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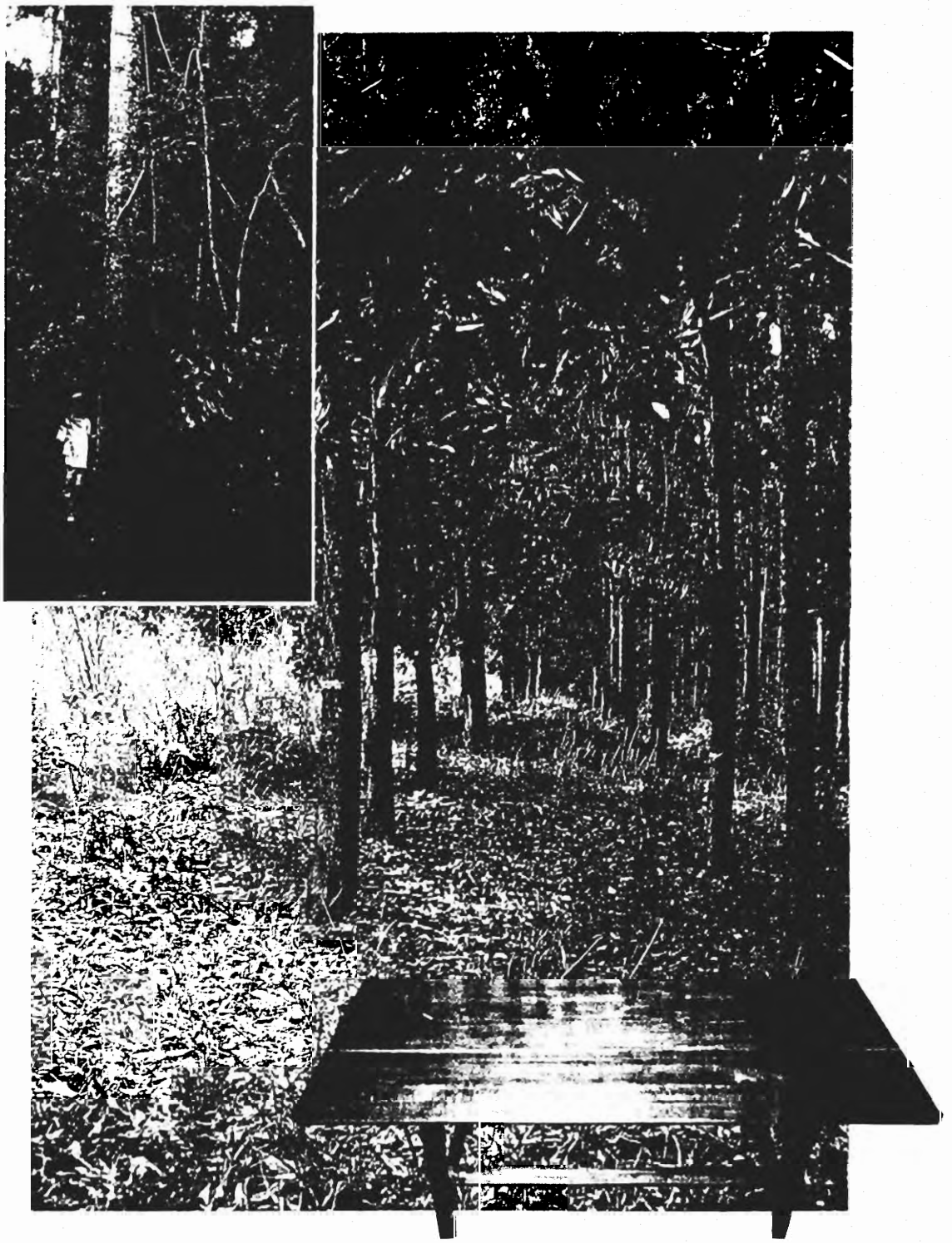
Acacia mangium

Growing and Utilization



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Acacia mangium

Growing and Utilization

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Cover: (upper left) Nineteen-year-old *Acacia mangium* tree in a natural stand at Cassowary Creek, Pascoe Catchment, Cape York; (middle) *A. mangium* plantation in Malaysia; (lower right) table made of *A. mangium* wood. Photos: Jock Morse, Lee Su See, and Mohd. Hamami Sahri.

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Contents

List of Tables and Figures	iv
Foreword	vii
Preface	viii
Introduction	ix
Taxonomy, Distribution, Biology, and Use as an Exotic	1
Reproductive Biology	21
Genetics and Tree Improvement	35
Vegetative Propagation	59
Nursery Practices	75
Symbiotic Associations	101
Silvicultural Practices	113
Growth and Yield	149
Insect Pests	163
Diseases	203
Properties and Utilization	225
Economics and Market Prospects	243
Summary	259
Appendix A: Seed Suppliers	269
Appendix B: Scientists Studying *Acacia mangium*	271
Index	278

List of Tables and Figures

Tables

Table 1.1. Common names of *Acacia mangium*. 2
Table 1.2. Climate data in *A. mangium*'s natural range. 4
Table 3.1. Chromosome characteristics. 36
Table 3.2. Characteristics of *A. mangium* seeds. 37
Table 3.3. Average abaxial stomatal frequency of phyllodes. 39
Table 3.4. Net and total photosynthesis. 41
Table 3.5. Foliar nutrient concentrations at 30 months. 42
Table 3.6. Provenance variations in flower and seed production. 43
Table 3.7. Provenances in international provenance trials. 44
Table 3.8. International provenance trial site descriptions. 45
Table 3.9. MAI in height and dbh of provenance regions. 46
Table 3.10. Percentage of trees with single stems at three trials. 48
Table 3.11. Mean total wood weight at 36 months. 49
Table 4.1. Effect of stock plant age on rooting of cuttings. 61
Table 4.2. Effect of phyllode number on rooting of cuttings. 61
Table 4.3. Effect of hormones on rooting of stem cuttings. 62
Table 4.4. Effect of rooting media on rooting of cuttings. 63
Table 4.5. Moisture content and pH of four rooting media. 64
Table 4.6. Effect of BAP concentration on shoot growth. 66
Table 4.7. Effect of culture cycle on shoot development. 67
Table 4.8. Effect of gibberellic acid on shoot development. 68
Table 4.9. Effect of nodal position on shoot development. 69
Table 4.10. Effect of growth substances on rooting of excised shoots. 70
Table 4.11. Effect of culture cycle on rooting of excised shoots. 70
Table 5.1. Mean number of seeds per kg. 79
Table 5.2. Seed size. 80
Table 5.3. Effect of heating dry seeds on germination. 81
Table 5.4. Germination of seven pretreated half-sib seedlots. 82
Table 5.5. Effect of container volume on seedling growth. 87
Table 5.6. Fertilization regime using peat and rice husk. 93
Table 6.1. Height of VAM-inoculated seedlings in grassland. 106
Table 6.2. Height of VAM-inoculated seedlings in the nursery. 106
Table 6.3. Height in the field after VAM inoculation with fertilizer. 107
Table 6.4. Growth in response to DSB-VAM treatments. 108
Table 7.1. Growth of spacing trial in Sabah at 2 years. 118
Table 7.2. Soil chemical properties in South Kalimantan. 121
Table 7.3. Mean height and diameter on various soils. 123
Table 7.4. Proposed diagnostic levels of foliage. 125
Table 7.5. Foliar nutrient levels, South Kalimantan. 126

Table 7.6. Foliar nutrient proportions, adjusted to N 100. 128
Table 7.7. Comparative mean foliar nutrient data. 128
Table 7.8. Growth comparison of fertilizer treatments. 130
Table 7.9. Thinning and pruning schedules for logs. 138
Table 7.10. Growth after thinning to different stocking in Sabah. 138
Table 7.11. Silvicultural and management schedule. 139
Table 7.12. Tending regimes. 140
Table 7.13. Priorities for silviculture research. 144
Table 8.1. Mean annual increments (MAI) at different ages. 153
Table 8.2. Volume estimates of a sample tree 20 cm dbh. 155
Table 8.3. Biomass estimates (oven dry basis) at different ages. 156
Table 8.4. Nutrient contents of stands and leaf litter. 158
Table 9.1. Insect damage and associated pest(s), by symptoms. 164
Table 11.1. Fiber morphology. 227
Table 11.2. Proximate chemical composition. 227
Table 11.3. Strength properties of popular furniture species. 229
Table 11.4. Mechanical properties. 230
Table 11.5. Knife tests of plywood. 232
Table 11.6. Glue line shear strength and wood failure. 233
Table 11.7. Shearing strength and delamination of LVL. 234
Table 11.8. Characteristics of solid wood and LVL. 235
Table 11.9. Bending strength of cement-bonded particle boards. 236
Table 11.10. Extractive and tannin contents of bark at different ages. 238
Table 11.11. Chemical characteristics and *in vitro* digestability of leaves. 238
Table 13.1. Priorities for future research. 267

Figures

Figure 1.1. Generalized range of natural distribution. 3
Figure 1.2. Natural distribution in North Queensland, Australia. 6
Figure 1.3. Map of Western Province, Papua New Guinea. 7
Figure 1.4. Map of Merauke region and southwestern PNG. 8
Figure 1.5. Map of Eastern Indonesia and Irian Jaya. 10
Figure 2.1. Monthly flowering intensity. 29
Figure 2.2. Diagram of peroxidases from phyllodes. 30
Figure 3.1. Mean annual increment (height) of provenances. 47
Figure 3.2. Mean annual increment in dbh of provenances. 47
Figure 7.1. Plantation productivity related to soil chemical parameters. 122
Figure 7.2. Stand and site details of sample plots of different ages. 124
Figure 7.3. Foliar nutrition related to plantation productivity and soils. 127
Figure 7.4. Response in diameter growth to fertilizer. 132
Figure 7.5. Stem taper lines for predicting diameter over stubs. 135

Preface

Acacia mangium is a major fast-growing tree species in forestry plantation programs in Asia and the Pacific. With deforestation in the region at an unsustainable rate of around 4.4 million ha per year, the future of forestry in the region depends on the extent to which commercial systems for supplying tree products address the need for sustainable production. Plantation forestry using fast-growing species has been adopted in many countries as one option for sustaining commercial supply of tree products and reducing pressure on natural forests. *A. mangium* is playing a growing role in this development due to its versatility and ability to recapture grasslands dominated by the noxious weed, *Imperata cylindrica*.

This monograph consolidates the knowledge on *A. mangium* from published literature, unpublished reports and studies, and observations by those familiar with the species. It clarifies where serious gaps remain in our knowledge of the species. For example, silviculture schedules and management of subsequent rotations are not yet well known. Priorities for further research are included in each topic chapter and summarized in the concluding chapter. The appendices list seed supply sources and researchers engaged in the study of *A. mangium*. This book is intended for forest managers, university students, and researchers who may benefit from its baseline of knowledge, and who may help to fill the gaps in that knowledge.

This book was made possible by the interests and expertise of the chapter authors, with funding support from two projects of the U.N. Food and Agriculture Organization—the Forestry Research Support Program for Asia-Pacific (FORSPA) and the Forest Tree Improvement Project (FORTIP) for Asia-Pacific—and from the Forestry/Fuelwood Research and Development (F/FRED) Project. F/FRED is a cooperative agreement between the U.S. Agency for International Development and the Winrock International Institute for Agricultural Development, a U.S.-based not-for-profit organization.

Foreword

The idea for this volume emerged during a meeting of the Consultative Group for Research and Development of Acacias (COGREDA) in 1992, sponsored at that time by the Forestry/Fuelwood Research and Development (F/FRED) Project. Scientific work with this species over the last 20 years, particularly in Southeast Asia, has generated a large body of unpublished information. This, coupled with a strong base of published information from CSIRO, ACIAR, and national research programs in Southeast Asia made the project very appealing to COGREDA and its current sponsors—F/FRED, the Forestry Research Support Programme for Asia-Pacific (FORSPA), and the Forest Tree Improvement Project (FORTIP).

The emergence of *Acacia mangium* from a relatively nondescript introduction from north Queensland to a premier plantation tree in Asia is a fascinating case study. The partnership of industry, universities, national research institutions, and bilateral donor agencies reflected in the list of authors has proven invaluable in assembling this volume.

This book is the first in a series planned by COGREDA, which has applied to the International Union of Forestry Research Organizations (IUFRO) to become a working group under that organization. It is hoped that this move will further strengthen COGREDA's ability to support research on the increasingly important genus of *Acacia*.

Rick J. Van Den Beldt
Winrock International
F/FRED Project

"This monograph is dedicated to the memory of Dr. Y.S. Rao who long served forestry in the region as FAO's Regional Forestry Officer and later as Senior Programme Advisor of FORSPA".

Introduction

The Status of *Acacia mangium* Growing and Utilization in Asia and the Pacific

Since its introduction to Sabah, Malaysia as an exotic in 1966, *Acacia mangium* has become one of the three or four most common plantation tree species in Asia, primarily in Indonesia, Malaysia, the Philippines, and Thailand. It is also widely planted in other tropical regions. Currently over 150,000 ha of *A. mangium* have been planted worldwide, and the area coverage is rapidly expanding. The Indonesian government alone aims to establish 4.4 million ha of forest plantation by the year 2000, using *A. mangium* as a principal species. In Sumatra, private plantation operations target 25,000 ha annually, and are currently planting about 18,000 ha each year.

While *A. mangium* is the most widely planted Australian acacia, others used in planting programs include *A. auriculiformis*, *A. holosericea*, *A. mearnsii*, and to a lesser extent *A. crassicarpa*, and *A. leptocarpa*.

Several factors explain these rapid increases in the use of fast-growing tree species in plantation forestry in the tropics. Natural tropical forests are quickly being depleted, and where natural forest resources remain, international political and economic pressure for their preservation has been growing steadily. In order to expand or even maintain production of tree products, tree-growing enterprizes need species that grow well not only on cleared forest sites but on "degraded" sites otherwise unsuitable for agriculture, such as weedy *Imperata* grasslands and former mining sites. *A. mangium* has proven its growth on these and other adverse sites.

While international wood-product markets are adapting to the dwindling supply of tropical hardwoods from natural forests, advances in utilization technologies have made feasible conversion of small-diameter logs for use as chips and composite materials, as well as for sawn timber and veneer. State-of-the art mills in Southeast Asia are now handling logs of five centimeters in diameter.

A. mangium is grown for pulp and paper production in Sumatra, Sabah, and Vietnam. In Taiwan (Republic of China), *A. mangium* sawdust provides a good-quality substrate in the lucrative production of shiitake

mushrooms. Other non-wood uses for which it shows potential include honey production and adhesives.

