forestry Promotion and Cooperation Center (JIFPRO)'s website (http://www.jifpro.or.jp/Database/Database_on_Artificial_Forests/Indonesia.html) and a report (Anonymous 1988 *in* Ginoga *et al.* 1989).

Table 2. Diameter and height of *A. moluccana* trees grown in several small farms in Indonesia

Location	Age	N	D (cm)			H (m)		
	(years)		min	mean	max	min	mean	max
South	3	22	3.2	8.4	12.5	2.9		7.2
Kalimantan	4	9	9.4	15.1	18.0	6.2	8.2	9.5
	5	2	20.9	21.4	21.9	12.5	12.5	12.5
	a	3	32.2	38.7	50.5	12.2	13.2	14.8
South Sumatra[b]	24.5	a	25.9	46.9	67.8	21.3	25.2	29.1

a No information

b Data taken from http://www.jifpro.or.jp/Database/Database_on_Artificial_Forests/Indonesia.html

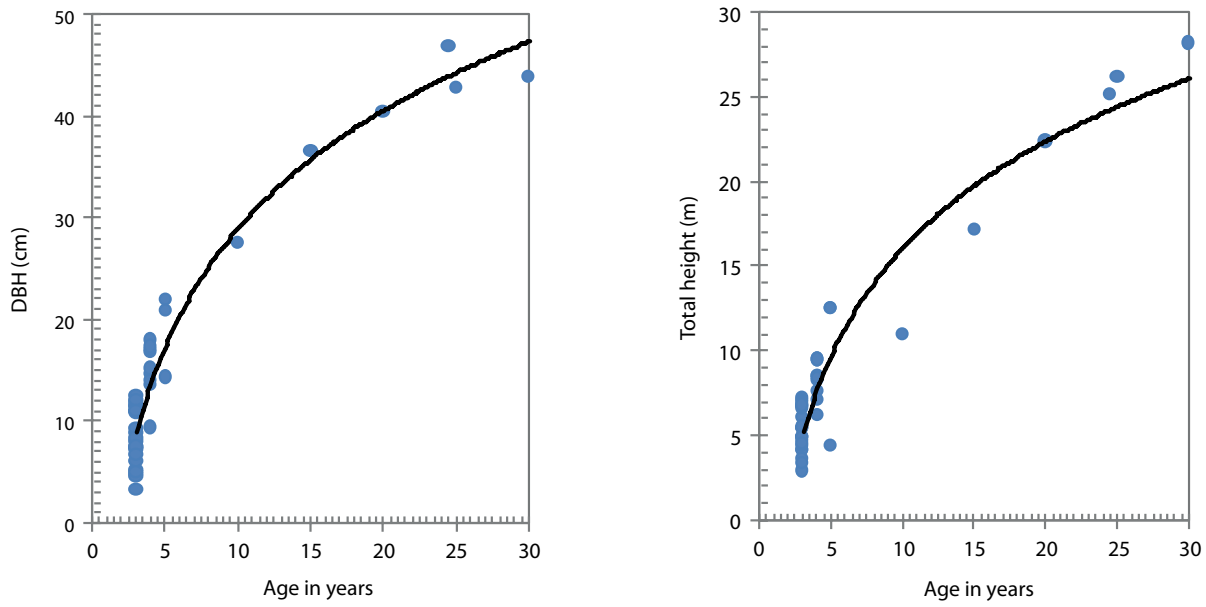

Figure 6. The relationships between age and diameter (left) and age and height (right) of *A. moluccana* trees