The species is also useful as an ornamental. In Malaysia, it is a widely-planted roadside tree, and in Thailand it has been recommended for wider use in urban forestry.

Unlike many plantation species, *A. mangium* and other acacias show potential for use in rural development as well as in industry. Some of the features that formerly made these trees unlikely plantation species now make them attractive for farm communities. Their variety of forms in natural stands permit selection for branchy fuelwood and foliage for animal fodder as well as for straight-boled trees for poles and timber. Their ability to grow on marginal soils and improve their fertility is also attractive to farmers.

In agroforestry, there are few reports of *A. mangium* being used in integrated planting systems like the homegarden. Experiments have shown that the species has potential in some intercropping combinations (for example, with maize and peanuts), but other acacias that are native locally (since many occur throughout Asia) may be as well suited to these niches and better known to farmers in the area.

A. mangium can play a larger role in many places where an industrial market for wood products exists alongside a local market for fuel and other tree products. One example of a planting program with both industrial and local development objectives is that managed by the Paper Industries Corporation of the Philippines (PICOP). In this program, advance funds to farmer cooperatives cover costs of growing *A. mangium* until the first harvest, at which time part of the yield goes to pay back the initial expenses and part is re-invested in the cooperative for further tree farm expansion.

Another example can be found in Sabah, Malaysia, where local farmers once strongly opposed forest plantations as threats to their practice of shifting cultivation. Sabah Forest Industries (SFI) worked out an arrangement with thefarmers whereby the farmers plant legume trees—primarily *A. mangium*—when they sow their upland rice. When the food crop is harvested the trees are left to claim the site. The trees remain the farmers' property and are sold to SFI at eight years for pulpwood harvest. The site can then be replanted with food crops and *A. mangium*.

This example also highlights the growing need for forest managers to recognize the socioeconomic conditions of communities near where the trees are grown, as well as conditions of national and export markets. In countries of the Asia-Pacific region, communities like those in Sabah are insisting on a greater role in forest management. Addressing local communities' demands in program planning is therefore an investment in forest resource security for many commercial growers as well as govern-

ments. Factors to consider in this regard can include: (1) Does the program contribute to local income generation? (2) Does it contribute to equitable access to local resources? (3) Does it promote sustainable management of the local environment?* Through programs like those of PICOP and SFI, forest managers can ensure long-term production in a more stable local environment.

The speed and wide range of the introduction of *A. mangium* and the growing dependence on this resource make it essential to recognize the associated risks of pest and disease epidemic and to manage for them, as described in Chapters 9 and 10. Foresters know that when introducing species, it is important to test a range of species and provenances that originate from environments similar to that of the site of introduction. To recoup the long-term investment in an introduced species, it is important to continue monitoring the stands, not only for growth and survival, but for trends in plant health and evidence of insect or disease damage. Varied planting patterns— either through mixed plantings of several tree species or provenances, or through intercropping with agricultural crops—also reduces the risk of epidemic or other crop failure.

Centers of Research and Information Exchange

The Australian Council for International Agricultural Research (ACIAR) and the Commonwealth Scientific and Industrial Research Organization (CSIRO) have for years led international efforts on acacias in developing countries. Since the mid 1980s they have been joined, in the Asia-Pacific region, by the Multipurpose Tree Species (MPTS) Research Network based in Bangkok, Thailand, and administered by Winrock International, with support from the U.S. Agency for International Development. More recently, regional programs of the U.N. Food and Agriculture Organization have also begun to support intensive institutional development and strategies for tree improvement that include research on acacias.

National research on acacias span a broad range of agencies and topics. In Southeast Asia, national clearinghouses of research results on *Acacia mangium* include:

Indonesia	Forest Research and Development Centre in Bogor
Malaysia	Faculty of Forestry, Universiti Pertanian Malaysia in Serdang, and the Forest Research Institute Malaysia in Kepong, Kuala Lumpur

*H.A. Francisco (in press). Acacias in rural development, in *Acacias for Rural, Industrial, and Environmental Development*. Bangkok: Winrock International and FAO.

Papua New Guinea	PNG Forestry Research Institute in Lae
Philippines	College of Forestry, University of the Philippines at Los Baños
Taiwan, ROC	Taiwan Forestry Research Institute in Taipei
Thailand	Faculty of Forestry, Kasetsart University; the Royal Forest Department of Thailand; and the Thailand Institute for Scientific and Technological Research, all in Bangkok

Appendix B lists individuals involved in research on *A. mangium* in the Asia-Pacific region. *National Research on Multpurpose Tree Species: 1975-1990* is a preliminary compendium of ongoing and completed national research on eight fast-growing tree genera in Bangladesh, Indonesia, Malaysia, the Philippines, and Thailand; it is available from the MPTS Research Network Secretariat in Bangkok.

Research by the private sector represents an important body of knowledge too often overlooked by scientists in universities and government agencies. The contributions of Sabah Forest Industries to Chapter 1 and of Sabah Softwoods Senderian Berhad to Chapter 11 indicate the areas in which private-sector experience is essential for further advances, and represent a foundation for further cooperation.

The Consultative Group on Research and Development of Acacias (COGREDA) was formed in 1992 to provide a means for scientists working on a wide range of acacia research to exchange information, assess research to date and future directions, and plan ways of filling knowledge gaps. Mostly Asian scientists, COGREDA emerged from a recommendation by the MPTS Research Network. The Consultative Group's first meeting, in Phuket, Thailand, in June 1992, prioritized research needs for: species assessment and improvement; silviculture for industrial, agroforestry, and site reclamation; utilization; and economic assessment. It also finalized plans for the preparation of this monograph. The MPTS Research Network is supporting several research proposals identified at the first meeting for hybrid testing.

The second meeting, held in Udon Thani, Thailand in February 1993, examined the contribution of acacias to the three broad areas of rural, industrial, and environmental development. Specifically, it reviewed the extent to which acacias are being used in Asia-Pacific countries for these purposes, identified sets of research needs for each purpose, and planned for further synthesis of results on several of the best-known species.

Chapter 1

Taxonomy, Distribution, Biology, and Use as an Exotic

Khongsak Pinyopusarerk, Sim Boon Liang and Brian V. Gunn

Introduction

Acacia mangium Willd. is a tropical species capable of colonizing difficult sites. Its important attributes include rapid early growth, good wood quality (for pulp, sawn timber, and fuelwood), and tolerance of a range of soil types and pH (National Research Council 1983). The species is especially suitable for controlling soil erosion and planting in areas heavily infested by weedy *Imperata* grass, which is widespread in the tropical Asian region.

A. mangium was unknown as an exotic until 1966, when it was introduced into Sabah, Malaysia by D.I. Nicholson, an Australian forester. This initial introduction consisted of some 200 seeds from a single mother tree at Mission Beach, Queensland. The initial seedlings were planted to form a firebreak around trial plots of pines at Ulu Kukut and in trial plots at Gum Gum and Sibuga in Sabah. The trees grew so well that they actually out-performed *Eucalyptus deglupta* and *Gmelina arborea*, which at the time were the main plantation species in Sabah. Seeds from the Ulu Kukut planting were subsequently harvested and the first pilot plantation was established by a private company, Sabah Softwood Sdn. Bhd., in 1976. Since then, plantations of this species have been extensively established in other areas of Malaysia and in other tropical countries, transforming what was once a species of limited use in Queensland into a popular plantation tree species for the humid and subhumid tropics.

This chapter provides a general description of the taxonomy, natural distribution, morphology, and physiological characteristics of *A. mangium*. It also discusses performance as an exotic and current planting programs of the species.

Nomenclature and Taxonomy

Acacia mangium Willd. is a leguminous tree species in the family Leguminosae, sub-family Mimosoideae. The genus *Acacia* includes more than 1,000 species of trees and shrubs which occur in Africa, the Americas, Asia, and Australia, with the majority of species found in Australia (Anon. 1982). *A. mangium* is native to Australia, Papua New Guinea, and Indonesia. It has many local names (Table 1.1).

Table 1.1. Common names of *Acacia mangium*.

Australia	Indonesia	Papua New Guinea	Malaysia	Thailand
brown salwood black wattle hickory wattle	mangge hutan tongke hutan (Ceram) nak (Maluku) laj (Aru) jerri (Irian Jaya)	arr	mangium kayu SAFODA	kra thin tepa

Sources: Hall et al. (1980); Turnbull (1986)

A. mangium was originally described as *Mangium montanum* Rumph. in Rumphius' *Herbarium Amboinense* 3:123, t.81 (1750). The generic name was then changed to *Acacia* by C.L. Willdenow (1765-1812) in *Sp. Plant* 4: 1053 (1806); his description was based on the type description and figure.

A. mangium is not closely related to other *Acacia* species, although it hybridizes readily with *A. auriculiformis* to produce a cross with characteristics intermediate between those of the two parents. Due to the superficial resemblance of *A. mangium* to *A. holosericea*, the two species have long been confused and their names misapplied (Pedley 1987). Prior to Pedley's classification, many taxonomists had considered *A. holosericea* and *A. mangium* to be conspecific; differences between the two species were not considered sufficient to warrant separation. C.T. White, cited in Pedley (1987), who knew both species in the field, reduced *A. holosericea* to a variety of *A. mangium*. He seems to have referred all taxa with glabrous, subglabrous or glabrescent phyllodes to *A. mangium* var. *mangium*. White also continued the misapplication by another taxonomist, Domin, of the name *A. holosericea* var. *neurocarpa* and referred *A. holosericea* var. *glabrata* to *A. mangium* var. *mangium*.

Pedley (1986) proposed a reclassification of the genus *Acacia* based on: the morphology of seedlings, leaves, flowers and inflorescences, anatomy of the pod, the occurrence of extrafloral nectaries, free amino acids of the seeds, flavonoid compounds in heartwood, cyanogenic compounds, porate and extraporate pollens, and susceptibility to rusts. These characteristics indicate that three genera—*Acacia* Miller, *Senegalia* Raf. and *Racosperma* Matius —should be recognized. In this reclassification, section Juliflorae of subgenus *Heterophyllum*

(characterized by inflorescences in spikes) in which *A. mangium* belongs, has been transferred to genus *Racosperma*. The new genus names, however, have not received general support of other taxonomists and have not been adopted (Pedley 1990). At present, the species is still commonly referred to as *A. mangium*.

Natural Distribution and Ecology

A. mangium has a fragmented natural distribution, which stretches from Indonesia (where it occurs on the islands of Sula, Ceram and Aru) to Irian Jaya, the Western Province of Papua New Guinea (PNG), and northeast Queensland in Australia (Figure 1.1). The latitudinal range is 1°-18°57'S and longitudinal range is 125°22'-146° 17'E. The main altitudinal range is from just above sea level to about 100 m, with an upper limit of 780 m. Distribution is strongly influenced by rainfall patterns and soil drainage. It is typically a low-elevation species associated chiefly with rainforest margins and disturbed sites on well-drained acid soils (pH 4.5-6.5) of low fertility. It also occurs behind mangroves, in seasonal swamps, along streams, and on well-drained flats, low ridges, and mountain foothills.

A. mangium is a species of the humid, tropical lowland climatic zone characterized by a short "winter" dry season and high total annual rainfall. Table 1.2

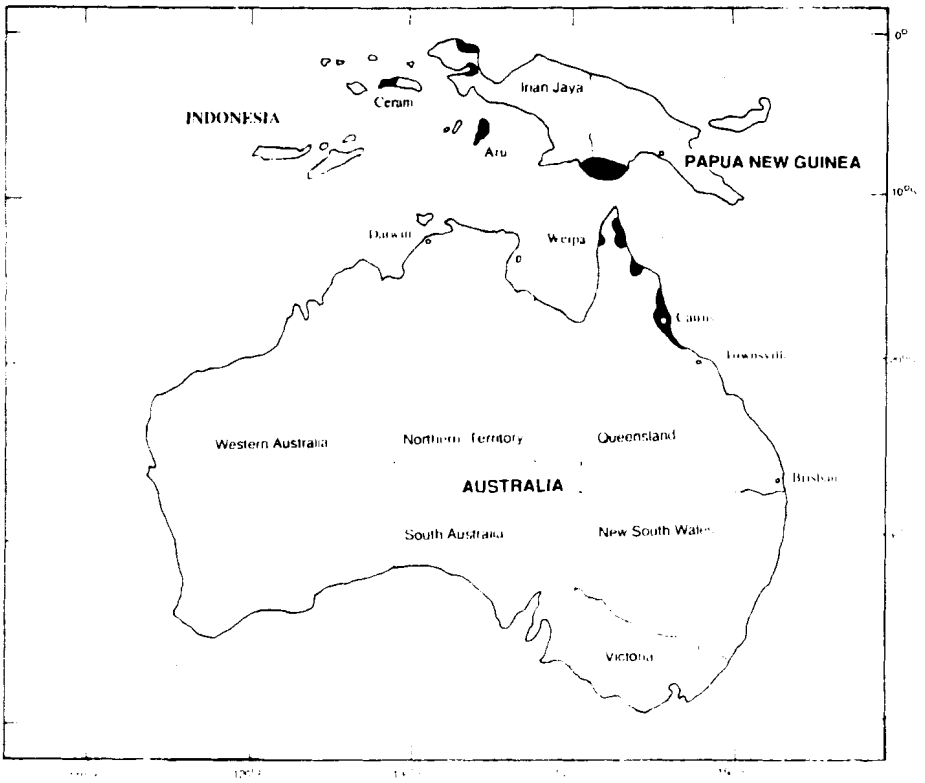

Figure 1.1. Generalized range of natural distribution of *Acacia mangium*.

Table 1.2. Climatic data for meteorogical stations associated with the natural distribution of *A. mangium*.