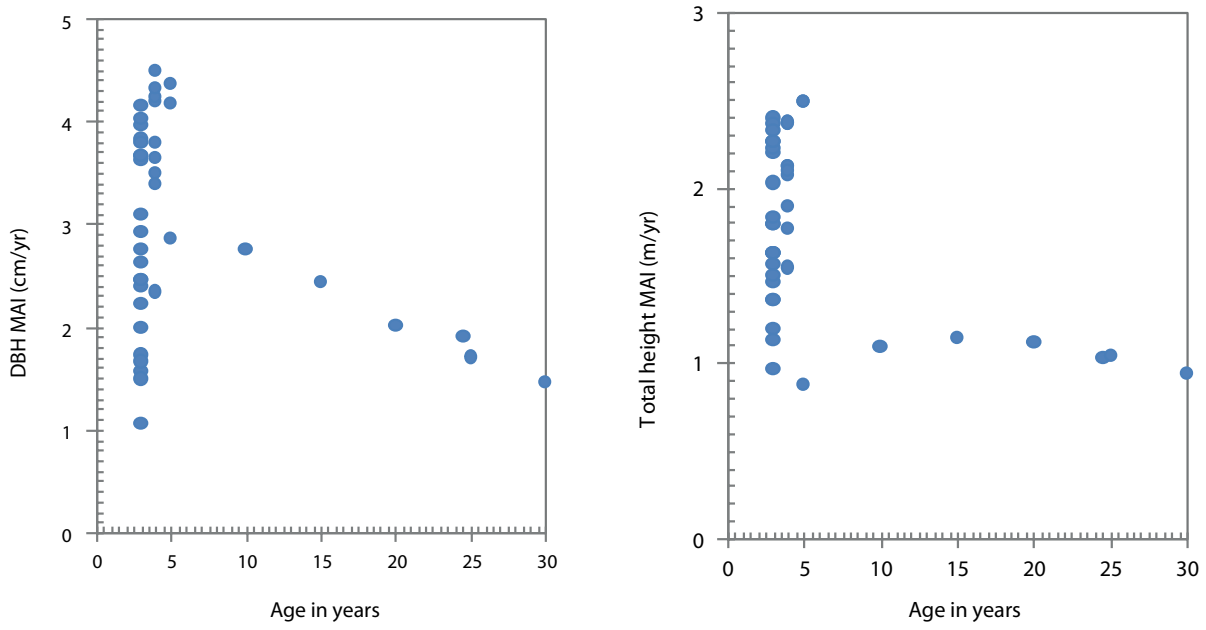

Figure 7. Mean annual increment (MAI) in diameter (left) and height (right) of *A. moluccana* trees

6.1. Growth rates

There is very little information on the growth and development of *A. moluccana*. According to Elevitch and Manner (2006), the tree grows moderately fast and readily colonises disturbed gaps and forest margins. Given these characteristics, *A. moluccana* probably has growth rates comparable to other common secondary forest tree species.

Our recent study in Tanah Laut District (South Kalimantan) recorded that young *A. moluccana* trees (up to 5 years old) growing in and around small farms have a diameter ranging from approximately 3.2 to 21.9 cm with the height of the same trees ranging from 2.9 to 12.5 m. Details are given in Table 2.

In South Sumatra, *A. moluccana* trees in a 24.5-year-old stand were reported to have a mean diameter of 46.9 cm (range: 25.9–67.8 cm) and a mean height of 25.2 m (range: 21.3–29.1 m) (Table 2). Data are not available for old or mature trees. However, Ginoga *et al.* (1989) reported that *A. moluccana* trees can reach a diameter of 110 cm by the age of 70 years.

The data presented in Table 2 indicate that young trees (3–5 years old) can grow 1.1–4.5 cm/year in diameter and 1.0–2.5 m/year in height. This height growth is greater than the growth of *A. moluccana* trees reported by Elevitch and Manner (2006) in Hawaii: 0.5–1.5 m growth in height per year in favourable conditions. The relationships between age and DBH and between age and height of *A. moluccana* trees growing in several sites in Indonesia are shown in Figure 6. In Figure 7, the mean annual increments (MAI) in diameter (DBH) and height (total height MAI) of *A. moluccana* trees are presented with regard to age. The MAI in diameter was 3.1 cm/year for trees up to 5 years old and the MAI in total height was 1.9 m/year. As trees age, the rate of growth declines. However, more data are needed, particularly for older trees and preferably for trees growing in stands, in order to gain a good picture of overall growth trends.