Location	Station location details				Temperature (°C)				Mean monthly rainfall (mm)												Mean annual rainfall (mm)
					January		July														
	Lat. (°S)	Long. (°E)	Alt. (m)	Years of record	Mean min.	Mean max.	Mean min.	Mean max.	J	F	M	A	M	J	J	A	S	O	N	D	
Australia																					
Cairns	16 53	145 45	3	44	24	32	17	25	421	422	460	264	110	72	39	42	43	50	98	203	2224
Cardwell	18 16	146 02	6	102	23	32	13	25	457	466	417	211	92	50	33	29	36	52	107	193	2143
Lockhart	12 47	143 18	23	30	23.5	31.3	19.0	26.8	383	384	456	338	127	57	43	28	17	19	61	212	2125
Indonesia																					
Bupul									285	267	268	259	166	111	121	82	90	138	231	294	2312
Ceram	3 15	128 21	5	5	22.8	31.7	21.8	28.7	110	145	115	134	195	334	294	299	244	136	81	75	2162
Manokwari	0 53	134 03	3		21.6	31.8	21.2	31.4	299	263	308	294	200	189	144	142	128	117	165	265	2514
Merauke	8 31	140 25	4	5	23.3	31.0	20.3	28.7	252	237	249	186	111	42	33	20	21	38	75	182	1446
Papua New Guinea																					
Balimo	8 03	142 55	10	11					258	323	236	269	243	160	108	70	129	130	132	277	2476
Boset Msn	7 14	141 07	90	2					297	272	306	234	105	134	54	87	211	211	154	327	2389
Lake Murray	7 00	141 30	50	3					303	386	566	219	317	161	133	177	122	244	204	290	2970
Morehead	8 43	141 38	31	6					332	262	318	157	154	86	54	52	38	80	114	224	1913

summarizes records of a selection of representative meteorological stations in Australia, PNG, and Indonesia. Annual rainfall ranges from 1,446 mm at Merauke, PNG, where there is a distinct dry season between June and October, to 2,970 mm at Lake Murray, PNG, which experiences no distinct dry season. Temperatures are high and equable throughout the year, with mean monthly minimum 13-21°C and mean monthly maximum 25-32°C. Temperatures seldom exceed 38°C, with virtually no frosts (Turnbull 1986).

Distribution in Queensland

The distribution of *A. mangium* in Queensland is restricted to two regions covering a latitudinal range from 11° 20'S (upper reaches of the Jardine River) to 18° 57'S (Crystal Creek) (Figure 1.2). In Cape York Peninsula, *A. mangium* is mainly associated with east-flowing drainage systems. These include the Claudie (Iron Range), Pascoe, Harmer, and Olive River catchments (Plate 1.1). Here the species occurs in the moist lower reaches, forming part of the rainforest-savanna ecotonal vegetation, and is often a common component of the tree layer (Gunn et al. 1990). Several isolated patches of *A. mangium* are located across the northern part of Cape York Peninsula, often associated with seasonally dry watercourses. These sites include areas near the mouth of the Wenlock River north of Weipa, Dulcie Creek, and several patches of trees associated with rainforest in the watershed of the Jardine River east of Heathlands.

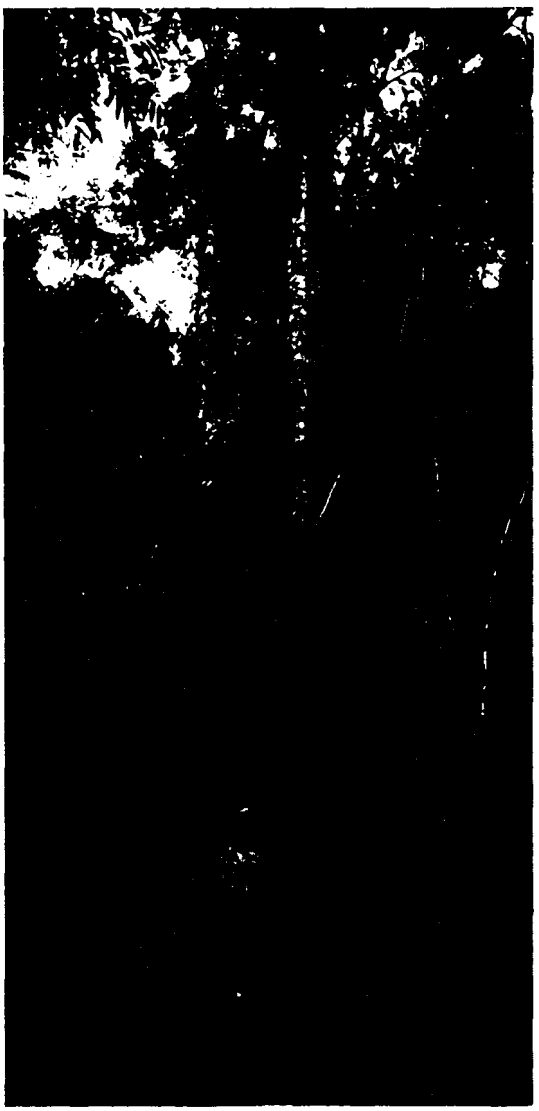

Plate 1.1. Natural stand of *A. mangium* at Cassowary Creek, Pascoe Catchment, Cape York. *Photo:* Jock Morse.

The Laura Basin region, which encompasses the rivers draining east into Princess Charlotte Bay, is vegetated by open *Melaleuca* and *Eucalyptus* savanna woodland, and forms a distinct ecological barrier between the northern and southern distribution of *A. mangium*.

The southern distribution stretches

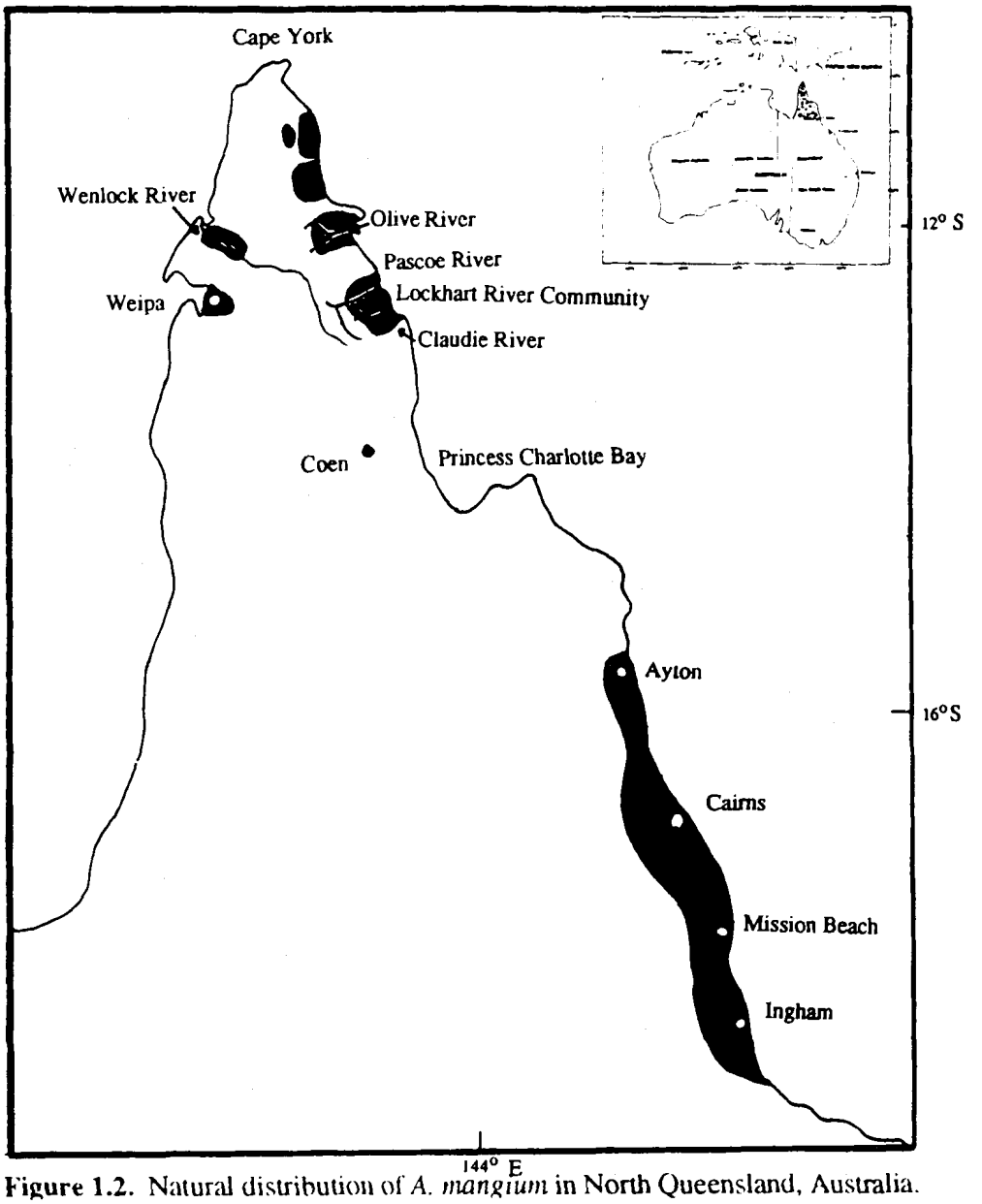

Figure 1.2. Natural distribution of *A. mangium* in North Queensland, Australia.

from Ayton (15° 54'S, 145° 21'E) in the north, more or less continuously to Crystal Creek just south of Ingham. Here it is principally associated with lowland flats in moist situations and extends up the ranges; the highest elevation occurs at Gadgarra on the Atherton Tableland (720 m)(Doran and Skelton 1982). Most of the lowland region has been cleared or heavily modified for sugar cane growing, which has removed most natural vegetation except in restricted areas, such as headlands, ridges, and water courses.

Population types

In Queensland, *A. mangium* grows mainly in closed forest (including rainforest), open forest grading into woodland, and on the margins of mangrove communities. Trees typically occur in small groups but never become dominant over large

areas.

In the rainforest (for example in the catchment of the Claudie River), tall, straight *A. mangium* trees with clear boles form a component of the upper canopy. Its more typical habitat is along rainforest-savanna boundaries, which are regularly affected by dry-season fire. Associated species include *Dillenia alata, Planchonia careya, Barringtonia acutangula, Parinari nonda, Lophostemon sauveolens, Buchanania arborescens, Aleurites moluccana, Acacia aulacocarpa, Jagera* spp., *Melaleuca dealbata, Eucalyptus tetradonta,* and *E. clarksoniana* (Gunn et al. 1990).

In a number of small, disjunct populations (including those at Weipa, Dulcie Creek, and Lannercost), the trees grow in almost pure stands either along seasonally dry river banks or in slight land depressions in open woodland. The stands are of uniform size and (with the exception of Lannercost, which experiences high annual rainfall) show signs of dry-season moisture stress through excessive leaf fall and chlorosis of the leaves. It is possible that these populations have only recently become established with seed transported by birds or floodwaters.

Distribution in Papua New Guinea

A. mangium is widespread in the lowland regions of the Western Province of PNG (Figures 1.3 and 1.4). It extends from the Lake Murray district south to the coast, and from the Irian Jaya border to east of the Fly River in the district of Balimo. The range of latitude is from 7° 37'-8° 59'S and longitude 141°09'-143° 08'E. The altitudinal range is from just above sea level to about 50 m, reaching 100 m in the northern part of its distribution near Boset. The limited rainfall data

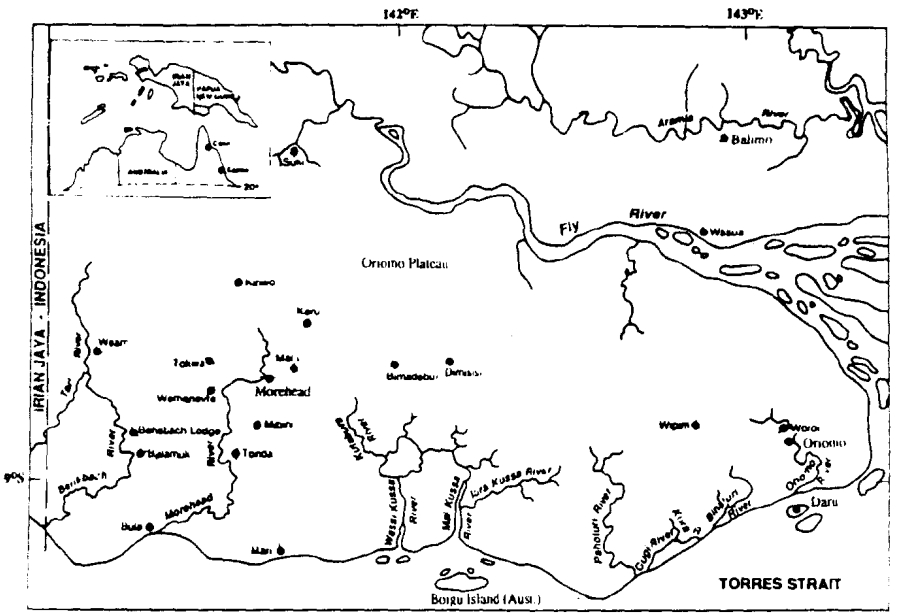

Figure 1.3. Location map of Western Province, Papua New Guinea.

available for the area indicate an annual range of 1,900 mm at Morehead, increasing to the north and east up to approximately 3,000 mm at Lake Murray and 2,500 mm at Balimo. Other *A. mangium* sites in PNG are thought to be chance introductions (Skelton 1987).

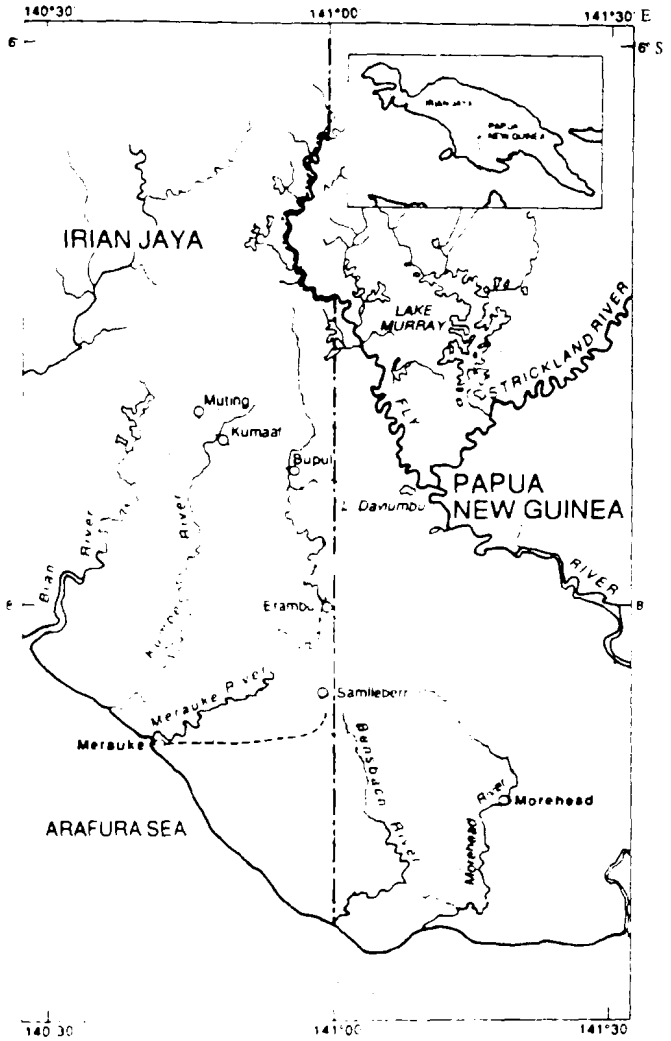

Figure 1.4. Location map of Merauke region of Irian Jaya and South-western Province of Papua New Guinea.