6.2. Height–diameter relationship

Information on height and diameter is essential for estimating tree volume. However, as often only the diameter is measured in the field, it is necessary to quantify the relationship between tree height and diameter. Despite the importance of height–diameter models in plantation management planning, almost no previous information is available for *A. moluccana*.

Using measurement data of *A. moluccana* collected from 36 scattered trees grown by smallholders in their home gardens or in and around farms in South Kalimantan (as used in Table 2), the relationship between total tree height (H) and diameter at breast height (D) of *A. moluccana* was investigated (Figure 8). The following non-linear models were tested: Chapman–Richards, Curtis, exponential, Gompertz, Korf and Patterson. Of these, the Gompertz model fit the data best with the following functional form:

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

The results of fitting the selected (best) 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. The model produced relatively low RMSE (about 0.8 m) and explained a relatively high proportion of the total variation in observed values of the tree height, accounting for 96.7%.

6.3. Stem volume estimation

A preliminary volume table for *A. moluccana* was developed by Hutadjulu (1967) to estimate 3 kinds of stem volumes: total stem volume, thickwood volume with an upper diameter limit of 7 cm, and saw-log volume with an upper diameter limit of 30 cm. Data used to construct the table were obtained from 289 sample trees collected from various stands scattered throughout East Java. The range of the diameter of the sample trees was 6–62 cm and the range of total tree height was 10–40 m. In constructing the table, the Stemform method of Wolff von Wulfing (cited in Hutadjulu 1967) was applied. The data available in the table were reanalysed, and the stem volume models were obtained by relating the diameter (D) and height (H) to the stem volumes (V):

$$\log V = b_0 + b_1 \log D + b_2 \log H$$

The results of fitting the selected model, including least squares estimates of the parameters, the standard error, t-statistic, p-value, the RMSE and the adjusted

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

Parameter	Estimate	*SE*	*t*	$Pr \geq \lvert t \rvert$	*RMSE*	R^2_{adj}
b_0	34.31556	3.9018	8.79	< 0.0001	0.7771	0.9667
b_1	3.120591	0.0877	35.57	< 0.0001		
b_2	0.044358	0.00503	8.82	< 0.0001		