Population Types

In the Western Province of PNG, *A. mangium* is found on two low-lying land forms: the Oriomo Plateau to the south of the Fly River and the Fly-Digoel Shelf to the north. The topography of the Oriomo Plateau, a slightly undulating plain with a number of shallow slopes, contrasts with the Fly-Digoel Shelf, which consists of closely spaced narrow ridges and valleys. Due to the Plateau's flatness and low elevation, impeded drainage is common and much of the area is flooded during the wet season.

A mosaic of grassland, savanna woodland, swamp forest, and monsoon vine forest covers the area. Local drainage conditions are the main factors determining vegetation patterns. However, the relationship is complicated by annual burning, which has strongly modified the natural vegetation. *A. mangium* is generally confined to soils with adequate drainage.

The species reaches its best form and exceeds 25 m in height on the margins of monsoon vine forest and where the forest canopy has been disturbed. These areas include Bimadebum, Dimisisi, Wipim, and Oriomo. In places where vine

forest merges into riparian or swamp situations, *A. mangium* is less frequent and of smaller stature. In vine forest situations, associated taxa include species in the genera *Flindersia*, *Grevillea*, *Syzygium*, *Planchonella*, and *Terminalia*. Common in wetter areas are *A. auriculiformis*, *Melaleuca cajuputi* ssp. '*platyphylla*' ms, *M. leucadendra*, *Barringtonia tetraptera*, and *Dillenia alata*.

In savanna woodland, where *A. mangium* is a common component, acacias form 5-20% of the woody species. Associates include *Lophostemon suaveolens*, and species in the genera *Melaleuca*, *Alstonia*, *Dillenia*, *Xanthostemon*, *Grevillea*, *Parinari*, *Planchonia*, *Syzygium*, *Acacia*, and *Eucalyptus*. These associations are common across the Oriomo Plateau from Weam and Bensbach in the west to Oriomo in the east.

Disturbed sites in riparian or monsoon vine forest, resulting from local shifting cultivation or other factors, are rapidly colonized by *Acacia* species, including *A. mangium*, *A. crassicarpa*, *A. auriculiformis*, *A. aulacocarpa*, and *A. simsii*. These develop into woodland or open forests that prevent the spread of the grass *Imperata cylindrica* (alang alang).

On the Fly-Digoel Shelf, *A. mangium* is known to occur from the PNG-Irian Jaya border in the Boset-Obo region west of the Fly River, Lake Murray, and Balimo district east of the Fly River (Gunn et al. 1990; House et al. 1991). In these areas the main acacias are *A. mangium* and *A. aulacocarpa*, with *A. crassicarpa* appearing to be rare in the Balimo district. Curiously, *A. auriculiformis* is absent from both the Balimo region and the areas of Boset and Lake Murray to the north. In its northern distribution, *A. mangium* becomes less common and of smaller stature. Here it is confined mainly to monsoon vine forest margins, edges of lakes, and disturbed sites.

Distribution in Indonesia

Irian Jaya

Merauke District: The main distribution of *A. mangium* in Indonesia is concentrated in the district of Merauke in southeast Irian Jaya (Figure 1.5) and is an extension of the distribution in the Western Province of PNG. The distribution is not well known but appears to be restricted to the lowlands, comprising savanna and lowland monsoon vine forest. For 120 km inland from Merauke to Erambu, the terrain is flat and poorly drained. Tall open melaleuca swamp forests are common, with *A. mangium* abundant along the disturbed verges of the newly built highway. North of Erambu to Muting (the most northerly point visited), acacias become less common (Gunn and McDonald 1991). This area is on the same latitude as Boset/Obo, where *A. mangium* reaches its most northerly natural distribution in Western Province.

Vogelkop Peninsula: The Vogelkop Peninsula is located in northwest Irian Jaya (1°-5° S, 131°-134° E). This area and other localities reported in Maluku Province are difficult to visit; a number of *A. mangium* locations are known only

from herbarium specimen collections, most of which were made during the Dutch colonial period.

There are two known populations on the peninsula, one west of Manokwari and another to the south in Fak Fak District in Bintuni Bay. The species grows on lowland flats in enclaves in primary rainforest and as pure stands in *Imperata cylindrica* grassland. Soils are infertile, pale grey to yellowish compact clays. Trees are of generally poor form, 10-15 m high, and 8-20 cm in diameter (Turnbull et al. 1983).

Maluku Province

This province consists of about 1,000 islands. *A. mangium* is known to occur in three main areas: the Sula Islands (1° 52'S, 125° 22'E), Ceram (ca. 3° S, 129°E) and the Aru Islands (ca. 6° S, 134° 30'E).

Sula Islands: The islands of Taliabu, Mangole, and Sanana (also called Sulabesi) make up the Sula Islands. *A. mangium* is reported to occur on Taliabu, the most westerly natural occurrence along with Sanana Island (Turnbull et al. 1983). It occurs near sea level (below 50 m) on the margins between rainforest and shifting cultivation.

Ceram Island: The occurrence of *A. mangium* in western Ceram is indicated by an herbarium specimen collected by Kuswata and Soepadmo in 1959 (Suratmo et al. 1980). An exploration made in 1979 in the vicinity of Piru in southwest Ceram reports that *A. mangium* occurs as scattered trees associated

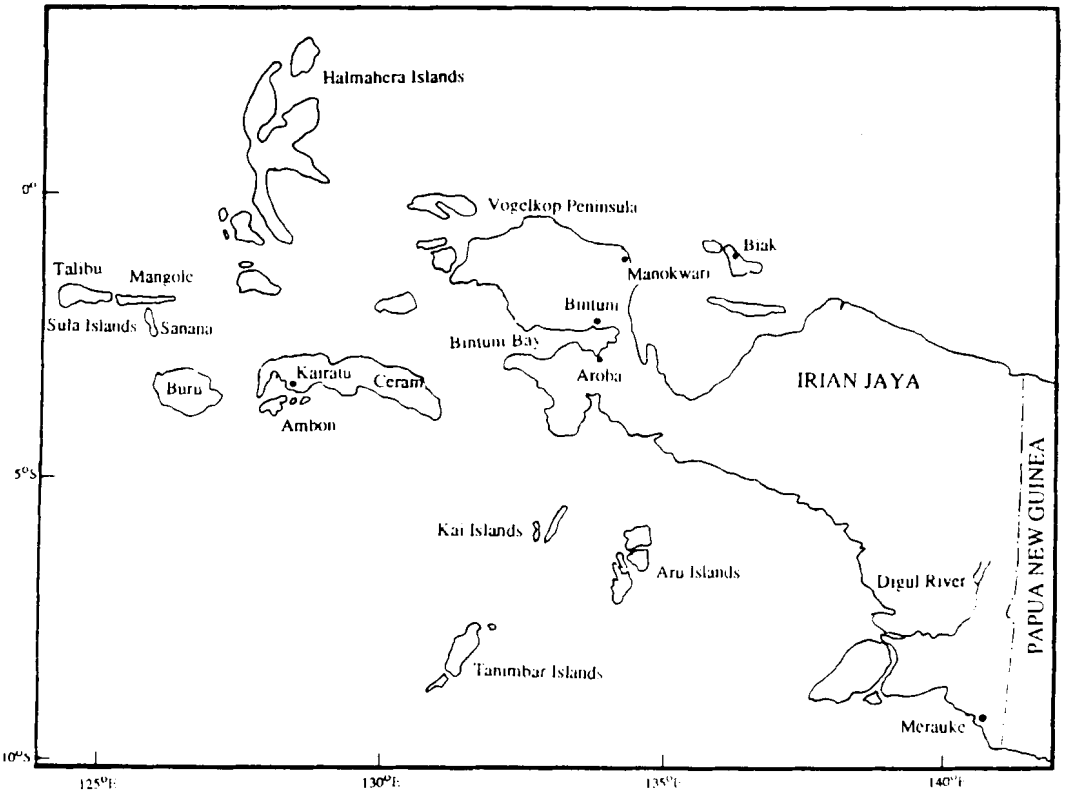

Figure 1.5. Location map of Eastern Indonesia and Irian Jaya.

with *Melaleuca* spp. adjacent to shifting cultivation. Trees were observed from near sea level to about 300 m. The annual rainfall was reported as 2,000 mm with a distinct dry season (Suratmo et al. 1980).

Aru Islands: The group comprises three large islands—Wokam, Kobroor and Trangan—and several smaller islands. The occurrence of *A. mangium* on Trangan Island is indicated by an herbarium specimen collected by Buwalda in 1938. At that time, scattered trees were growing on flat terrain in a sandy clay soil on the margins of primary forest. Other sites are reported on Wamar Island in the northwest of the Aru Islands and in the east of Trangan Island (Turnbull et al. 1983).

Morphology

Foliage

Mature phyllodes are large, up to 25 cm long and 10 cm broad. They are dark green, glabrous, or slightly scurfy with a glabrous pulvinus 6-10 mm long. Four conspicuous longitudinal main nerves run together near the base of the phyllode along the dorsal margin, with many fine, anatomizing inconspicuous secondary nerves. A gland (extrafloral nectary) is conspicuous at the base of the phyllode.

Inflorescence

Inflorescences occur as rather loose spikes up to 10 cm long, singly or in pairs in the upper axils. The inflorescence is composed of many tiny white or cream colored flowers. Peduncles are canescent and pubescent, about 1 cm long; the rachis is also canescent and pubescent. Flowers are quinquefloral; the calyx 0.6-0.8 mm long, with short obtuse lobes; the corolla is about twice as long as the calyx. In Australia, flowering occurs around May, and seed matures between late October and December. Seed matures earlier in northern locations: July in Indonesia, and October to November in PNG.

Pods (Legumes)

The seed pods are broad, linear, and irregularly coiled when ripe. They are slightly woody, 3-5 mm wide, and 7-8 cm long. Seed maturity is indicated by the development of a dark brown to black seed coat, orange to red funicle and brown coloration of the pods, about 6-7 months after flowering. Ripening pods change from flexible green to stiff and dry brown.

Seeds

The seeds are black and shiny with shape ranging from longitudinal, elliptical, ovate, to oblong, 3-5 mm x 2-3 mm. The seeds are arranged longitudinally and are attached to the pod by an orange to red folded funicle connected to a broader, oily, fleshy aril.

Seedling Morphology

Like many Australian phyllodinous acacias, the typical foliage sequence from seedling to adult is 'pinnate - bipinnate - phyllode' (New 1984). Typically, newly germinated seedlings are characterized by having the first leaf pinnate and the second bipinnate, arranged alternately. The third and fourth leaves are bipinnate, each pinna bearing 12-18 pinnules (leaflets) arising from the main rachis. The bipinnate leaves (formed at about Week 4 or 5) each have a small, flattened petiole. From six weeks after germination, the flat petiole of newly-emerged bipinnate leaves expands to form a phyllode, although bipinnate leaves remain intact at the tip. After this stage, seedlings develop to full phyllode stage (that is, phyllodes without intact bipinnate leaves), indicating adult foliage form from about nine weeks after germination.

Adult Tree

A. mangium trees generally grow to a height of 25-35 m with a straight bole which may be over half of the total height. The diameter at breast height (dbh) can be over 60 cm. However, on relatively poor sites the trees are usually much smaller, with average heights between 7 and 10 m (Turnbull 1986). Young trees of *A. mangium* have greenish, smooth bark on the upper part of the stem and brownish bark on the lower part of the stem in which fissures begin to develop at 2-3 years of age. Glaucousness on young stems or branches is a typical, but not universal, characteristic of the species. Stems of adult trees are characterized by longitudinal furrows and thick, rough, hard bark that is dark brown to fawn in color. Fluting of the lower bole is often present in old trees. Natural pruning is usually poor.

Phyllode Anatomy and Stomatal Characteristics

Atipanumpai (1989) reported phyllode anatomy and stomatal characteristics of 30-month old *A. mangium* trees from different provenances. The epidermis of the phyllode is heavily cutinized on both surfaces, and cells are square or rectangular in transection. The mesophyll consists of two-layer palisade tissues, densely arranged and filled with abundant chloroplasts. The spongy parenchyma is

slightly round and loosely arranged in the middle of the phyllode blade.

Phyllodes of *A. mangium* are amphistomatic with numerous stomata regularly distributed on both surfaces of the phyllode. The stomata are of the paracytic type, either levelling with the epidermis or protruding a little beyond it. The size and frequency of stomata are very variable on both surfaces of the phyllode. The length of guard cells varies from 23 to 32 µm. The number of stomata per mm^2 ranges from 265 to 450, with an average of 385. Stomatal frequency increases progressively from the tip to the base on both surfaces.

Physiological Characteristics

Though regarded as an evergreen species, *A. mangium* does not grow continuously throughout the year. Monthly phenological observations over two years on *A. mangium* planted at six sites in Thailand, varying in climatic conditions, revealed that shoot growth continued throughout the first 12 months after planting but slowed down for some months in the second year (Wasuwanich 1989). In Thailand, growth appears to slow down or cease in response to the combination of low rainfall and cool temperatures in January-February. Growth becomes active in April before the wet season starts (Atipanumpai 1989). This growth rhythm is reflected in the pattern of wood production; growth rings are visible on the transverse section.

A. mangium has a relatively high light saturation point of 600 $\mu mol m^{-2} s^{-1}$ (Atipanumpai 1989) and is shade intolerant. In its natural habitat, especially in PNG, *A. mangium* is a pioneer species in areas cleared for gardens by villagers. In plantations, slow-starting individuals are suppressed by their neighbors.

Measurement of photosynthesis of glasshouse-grown *A. mangium* seedlings showed that maximum photosynthetic rate was within the range 7-10 $mgCO_2/dm^2h$ at a temperature about 25°C and at a photon flux near 600 $\mu mol^{-2} s^{-1}$ (Atipanumpai 1989). This photosynthetic rate seems low in relation to the fast growth of the species. The most productive provenances have not exhibited high photosynthetic rates, indicating that there may be no relationship between photosynthetic rate and biomass production in *A. mangium*.

Performance as an Exotic

A. mangium is one of the most widely planted *Acacia* species in the humid/subhumid tropics. Its successful introduction in Sabah, Malaysia led to its introduction into China (Pan and Yang 1987), Fiji (Zed 1987), Laos (Sylavong 1991), the Philippines (Audin 1980), Sri Lanka (Midgley and Vivekanandan 1987), Thailand (Boontawee and Kuwalairat 1987), Vietnam (Le and Nguyen 1991), and some countries in Africa (Kessy 1987; Gwaze 1987). Most countries

have introduced the species for trial in revegetation and rehabilitation programs. In Southeast Asia (for example, in Thailand and the Philippines), *A. mangium* is planted in areas abandoned after shifting cultivation and heavily infested with *Imperata cylindrica* (Plate 1.2). In Sumatra, Indonesia the majority of the area planted to date is logged-over forest sites (Werren 1991). *A. mangium* has also been included in reforestation projects intended primarily for producing fuelwood for local needs.

Plate 1.2. Three-year-old *A. mangium* on an *Imperata cylindrica* site in Kalimantan, Indonesia. Photo: Markku Temmes.

A. mangium prefers wet sites with an annual rainfall of 1,000-4,500 mm. Prolonged dry periods will slow tree growth (National Research Council 1983). While the annual rainfall of over 2,500 mm in the Bengkoka/Kudat region of Sabah is considered adequate for *A. mangium*, tree growth is still affected by seasonal conditions (Miller and Hepburn 1991). During the dry season, when monthly rainfall is below 100 mm and the evaporation rate exceeds 130 mm per month, the trees are under moisture stress (Mead 1989). Dieback due to a prolonged dry season (5-6 months) and high temperature has been observed in Thailand (Pinyopusarerk, unpublished data).

A. mangium is very site-adaptable and shows satisfactory growth even on eroded, rocky, thin mineral and deeply weathered, alluvial soils. Its symbiotic relationship with the nitrogen-fixing soil bacteria of the *Rhizobium* genus, provides the tree with sufficient nitrogenous compounds to sustain growth (see Chapter 6). Its relationship with the mycorrhizal fungus *Thelephora ramariodes*, which has been identified in Sabah, helps the tree to absorb micronutrients from the soil, especially phosphorus (Sim 1987).

The ability of *A. mangium* to attain modest growth on otherwise unproductive sites makes it an attractive species for reforestation. On good sites, average increase in diameter commonly reaches 3-4 cm per year. On weedy sites and shallow, sandy soils in Sabah, however, *A. crassicarpa* has been reported to grow faster than *A. mangium* (Sim and Gan 1991). An untended, 9-year-old stand of *A. mangium* in Sabah was reported to produce 415 m^3 of wood per ha (Tham 1976), which represents an annual production of 46 m^3 per ha.

A. mangium grows well on *Imperata cylindrica* grasslands, which are usually difficult to reforest due to adverse soil conditions and weed competition (Hadi et al. 1990). It can also grow on acidic soils with pH as low as 4, compared to other species like *Leucaena leucocephala*, which requires a pH level above 5.5 (NAS 1977). This represents a major advantage of *A. mangium* because acidic soils are

widespread throughout the tropics. On saline soils, however, *A. mangium* is not recommended because of its low salt tolerance (Thomson 1987).

A. mangium has a vigorous but shallow root system, and appears to be more susceptible to wind damage than *A. auriculiformis*. This problem is further exacerbated by the tree's broad phyllodes and dense foliage. In Zhanjiang, China, 11% of stems were leaning and 3% broken by wind damage (Pan and Yang 1987). On Hainan Island, more than 50% of 2-year-old *A. mangium* trees were uprooted by typhoon-force winds (Pan and Yang 1987). *A. mangium* is also sensitive to prolonged low temperature and frost. Pan and Yang (1987) noted the mortality of 5-year-old trees after prolonged exposure to low temperature of 5-6°C, with cold rain.

Current Planting Programs

Although the potential of *A. mangium* has been recognized since the 1970s, large-scale plantations did not start until the 1980s. Currently over 150,000 ha of *A. mangium* have been planted worldwide, with the largest planted areas being in Indonesia and Malaysia (Setyarso 1992; Raymond Tan 1992). A huge and rapid expansion of *A. mangium* plantings is anticipated, with a further half million ha of plantations already committed, mainly in Indonesia and Malaysia, for the paper-making industry.

In Malaysia, about 50,000 ha of *A. mangium* plantations have been established in Sabah by commercial firms for chip wood for pulp, paper, and wood composite products, and by state agencies for afforestation of grasslands. In Peninsula Malaysia, 42,000 ha have been established during the 1980s by the Forestry Department for general utility timber. However, the Forestry Department has recently suspended *A. mangium* planting until the impact of heart rot on the species is evaluated. The heart rot does not seem to affect the quality of paper or chips significantly. The species will continue to be a major pulpwood tree for industrial plantations, and a popular reforestation species for wasteland rehabilitation in Sabah; a planting rate of 4,000 ha per year is targeted. Shifting cultivators also show a growing interest in interplanting *A. mangium* as a legume cover crop with hill paddy.

In Indonesia, *A. mangium* has been selected for reforestation since the late 1970s. Large-scale establishment has taken place at Riau, North Sumatra by PT Indah Kiat Pulp and Paper Corp. (PT Arara Abadi 1992). Having started planting at 500-2,000 ha per year, this private timber estate company is currently establishing 16,000 ha each year. Another giant plan is also underway in South Sumatra to cover 300,000 ha of forest land, predominantly with *A. mangium* plantations, in order to supply 1.2 million tons of pulpwood annually (Arisman and Prakarsa 1992). Widyarsono (1992) reports that his company, PT Musi Hutan Persada Barito Pacific Group (also in South Sumatra) is producing 89 million seedlings to be planted in 1992. At Paulu Laut, South Kalimantan, *A.*

mangium has also been selected for timber estate development. In West Java, a state enterprise, Perum Perhutani, has established 36,000 ha of forest plantation, of which *A. mangium* is one of the main species (Setyarso 1992). Outside timber estates, *A. mangium* has been planted in South and East Kalimantan, Sulawesi, and other parts of Indonesia, particularly for site rehabilitation.

In 1989, Sabah Forest Industries Sdn. Bhd., a pulp and paper company in Malaysia, was the first to produce paper from *A. mangium* pulp on a commercial scale (Sim 1992). The quality of the (printing and writing) paper was acceptable, and there is great potential for blending *A. mangium* wood with residual mixed tropical wood to produce high-quality printing and writing paper. This important development removed doubts about the suitability of *A. mangium* wood as raw material for making quality paper. Results of commercial testing have boosted the confidence of many investors and given strong impetus to tree-planting industries in Malaysia and abroad.

Commercial planting of *A. mangium* in other countries like China, the Philippines, Thailand, and Vietnam is increasing. A large expansion in *A. mangium* plantations is anticipated in the next few years.

Summary

A. mangium can grow satisfactorily on otherwise unproductive sites, and is particularly suited for controlling soil erosion and weeds in areas heavily infested with *Imperata* grass. Its wood is used for pulp, sawn timber, chips, and fuelwood. Its natural distribution stretches from the islands of Sula, Ceram, and Aru in Indonesia, through the Western Province of Papua New Guinea, to northeastern Queensland, Australia. It is typically a low-elevation species associated with rainforest margins and disturbed sites on well-drained, acid soils. On favorable sites it can grow to a height of 25-35 m and a dbh of over 60 cm. It prefers wet sites; prolonged dry periods slow its growth.

Recent developments in using *A. mangium* as pulpwood have confirmed its suitability for making quality paper. The area under plantation with this species is rapidly expanding, with 150,000 ha already planted worldwide and another half million ha committed for planting for the paper industry.

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References

Anon. 1982. The genus *Acacia* in Australia. Australian Acacias Leaflet, revised 1982. CSIRO Forest Research, Canberra.

Arisman, H. and Prakarsa. 1992. Pengalaman dalam pembangunan HTI di PT Musi Hutan Persada Barito Pacific Group. A paper presented at the national seminar on the status of Indonesian Silviculture. 27-29 April 1992, Yogyakarta.

Atipanumpai, L. 1989. *Acacia mangium*: studies on the genetic variation in ecological and physiological characteristic of a fast growing plantation species. *Acta Forestia Fennica* 206.

Audin, N.A. 1980. *Acacia mangium*: a resource to be developed. *Canopy* 6(1):11.

Boontawee, B. and P. Kuwalairat. 1987. Introduction of *Acacia mangium* to Thailand. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 149-150. ACIAR Proceedings No.16. Canberra, Australia: Australian Centre for International Agricultural Research.

Doran, J.C. and D.J. Skelton. 1982. *Acacia mangium* seed collections for international provenance trials. Forest Genetic Resources Information No. 11:46-53. Rome: FAO.

Gunn, B.V., J. Morse, and L.A.J. Thomson. 1990. 1989 seed collections of tropical acacias in Papua New Guinea and north Queensland. Internal report, Australian Tree Seed Centre, CSIRO, Canberra.

Gunn, B.V., and M.W. McDonald. 1991. Seed collections of *Eucalyptus urophylla*, *E. pellita* and *Acacia* species from Indonesia. August-November 1990. Internal report, Australian Tree Seed Centre, CSIRO, Canberra.

Gwaze, D.P. 1987. Status of Australian acacias in Zimbabwe. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 126-127. ACIAR Proceedings No.16. Canberra, Australia: Australian Centre for International Agricultural Research.

Hadi, T.S., G. Adjers, and R. Vuokko. 1990. Performance of different provenances of *Acacia mangium* at 30 months after planting on an alang-alang (*Imperata cylindrica*) grassland site in South Kalimantan, Indonesia. Technical Report II/Iv, June 1990. Jakarta, Indonesia: Ministry of Forestry, Directorate General of Forestation and Land Rehabilitation.

Hall, N., J.W. Turnbull, J.C. Doran, and P.N. Martensz. 1980. *Acacia mangium* Willd. In Australian Acacias. CSIRO Forest Research Leaflet 9. Canberra, Australia: CSIRO.

House, A., J. Larmour, J. Morse, M.W. McDonald, and T.K. Vercoe. 1991. Seed collections from Cape York Peninsula and Western Province, Papua New Guinea, 1990/91. Internal report, Australian Tree Seed Centre, CSIRO, Canberra.

Kessy, B.S. 1987. Growth of Australian acacias in Tanzania. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 123-125. ACIAR Proceedings No.16. Canberra, Australia: Australian Centre for International Agricultural Research.

Le Dinh Kha and Nguyen Hoang Nghia. 1991. Growth of some *Acacia* species in Vietnam. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 173-176. ACIAR Proceedings No. 35. Canberra, Australia: Australian Centre for International Agricultural Research.

Mead, D.J. 1989. Contrasting plantation projects in Malaysia. Paper pesented to N.Z.-Asia Conference, University of Canterbury, Christchurch, New Zealand.

Midgley, S.J. and K. Vivekanandan. 1987. Australian acacias in Sri Lanka. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 132-135. ACIAR Proceedings No.16. Canberra, Australia: Australian Centre for International Agricultural Research.

Miller, R.R. and A.J. Hepburn. 1991. A review of the growth of *Acacia mangium* at the Bengkoka afforestation and settlement project, North Sabah. In *Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 93-110. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

National Academy of Sciences. 1977. Leucaena: *promising forage and tree crop for the tropics*. Washington, D.C.: National Academy Press.

National Research Council. 1983. Mangium *and other fast-growing acacias for the humid tropics*. Washington, D.C.: National Academy Press.

New, T.R. 1984. *A Biology of Acacias*. Melbourne: Oxford University Press.

Pan, Z., and M. Yang. 1987. Australian acacias in the Republic of China. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 136-138. ACIAR Proceedings No.16. Canberra, Australia: Australian Centre for International Agricultural Research.

Pedley, L. 1986. Derivation and dispersal of *Acacia* (Leguminosae), with particular reference to Australia, and the recognition of *Senegalia* and *Racosperma*. *Botanical Journal of the Linnean Society* 92: 219-254.

_____ . 1987. Acacias in Queensland. Queensland Herbarium. Brisbane: Department of Primary Industries.

_____ . 1990. New combinations in *Acacia* (Leguminosae: Mimosoideae). *Austrobaileya* 3: 215-216.

P.T. Arara Abadi. 1992. Pelaksanaan pembangunan HTI PT Arara Abadi. Paper presented at the national seminar on the status of Indonesian silviculture, April 27-29, 1992, Yogyakarta.

Raymond Tan, G.S. 1992. Economics of planting and marketing *Acacia mangium*. In *Tropical Acacias in East Asia and the Pacific*, eds. Kamis Awang and D.A. Taylor; 96-102. Proc. of a first meeting of the Consulatative Group for Research and Development of Acacias (COGREDA), held in Phuket, Thailand, June 1-3, 1992. Bangkok, Thailand: Winrock International.

Setyarso, A. 1992. The state of growth and yield study of *Acacia mangium* in Indonesia. In *Tropical Acacias in East Asia and the Pacific*, eds. Kamis Awang and D.A. Taylor; 76-80. Proc. of a first meeting of the Consultative Group for Research and Development of Acacias (COGREDA), held in Phuket, Thailand, June 1-3, 1992. Bangkok, Thailand: Winrock International.

Skelton, D.J. 1987. Distribution and ecology of Papua New Guinea acacias. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 38-44. ACIAR Proceedings No.16. Canberra, Australia: Australian Centre for International Agricultural Research.

Sim, B.L. 1987. Research experience of *Acacia mangium* in Sabah. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 139-142. ACIAR Proceedings No. 16. Canberra, Australia: Australian Centre for International Agricultural Research.

_____ . 1992. Overview of acacia research in Sabah. In *Tropical Acacias in East Asia and the Pacific*, eds. Kamis Awang and D.A. Taylor; 28-33. Proc. of a first meeting of the Consulatative Group for Research and Development of Acacias (COGREDA), held in Phuket, Thailand, June 1-3, 1992. Bangkok, Thailand: Winrock International.

Sim, B.L. and E. Gan. 1991. Performance of *Acacia* species on four sites of Sabah Forest Industries. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 159-165. ACIAR Proceedings No. 35. Canberra, Australia: Australian Centre for International Agricultural Research.

Suratmo, F.G., D.I. Utomo, and E. Risjona. 1980. Studi kelayakan Pendadaan benih Pericopsis moniana dan *Acacia mangium* untuk pelestarian hutan alam yang diuysahakan di Maluku. Fakultas Kehutanan Institut Pertanian Bogor. No. 242c/Bnh/V1.1979.