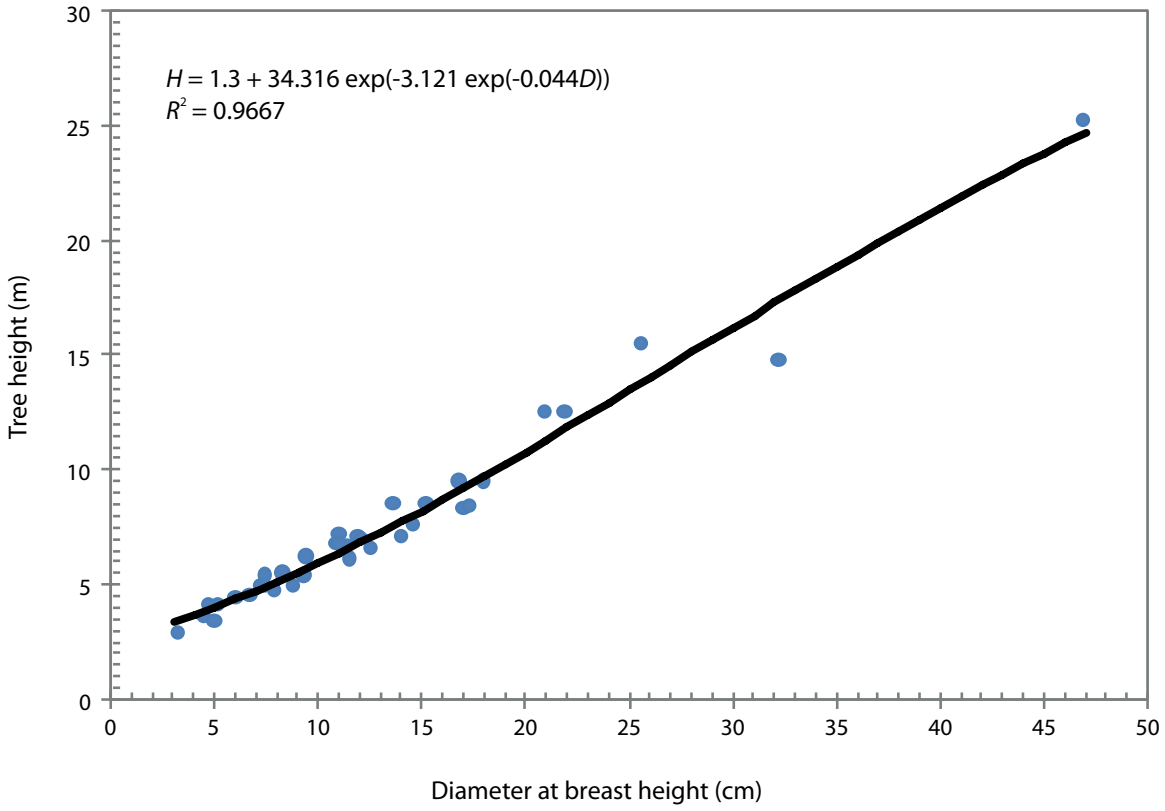

Figure 8. The relationship between height and diameter of *A. moluccana* trees (*points*: measured values; *solid line*: model)

coefficient of determination, are presented in Table 4. Shown in Figure 9 is the development of total wood volume of *A. moluccana* trees obtained using Hutadjulu's table and the total wood volume model. The model gives predictions of total wood volumes of more than 2 m^3 for trees with a diameter of more than 50 cm depending on total tree height. Similar curves can be applied for thickwood and saw-log volumes.

6.4. Productivity

Seed production is reported to increase until the age of 20 years and starts to decrease at the age of 70 years (Rosman and Djauhariya 2006). Given a spacing of 200 trees/ha and an expected yield of approximately 80 kg of seeds per tree per year, about 16 mt/ha/year can be produced. About 20% of this yield can be extracted as oil, which is equivalent to 3.2 mt/ha of unrefined oil per year (Elevitch and Manner 2006). Fruit yields range between 4 and 20 mt/ha/year and an oil yield of 3100 kg/ha has been reported (Duke 1983).

For wood production, in 30-year-old *A. moluccana* trees growing in Maros, South Sulawesi, Indonesia, the stand attained a mean diameter of 43.8 cm and a mean height of 28.6 m, producing a basal area of 30.2 m^2/ha and wood volume of 432 m^3/ha (Anonymous 1988 *in* Ginoga *et al.* 1989). The average wood productivity of the stand to 30 years old is shown in Table 5.

Table 4. Parameter estimates, standard errors and related fit statistics of the selected stem volume models for *A. moluccana* trees obtained by reanalysing Hutadjulu's volume table

Parameter	Estimate	*SE*	*t*	$Pr \geq \|t\|$	*RMSE*	R^2_{adj}
Total stem volume						
b_0	–4.41727	0.00315	–1401.2	< 0.0001	0.00874	0.9998
b_1	2.034754	0.00435	468.25	< 0.0001		
b_2	0.85938	0.00480	179.03	< 0.0001		
Thickwood volume with an upper diameter limit of 7 cm						
b_0	–4.65902	0.0269	–173.13	< 0.0001	0.0746	0.9893
b_1	2.230186	0.0371	60.12	< 0.0001		
b_2	0.799945	0.0410	19.52	< 0.0001		
Saw-log volume with an upper diameter limit of 30 cm						
b_0	–7.19717	0.1093	–65.86	< 0.0001	0.0731	0.9691
b_1	3.58172	0.0764	46.87	< 0.0001		
b_2	0.878252	0.0754	11.65	< 0.0001		