Sylavong, L. 1991. Australian acacias in Laos. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 227. ACIAR Proceedings No. 35. Canberra, Australia: Australian Centre for International Agricultural Research.

Tham, C.K. 1976. Introduction to a plantation species: *Acacia mangium* Willd. Sixth Malaysian Forestry Conference, Kuching, Sarawak, Malaysia.

Thomson, L.A.J. 1987. Australian acacias for saline soils in the hot, dry subtropics and tropics. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 66-69. ACIAR Proceedings No. 16. Canberra, Australia: Australian Centre for International Agricultural Research.

Turnbull J.W., ed. 1986. *Multipurpose Australian Trees and Shrubs: Lesser-known Species for Fuelwood and Agroforestry*. ACIAR Monograph No. 1. Canberra, Australia: Australian Centre for International Agricultural Research.

Turnbull, J.W., D.J. Skelton, M. Subagyono, and Eko Bhakti Hardiyanto. 1983. Seed collections of tropical acacias in Indonesia, Papua New Guinea and Australia. Forest Genetic Resources Information No. 12: 2-15. Rome: FAO.

Wasuwanich, P. 1989. Phenological investigation of Australian tree species in field trials in Thailand. Report to the Australian International Development Assistance Bureau as part of "Seeds of Australian Trees" Project. Canberra, Australia: CSIRO Division of Forestry.

Werren, M. 1991. Plantation development of *Acacia mangium* in Sumatra. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 107-109. ACIAR Proceedings No. 35. Canberra, Australia: Australian Centre

for International Agricultural Research.

Widyarsono. 1992. Pengalaman pembuatan pesemaian dan produksi bibit di PT Musi Hutan Persada Barito Pacific Group. Paper presented at the national seminar on the status of Indonesian silviculture, April 27-29, 1992, Yogyakarta.

Zed, P.G. 1987. Use of acacias in Fiji. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 185. ACIAR Proceedings No. 16. Canberra, Australia: Australian Centre for International Agricultural Research.

Chapter 2

Reproductive Biology

Zakaria Ibrahim

Introduction

In the plant kingdom, reproduction is either sexual or asexual. Sexual reproduction (in which offspring are produced by union of male and female gametes) maintains genetic variability, which has benefits in terms of reduced risk of widespread disease losses, but has disadvantages in terms of the heterogeneous individuals produced. Asexual reproduction, or vegetative propagation (in which individuals are multiplied without combination of gametes), includes the techniques of cutting, budding, grafting, and tissue culture (see Chapter 4). The economic advantage of asexual reproduction is the ability to produce uniform planting materials of identical genetic composition as ortets with known characteristics. This advantage has been widely exploited by horticulturists and agronomists for improving annual and biennial crops. Forestry in general, however, still relies on sexual reproduction for propagating timber species, except for a few species for which vegetative propagation is an economic option.

Most reforestation and afforestation programs use seedlings as planting materials, with quality planting materials obtained from seedling or clonal seed orchards after rigorous genotypic selection. Hybridization is another method that holds potential for improving planting materials in forestry. In either case, understanding the species' reproductive biology is important for developing an improvement strategy.

This chapter describes the reproductive biology of *Acacia mangium*, including its floral biology, phenology, breeding system, and hybridization potential.

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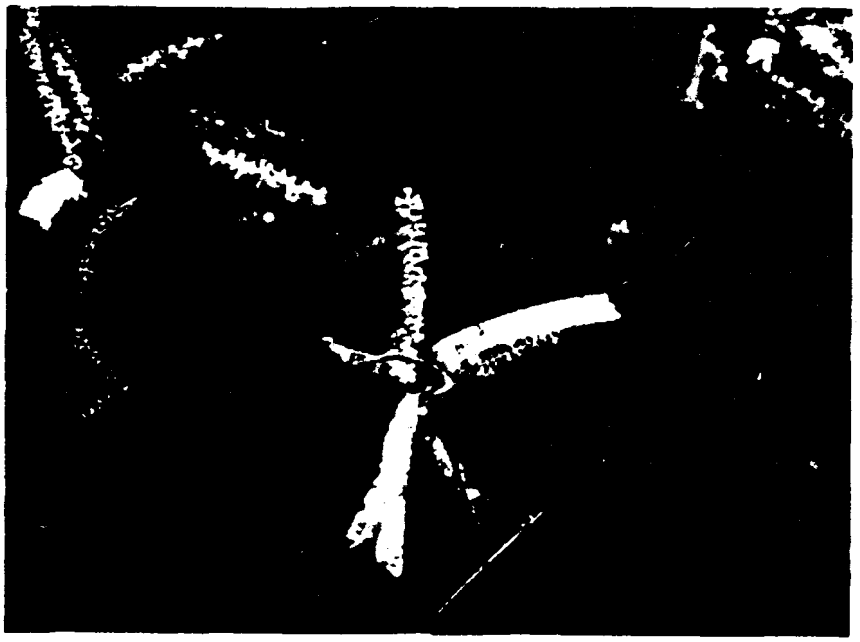

Plate 2.1. Inflorescence of *Acacia mangium*. *Photo:* Zakaria Ibrahim.

Floral Biology

Male and female gametes, the structures responsible for sexual reproduction, are produced by angiosperm flowers. As floral morphology plays a definitive role in pollination, close observation of a species' flowers can lead to an understanding of its breeding system.

The floral morphological characteristics of *A. mangium* are well documented. Pedley (1975, 1978), Vercourt (1979), NAS (1983), and Turnbull et al. (1986) give brief descriptions of the inflorescences of *A. mangium* and *A. auriculiformis*.

Inflorescence Description

The inflorescence of *A. mangium* belongs to the spicate group (Guinet and Vassal 1978) and consists of numerous flowers borne on a loose, pendulous spike. Three to eight inflorescences are arranged spirally along the spike of each phyllode axil (Plate 2.1).

A. mangium has a mean inflorescence length of 97 mm, compared to 70 mm for *A. auriculiformis* (Zakaria and Kamis 1991). *A. mangium* also has a higher number of flowers per inflorescence (195) than *A. auriculiformis* (105).

During peak flowering season, the entire crown is covered with inflorescences. When in full blossom, the inflorescences resemble bottle brushes. Flowering is conspicuous in that the inflorescences, with many brightly colored flowers, are located at the distal portion of the crown.

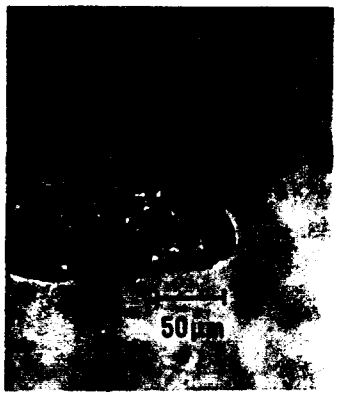

Plate 2.2. Style of *A. mangium* with a polyad adhered to the stigma (magnified 20x).

Plate 2.3. Bilobed anther of *A. mangium* showing anther dehiscence lines (magnified 20x).

Plate 2.4. A polyad of*A. mangium* showing the conglomeration of 16 pollen grains (magnified 20x).

Flower Description

The flower of *A. mangium* is regular in symmetry, consisting of five sepals, five petals, numerous stamens, and one gynoecium. The open flower measures about 4.9 x 4.6 mm. Its creamy white color arises from the white of the petals and filaments and the yellow of the anthers (Plate 2.7 on p. 24).

The flower has a mild, sweet fragrance, which is particularly distinct in the early morning when individual flowers are in bloom.

Microscopic examination of the stigma reveals that it is non-papillate, measuring about 63 microns in diameter (Plate 2.2), and forms a cup-shaped depression at the tip of the solid style (Zakaria and Kamis 1991). Since the style and the surrounding filaments are the same length, the stigma lies on the same plane as the anthers. Exudate present on the stigma causes it to glisten when observed under a dissecting microscope.

The anther of *A. mangium* is a bilobed structure set terminally on the filament and measuring 183 microns (Plate 2.3). Each lobe has four separate loculi, with each loculus enclosing a polyad (composite pollen grains). On average, *A. mangium* has about 113 stamens per flower (Zakaria and Kamis 1991).

As mentioned, *A. mangium* pollen comes in polyad form. Each polyad consists of 16 pollen (Plate 2.4). The polyad is spherical in shape with a diameter of about 30-40 microns.

The ovary is sessile, normally with minute hairs, with 12-14 ovules per ovary (Zakaria and Kamis 1991).The variation in ovule number is due to variation in pistil size and structure, which ranges from normal pistil with long style and hairy ovary to small pistil with very short style and without ovary hairs.

Generally the flowers are hermaphroditic. However, in some inflorescences staminate flowers are also present. Zakaria and Kamis (1991) estimate that the incidence of staminate flowers in *A. mangium* is only 4.0%, and the occurrence

of staminate flowers per inflorescence ranges from 1-46. Staminate flowers occur randomly in any position of the inflorescence. Microscopic investigation reveals that in staminate flowers, the ovary is either completely absent or vestigial.

The same authors also calculated that, with an estimated 27 inflorescences per twig (270 inflorescences per branch, thus 52,000 flowers per branch), each *A. mangium* branch holds approximately 47,595,600 polyads.

Phenology

Flowering Event

Flowering in *A. mangium* consists of six stages of floral events, from initiation of inflorescence to shedding of flowers (Zakaria 1991).

Stage 1 Floral development begins with initiation of floral primordium. It is not clear at which stage the auxiliary bud differentiates as floral primor dium. However, once differentiation occurs it can be recognized macroscopically as the inflorescence elongates.

Stage 2 As the inflorescence elongates, young flower buds begin to form (Plate 2.5). The flower buds are seen to be evenly distributed along the spike in a spiral manner when the spike reaches its maximum length.

Stage 3 The flower buds then turn from green to greenish yellow (Plate 2.6), signifying their maturity.

Stage 4 At anthesis, which lasts 3-4 days, inflorescences with open flowers resemble the shape of a bottle brush (Plate 2.7). It takes about 89 days for the young inflorescences to reach anthesis.

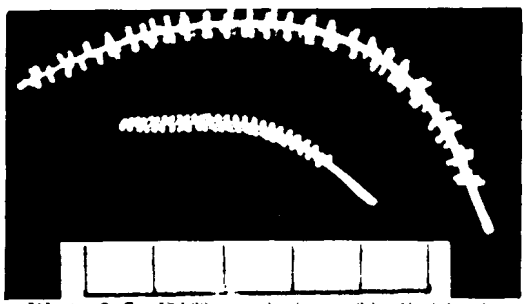

Plate 2.5. Differentiation of individual flower buds and maximum elongation of spike length (Stage 2). *Photo:* Z.Ibrahim.

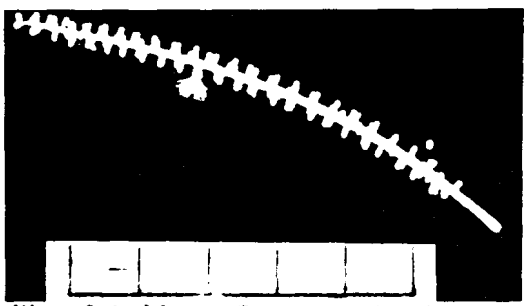

Plate 2.6. Mature flowers turning from green to greenish-yellow (Stage 3). *Photo:* Zakaria Ibrahim.

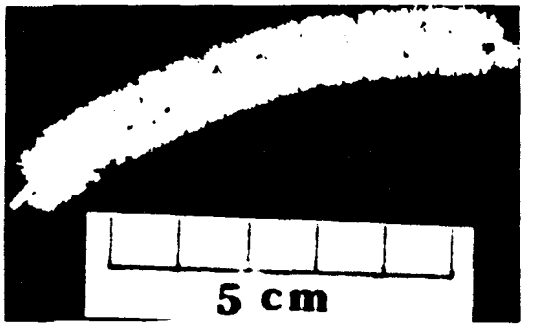

Plate 2.7. Anthesis of *A. mangium* (Stage 4). *Photo:* Zakaria Ibrahim.

Plate 2.8. Flowers shedding and turning brown (Stage 5). *Photo:* Zakaria Ibrahim.

Stage 5 The flowers begin to shed with the withering of petals and stamens (Plate 2.8) and the change of their color to brown.

Stage 6 This is followed by shedding of flowers from the spike; eventually the spike aborts.

Flowering Phenology

Flowering in acacias is precocious. *A. mangium* starts to flower and produce seeds 18-20 months after planting (NAS 1983). In Australia a single major peak of flowering occurs between March and May (Sedgley et al. 1992); in Peninsular Malaysia flowering occurs throughout the year, with a distinct flowering season occurring between June and July (Zakaria and Kamis 1991). Sedgley et al. (1992) report that in Sabah, the major peak flowering of *A. mangium* is in January. In Papua New Guinea, the species flowers in April and July (Skelton 1980; Turnbull et al. 1983), with seeds ripening toward the end of September. In Taiwan, flowering is from October to November (Kiang et al. 1989). In Thailand, flowering peaks in September (Kijkar 1992).

Though most acacias generally flower synchronously each year for a period of a few weeks (New 1984), some individual trees may flower sporadically at different times. In Malaysia, flowering usually lasts about one month. This extended flowering period is due to the progressive development of inflorescences along the twigs and the resulting disparity in flowering times. Within trees, anthesis is synchronous; however, between trees of a population, anthesis is staggered because of differences in inflorescence development.

Mature fruits occur three to four months after the flowering period (Zakaria and Kamis 1992). The time from the onset of flower buds to pod maturity is about 199 days.

Breeding Biology

Breeding System

At their extremes, plant breeding systems can either be selfing (autogamy) or outcrossing (allogamy). Selfing can lead to restricted genetic recombination, which has its own advantages and disadvantages in plant breeding. Outcrossing, on the other hand, gives the greatest possibility for recombination and maintenance of genetic diversity. Between these two extremes, some plants can be both selfing and outcrossing.

Acacias are generally outcrossing species (Philp and Sherry 1946; Moffett 1956; Coaldrake 1971). For *A. mearnsii*, the estimated natural outcrossing rate is high, 67-89% (Moffett 1956; Sherry 1971). In general, species maintain outcrossing by providing abundant food to attract pollinators and other means, such as floral devices to prevent self-pollination, self-sterility, and self-incompatibility (Percival 1965). In acacias, it has been proposed that outcrossing is maintained through protogynous dichogamy (stigma becomes receptive before anther ripens), andromonoecy (spatial separation of sex organs), and self-incompatibility (Sedgley 1987; Sedgley and Griffin 1989).

A. mangium is generally an outcrossing species with the tendency toward selfing (Zakaria 1991). In *A. mangium* andromonoecy, spatial separation of the sexes is not prominent (see flower description above). In terms of temporal separation of the sexes, protogynous dichogamy is not prevalent. Anthesis occurs very early in the day, with flowers opening the preceding night at about 2100 hr. The synchronous emergence of styles and stamens, the immediate anther dehiscence, and stigma receptivity after anthesis (Zakaria 1991) signify that the flowers of *A. mangium* are homogamous. Zakaria (1991) also found that the species' Index of Self-Incompatibility (ISI) rating was 0.38, which could lead it to be classified as an outcrossing species with some degree of selfing despite being partially self-incompatible. Its partial self-incompatibility is probably due to the presence of Sc (nonfunctional) alleles with post zygotic lethal genes, as in *A. terminalia* and *A. myrtifolia* (Kenrick and Knox 1989).

It may be that *A. mangium* is in the process of evolving from an outcrossing species to a selfing species, given the observation of some mechanisms of autogamy, including overlap in style receptivity and pollen shedding and mixed cross- and self-pollinations (Frankel and Galun 1977). The latter indicates the breakdown of an outcrossing system to be replaced by an as yet indefinite autogamy system.

A. mangium requires biotic agents to transfer pollen from the anthers to the stigmas. Pollinators are mainly entomophilic, with *Trigona* and *Apis* spp. (Sedgley et al. 1992; Zakaria 1991) as the consistent pollen vectors. The most active time of day for these pollinators is between 07:30 and 11:00 hr., after which their activity decreases; very few pollinators are observed later in the day

(15:30 hr.). In spite of its dense and conspicuous inflorescences, *A. mangium* fails to attract a more varied spectrum of pollinators, probably because it lacks floral nectaries like those observed in *A. retinodes* (Bernhardt et al. 1984).

In acacias, polyad morphology (Kenrick and Knox 1982) and the presence of post-pollination exudate (Kenrick and Knox 1981; Marginson et al. 1985) play important roles in ensuring successful seed set following a single pollination event. A successfully placed polyad fits well into the depression of the cup-shaped stigma. Since the polyad is a biconvex disc two grains thick in the center (Kenrick and Knox 1979), only half of its pollen grains are in contact with the stigma. The exudate, which is produced profusely after pollination, helps to engulf the polyad and allows germination of grains not in contact with the stigma surface (Marginson et al. 1985).

Hybridization

Hybridization broadly refers to any cross-mating of two genetically different individuals that leads to hybrid progeny (Rieger et al. 1968). The use of hybrids is very common for agricultural crops and in forestry, hybrid trees have long been known (Tanaka 1882, as cited in Zobel and Talbert 1984). Larsen (1956) reported the successful application of hybrids of *Populus* and *Larix* in Europe. In Korea, hybrid pines are widely used due to the availability of cheap labor to produce hybrid pine seeds (Wright 1976). Forest genera known to hybridize freely in nature are *Eucalyptus* (Kirkpatrick 1971), *Populus* (Einspahr and Joranson 1960), and *Pinus* (Critchfield 1973). Within *Acacia*, there are reports of hybrid swarms between *A. brachybotrya* and *A. calamifolia* (Leach and Wahiffin 1978), hybridization between *A. nilotica* ssp. *indica* x *A. nilotica* ssp. *hemispherica* (Ali and Qaiser 1980), natural hybrids between *A. auriculiformis* x *A. leptocarpa* (F/FRED 1987), and natural hybrids between *A. mangium* x *A. auriculiformis* (Tham 1979; Turnbull et al. 1983).

The hybrid *A. mangium* x *A. auriculiformis* has the potential to become an important source of planting material in plantation forestry. The general tree form is satisfactory where it inherits the better stem straightness of *A. mangium* and self-pruning ability and better stem circularity of *A. auriculiformis*. Sinning (1991) reported that the physical and mechanical properties of the hybrid are intermediate between the two parent species (that is, better than *A. mangium*). While *A. mangium* 's susceptibility to heart rot (FRIM 1992) renders it less suitable for sawn timber production, the hybrid appears more resistant.

Natural Hybrids of *A. mangium* x *A. auriculiformis*

Natural hybrids between *A. mangium* and *A. auriculiformis* have been reported in

Sabah (Tham 1976) and Papua New Guinea (Turnbull et al. 1986). In Sabah these hybrids occur where *A. mangium* and *A. auriculiformis* grow in close proximity, with possibly overlapping flowering times (Plate 2.9). Natural hybrids have also been observed in plantations at Ulu Sedili, Johor, Peninsular Malaysia (Darus and Rasip 1989). Tham (1979) found that hybrid trees grow more vigorously than trees of *A. mangium*, but tend to inherit the overall poor form of *A. auriculiformis*. However, hybrids' branching characteristics (branch size and self-pruning ability) appear to be better than those of *A. mangium* (Bowen 1981; Rufelds and Jaffirin 1986).

Plate 2.9. Natural hybrid of *A. mangium* x *A. auriculiformis* at 19 years old, at SAFODA's Ulu Kukut plantation. *Photo:* Kamis Awang

The ability of *A. mangium* and *A. auriculiformis* to hybridize is evident from the facts that both species (Zakaria 1991):

- are pollen-pistil compatible (meaning both species are partially self-incompatible)
- occur within the same habitats
- have overlapping flowering period (Figure 2.1), and
- share common pollinators

Hybrid Identification

Natural hybrids can sometimes lead to taxonomic confusion. For example, the fact that certain *Eucalyptus* species hybridize easily causes the number of species in that genus to vary from one taxonomist to another (Zobel et al. 1987). Some hybrids can be easily distinguished from their parents. Hybrids of *Pinus coulteri* x *Pinus jeffreyi* can be easily distinguished from their parents because the hybrids had intermediate features between the two species (Zobel 1951). More often, however, hybrids cannot be identified easily by their morphological characteristics alone; their identification becomes more difficult as the hybrid generation advances (F2, F3, and so forth). This is especially the case when introgressive hybridization occurs in a population.

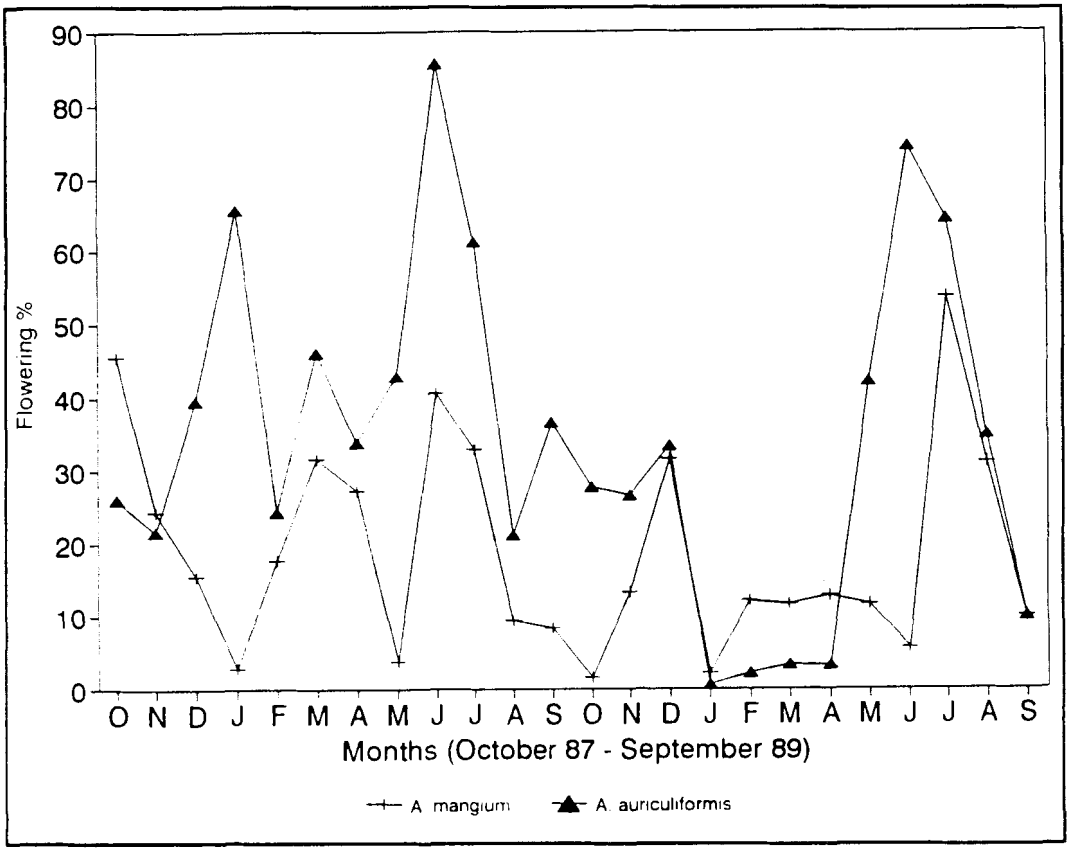

Figure 2.1. Monthly flowering intensity of *A. mangium* and *A. auriculiformis*. *Source:* Zakaria (1991)

In the field, the *A. mangium* x *A. auriculiformis* hybrid can be distinguished from its parent species by the lighter color of its bark. However, this is not apparent in the seedling stage. Rufelds (1988) studied seedling morphology of *A. mangium*, *A. auriculiformis*, and their hybrids, and concluded that many of the parental and hybrid progenies can be distinguished by using both the taxonomic and leaf development pattern, with assessments carried out on a weekly basis for at least eight weeks.

Isozyme analysis is commonly used to identify hybrids, and has been used to identify hybrids in *Acacia* (Adams 1983; Yongbi 1987; Wickneswari 1989). Using the isozyme analysis technique developed by Wickneswari (1989), Zakaria (1991) found that *A. mangium* has a homozygous 2,2 genotype at Per-2, whereas *A. auriculiformis* has a homozygous 1,1 genotype at the same locus. The reciprocal interspecific hybrids between *A. mangium* and *A. auriculiformis* were identified as a two-banded (1,2) heterozygotes locus (Figure 2.2).

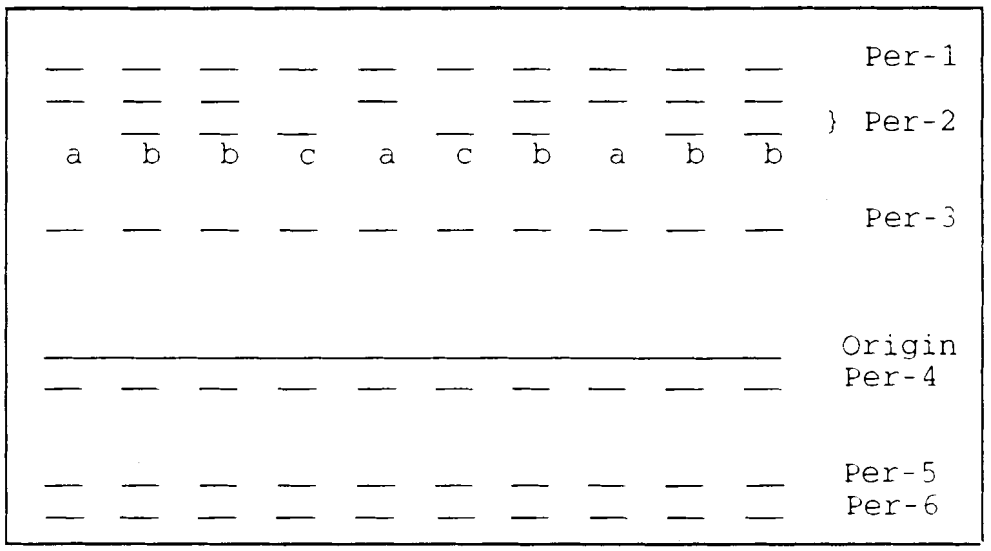

Figure 2.2. Diagram of peroxidases from phyllodes showing 1, 1 (a) homozygotes of *A. auriculifromis*, 2, 2 (c) homozygotes of *A. mangium*, and 1, 2 (b) heterozygotes of *A. mangium* and *A. auriculiformis* at Per-2.

Manipulated Hybrids of *A. mangium* x *A. auriculiformis*

Sedgley et al. (1992) developed hybridization techniques for acacias (with emasculation). Using the anther method (without emasculation) Zakaria (1991) found that both *A. mangium* and *A. auriculiformis* hybridize with each other quite readily. The percentage of infructescences formed as a result of hybridization was almost double (44%) when *A. auriculiformis* hybridized with *A. mangium*, compared to 23% successful hybridization between *A. mangium* and *A. auriculiformis* (Zakaria 1991). However, the production of pods per infructescence was found to be higher in crosses between *A. mangium* x *A. auriculiformis* than *A. auriculiformis* x *A. mangium*. In addition, seed yield was also higher in crosses of *A. mangium* x *A. auriculiformis* than in *A. auriculiformis* x *A. mangium*.

Zakaria (1991) and Rufelds (1988) found that the hybrid potential is higher when *A. auriculiformis* functions as the female parent than when *A. mangium* does. This is probably due to the higher outcrossing rate in *A. auriculiformis* — about 93% (Moran et al. 1989) compared to 15% for *A. mangium* (Wickneswari, personal communication). Though a large number of seeds are produced in crosses where *A. mangium* is the female parent, the progeny is apparently selfed.

Prospects of the Hybrid

The hybridization techniques developed by Zakaria (1991) and Sedgley et al. (1992) provide opportunities for tree breeders to explore the potential of different hybrid combinations in order to maximize genetic gains. The bi-clonal seed

orchard of *A. mangium* and *A. auriculiformis* in Sabah (Griffin et al. 1992) has produced some hybrid seeds. Mass production of hybrid plantlets through tissue culture has also shown promise (Darus 1992), suggesting that hybrid plantlet production could be accelerated.

Research is needed to determine the optimum hybrid combinations and their site specificity. This requires structured experiments to evaluate the breeding values and structured observations of hybrid performance in the field.

Summary

The flowers of *A. mangium* occur as inflorescences consisting of many flowers borne on loose, pendulous spikes. The flower is regular in symmetry and consists of five sepals, five petals, numerous stamens, and a gynoecium. Generally, the flowers are hermaphroditic, with some occurrence of staminate flowers. Pollen occurs in polyads of 16 pollen grains.