Table 5. The development of diameter, height, basal area and wood volume of *A. moluccana* trees to 30 years in Camba Subdistrict, Maros District, South Sulawesi

Age (years)	N. of trees per ha	Mean diameter (cm)	Mean height (m)	Basal area (m^2/ha)	Wood volume (m^3/ha)
5	200	14.3	4.4	3.2	6.9
10	200	27.6	11.0	12.0	64.7
15	200	36.6	17.2	21.0	177.0
20	200	40.4	22.4	25.6	281.0
25	200	42.8	26.2	28.8	369.7
30	200	43.8	28.6	30.2	423.2

Source: Anonymous (1988) *in* Ginoga *et al.* (1989)

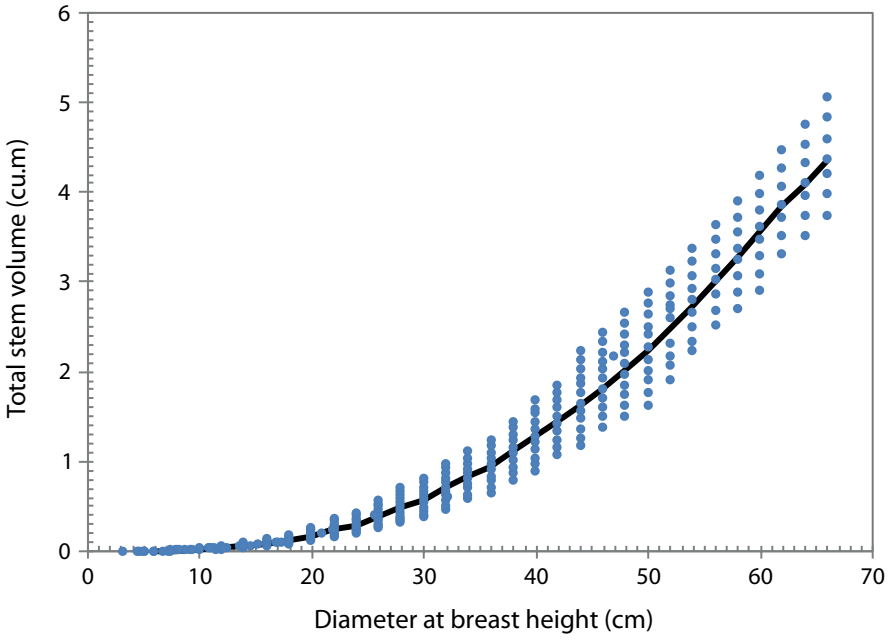

Figure 9. Total stem volume of *A. moluccana* taken from Hutadjulu's table (*points*) overlaid with the model ($\log V = -4.417 + 2.035 \log D + 0.859 \log H$) obtained by relating the diameter and height available from the table (*solid line*)

6.5. Rotation

There are no data available for the recommended rotation length, but the biological rotation of *A. moluccana* trees is estimated to be around 40–60 years (Elevitch and Manner 2006). Based on data in Table 5, a productive rotation period of 20 years may also be recommended.

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This manual gathers information on the ecology and silviculture of *Aleurites moluccana* (L.) Willd., with a focus on Indonesia. It also includes growth and yield data from published sources and collected from smallholders' farms in the research sites in South Kalimantan province. The manual is one of five manuals to guide smallholder tree planting of five selected tree species in Indonesia. The other four species are: *Acacia mangium* Willd.; *Anthocephalus cadamba* Miq.; *Paraserianthes falcataria* (L.) Nielsen; and *Swietenia macrophylla* King. Smallholders in Indonesia have planted trees on private or community land for a long time. Various actors have encouraged this activity to improve local livelihoods, environmental sustainability and industrial wood supply. These efforts have been generally successful, but they are often undertaken without technical assistance. 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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