Flowering consists of six stages, from floral initiation to shedding of flowers. Anthesis lasts from three to four days. The time of peak flowering varies from country to country. The species is generally outcrossing, with a tendency to self due to the fact that its flowers are homogamous and partially self-incompatible.

Natural hybrids of *A. mangium* x *A. auriculiformis* have been found in Sabah, Malaysia and Papua New Guinea. This hybrid, which can easily be identified using isozyme analysis, has tremendous potential as plantation material, as it possesses the stem straightness of *A. mangium* and the self-pruning ability and stem circularity of *A. auriculiformis*. In manipulated hybridization of the two species, hybrid potential is greater when *A. mangium* is the female parent.

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References

Adams, W.T. 1983. Application of Isozyme in Tree Breeding. In *Isozymes in Plant Genetics and Breeding*, Part A; eds. S.D. Tanskley and T.J. Orton; 381-400. New York: Elsevier.

Ali, S.I. and M. Qaiser. 1980. Hybridization in *Acacia nilotica* (Mimosoideae) complex. *Bot. J. Linnean Soc.* 80:69-77.

Bernhardt, P., J. Kenrick, and R.B. Knox. 1984. Pollination biology and the breeding system of *Acacia retinodes* (Leguminosae: Mimosoideae). *Annals of Missouri Bot. Garden* 71:17-29.

Bowen, M.R. 1981. A note on seed collection, handling and storage techniques including some experimental data and information on *Acacia auriculiformis* and the probable *A. mangium* x *A. auriculiformis* hybrid.

Seed Series No. 3. FAO/UNDP-MAL/78/009. Sabah, Malaysia: Forest Research Centre.

Coaldrake, J.E. 1971. Variation in some floral, seed, and growth characteristics of *Acacia harpophylla* (Brigalow). *Aust. J. of Bot.* 19:335-352.

Critchfield, W.B. 1973. Interspecific hybridisation in *Pinus*: a summary review. In Proc. 14th Meeting Canadian Tree Improvement Association. 2: 99-105.

Darus Ahmad. 1992. Micropropagation techniques for *Acacia mangium* x *Acacia auriculiformis*. In *Breeding Technologies for Tropical Acacais*. eds. L.T. Carron and K.M. Aken; 119-121. ACIAR Proceedings No. 37. Canberra: ACIAR.

Darus Ahmad and Ab. Rasip Ab. Ghani. 1989. A note on the *Acacia* hybrids in forest plantations in Peninsular Malaysia. *J. Trop. For. Sci.* 2(2):170-171.

Einsparh, D.W. and P.N. Joranson. 1960. Late flowering in aspen and its relation to naturally occurring hybrids. *For. Sci.* 6(3):221-224.

Forest Research Institute Malaysia. 1992. The incidence of heartrot in *Acacia mangium* plantations in Peninsular Malaysia. Report to the Ministry Primary Industries, Malaysia. Serdang, Malaysia: FRIM.

Forestry/Fuelwood Research and Development Project. 1987. 1987 Seed collections of *Acacia auriculiformis* in Papua New Guinea and northern Australia. MPTS Research Series Report No. 4. Bangkok: Winrock International.

Frankel, R. and E. Galun. 1977. *Pollination Mechanisms, Reproduction and Plant Breeding*. Monographs on Theoretical and Applied Genetics 2. Berlin: Springer-Verlag.

Griffin, A.R. 1989. Sexual reproduction and tree improvement strategy - with particular reference to *Eucalyptus*. In *Breeding Tropical Trees: Population Structure and Genetic Improvement Strategies in Clonal and Seedling Forestry*, eds. G.L. Gibson, A.R. Griffin and A.C. Matheson; 52-67. Oxford: Oxford Forestry Institute and Winrock International.

Griffin, A.R., C.Y. Yong, R. Wickneswari, and E. Chia. 1992. Mass production of hybrid seed of *Acacia mangium* x *Acacia auriculiformis* in biclonal seed orchard. In *Breeding Technologies for Tropical Acacias*. eds. L.T. Carron and K.M. Aken; 70-75. ACIAR Proceedings No. 37. Canberra: ACIAR.

Guinet, P. and J. Vassal. 1978. Hypotheses on the differentiation of the major groups in the genus *Acacia* (Leguminosae). *Kew Bulletin* 32:509-527.

Kenrick, J. and R.B. Knox. 1979. Pollen development and histochemistry in some Australian species of *Acacia*. *Aust. J. of Bot.* 27:413-427.

_____. 1981. Post-pollination exudate from stigma of *Acacia*. *Annals of Botany* 48:103-106.

_____. 1982. Function of the polyad in reproduction of *Acacia*. *Annals of Botany* 50:721-727.

_____. 1989. Quantitative analysis of self-incompatibility in trees of seven species of *Acacia*. *J. Heredity* 80(3):240-245.

Kiang, T., C.Y. Jeng, P. Fuh-Jiunn, and M. Fuh-Jing. 1989. Peroxidase isozyme evidence for natural hybridization between *Acacia mangium* and *A. auriculiformis*. In *Breeding Tropical Trees: Population Structure and Genetic Improvement Strategies in Clonal and Seedling Forestry*, eds. G.L. Gibson, A.R. Griffin and A.C. Matheson; 392-393. Oxford: Oxford Forestry Institute and Winrock International.

Kijkar, S. 1992. *Vegetative Propagation of* Acacia mangium *x* Acacia auriculiformis. Handbook No. 1. Muak Lek, Saraburi, Thailand: ASEAN-Canada Forest Tree Seed Centre.

Kirkpatrick, J.B. 1971. A probable hybrid swarm in *Eucalyptus*. *Silvae Genetica* 20(5-6):157-159.

Larsen, C.S. 1956. *Genetics in Silviculture*. Fairlawn, New York: Essential Books.

Leach, G.J. and F.L.S. Whiffin. 1978. Analysis of hybrid swarms between *Acacia brachybotrya* and *Acacia calamifolia* (Leguminosae). *Bot. J. Linnean Soc.* 76:53-69.

Marginson, R., M. Sedgley, and R.B. Knox. 1985. Physiology of post-pollination exudate production in *Acacia*. *J. Exper. Bot.*45:217-236.

Moffett, A.A. 1956. Genetical studies in acacias I. The estimation of natural crossing in black wattle. *Heredity* 10:57-67.

Moran, G.F., O. Muona, and J.C. Bell. 1989. Breeding systems and genetic diversity in *Acacia auriculiformis* and *A. crassicarpa*. *Biotropica* 21(3):250-256.

National Academy Science. 1983. Wood products and uses. In *Mangium and Other Fast-Growing Acacias for the Humid Tropics*, 21-23. Washington, D.C.: National Academy Press.

New, T.R. 1984. *A Biology of Acacia*. Melbourne: Oxford University Press.

Pedley, L. 1975. Revision of the extra-Australian species of *Acacia* subg *Heterophyllum*. Contribution to the Queensland Herbarium No. 18.

_____. 1978. A revision of *Acacia* Mill. in Queensland. *Austrobaileya* 1(2):75-234.

Percival, M.S. 1965. *Floral Biology*. Oxford: Pergamon Press.

Philp, J. and S.P. Sherry. 1946. The degree of natural crossing in Green Wattle (A. decurrens Willd.) and its bearing on Wattle breeding. *J. S. African For. Assoc.* 14:1-28.

Rieger, R., A. Michaelis, and M.M. Green. 1968. *A Glossary of Genetics and Cytogenetics*. Berlin: Springer-Verlag.

Rufelds, C.W. 1988. *Acacia mangium, A. auriculiformis* and hybrid *A. auriculiformis* seedling morphology study. FRC Publication No. 41. Sabah, Malaysia: Forest Research Centre.

Rufelds, C.W. and Jaffirin Lapongan. 1986. The occurrence of hybrid *Acacia auriculiformis* A. Cunn. ex Benth. in Sabah. In Proc. 9th Malaysian Forestry Conference, ed. H.S. Lee. Kuching, Sarawak: Forestry Department Malaysia.

Sedgley, M. 1987. Reproductive biology of *Acacia*. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 154-156. ACIAR Proceedings No. 16. Canberra: ACIAR.

Sedgley, M., H. Jane, and R.M. Smith . 1992. Hybridization techniques for *Acacia*. ACIAR Technical Report 20. 11 pp.

Sedgley, M., C.Y. Yong, N. Valerie, H. Jane, Smith, R.M., K.G. Koh, and Ahmad Tajuddin. 1992. Phenology of *Acacia mangium* and *Acacia auriculiformis* in Australia and Malaysia. In *Breeding Technologies for Tropical Acacias*, eds. L.T. Carron and K.M. Aken; 36-44. ACIAR Proceedings No. 37. Canberra: ACIAR.

Sherry, S.P. 1971. *The Black Wattle* (Acacia mearnsii *De. Wild.*). Natal, South Africa: University of Natal Press.

Skelton, D.J. 1980. Provenance seed collection of *Acacia mangium* Willd. in Western Province, Papua New Guinea. Working Paper No. 10 MAL/78/009. Sabah, Malaysia: Forest Research Centre.

Tanaka, Z. 1882. A variation of Pine. *Bull. Japanese For. Assoc.* 7.

Tham, K.C. 1976. Introduction to plantation species - *Acacia mangium* Willd. In *Proceedings of the 6th Malaysian Forestry Conference*, 11-17 October 1976, Kuching, Sarawak: Malaysia; 153-158. Sarawak: Forest Department.

_____. 1979. *Acacia mangium* Willd. as a plantation species in Sabah. Forest Genetic Resource Information No. 9, 32-35. Rome: FAO.

Turnbull, J.W., P.N. Martensz, and N. Hall. 1986. Notes on lesser-known Australian trees and shrubs with potential for fuelwood and agroforestry. In *Multipurpose Australian Trees and Shrubs: Lesser-known Species for Fuelwood and Agroforestry*, ed. J.W. Turnbull; 81-313. Canberra: ACIAR.

Turnbull, J.W., D.J. Skelton, M. Subagyono, and E.B. Hardiyanto. 1983. Seed collections of tropical acacias in Indonesia, Papua New Guinea and Australia. Forest Genetic Resources Information No. 12; 2-15. Rome: FAO.

Verdcourt, B. 1979. *Manual of New Guinea Legumes*. Botany Bulletin No. 11. Madang, Papua New Guinea: Kristen Press.

Wickneswari, R. 1989. Use of isozyme analysis in a proposed *Acacia mangium* x *Acacia auriculiformis* seed production orchard. *J. Trop. For. Sci.* 2(2):157-164.

Wright, J.W. 1976. *Introduction To Forest Genetics*. New York: Academic Press.

Yongbi, F. 1987. An overview of the application of isozyme analysis to genetic breeding of forest trees in China. *Commonwealth For. Rev.* 66(4):343-349.

Zakaria Ibrahim. 1991. Reproductive Biology of *A. mangium* Willd. and *A. auriculiformis* A. Cunn. ex. Benth. Ph.D. Dissertation, Universiti Pertanian Malaysia.

Zakaria Ibrahim and Kamis Awang. 1991. Comparision of floral morphology, flower production and pollen yield of *A. mangium* and *A. auriculiformis*. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 26-29. ACIAR Proceedings No. 35. Canberra: ACIAR.

_____. 1992. Flowering and fruiting phenology of *Acacia mangium* and *Acacia auriculiformis* in Peninsular Malaysia. In *Breeding Technologies for Tropical Acacias*, eds. L.T. Carron and K.M. Aken; 45-48. ACIAR Proceedings No. 37. Canberra: ACIAR.

Zobel, B.J. 1951. The natural hybrid between Coulter and Jeffrey pines. *Evolution* 5(4):405-413.

Zobel, B.J and J. Talbert. 1984. *Applied Forest Tree Improvement*. New York: John Wiley & Sons.

Zobel, B.J., G. Van Wyk, and P. Stahl. 1987. *Growing Exotic Forests*. New York: John Wiley & Sons.

Chapter 3

Genetics and Tree Improvement

Kamis Awang and Suree Bhumibhamon

Introduction

Agriculture and horticulture commonly make use of improved genetic materials (for example, with rubber, oil palm, cocoa, and a number of fruit trees) for higher yields and/or resistance to identified pests and diseases. The advantages of these higher yields and economic returns are readily understood by farmers.

These common gains from using improved seeds generally have not been obtained by forestry in most countries in Asia and the Pacific. Initial plantings of *Acacia mangium* outside its natural range have generally relied on unimproved materials, usually from a narrow genetic base. Consequently, the growth obtained is variable and tends to decline over several generations due to genetic erosion. In view of the increasing area being planted with *A. mangium*, improved materials need to be developed to safeguard this increasing investment. Furthermore, where the species is introduced for use by farmers, they must be assured of better planting materials with consistent, desirable characteristics.

Tree improvement research that combines developmental and operational phases is time consuming however, and has begun relatively recently with *A. mangium*. In many cases, the efforts have been skimpy, without clearly defined, long-term programs. Provenance studies were begun in many countries but follow-up has been lacking. This chapter provides an overview of what is known about genetic variation and tree improvement of *A. mangium* from such programs. Sexual and vegetative biology is not discussed, as these are covered in Chapters 2 and 4. Where statements are not referenced, they are based on the authors' own experience and observations.

Chromosome Characteristics

A plant's somatic chromosome complements can be regarded as a basic taxo-

nomic feature and described both in terms of chromosome number and morphology of the individual components. These karyotypic features can serve as additional information for taxonomic classification. They are usually constant in each somatic cell of an organism, in all populations of a species, and in most cases, in every individual of a species (Williams 1964; Zobel and Talbert 1984). Since *A. mangium* is known to hybridize, especially with *A. auriculiformis* (see Chapter 2), these karyotypic features can also be useful in hybrid identification.

Like many other Australian acacias, *A. mangium* possesses a somatic chromosome number of 2n=26 (Darus 1989; Nor Aini Shukor et al. 1992). Plate 3.1 shows the species' chromosome characteristics. The majority of the chromosomes are short. Although many plants have been observed to undergo chromosomal change when tissue cultured, this is not the case with *A. mangium*. Clonal propagation of this species by nodal cultures produces normal diploid plantlets (Darus 1989). Compared to *A. auriculiformis* and the hybrids of the two species, *A. mangium* has much greater chromosome length and volume (Table 3.1). Indeed, for both traits the average value in *A. mangium* is more than twice that in *A. auriculiformis*. Their hybrid shows intermediate values, but the fact that they increase from F1 to F2 suggests a greater influence of *A. mangium*.

Plate 3.1. *A. mangium* chromosome characteristics. *Photo*: L. Atipanumpai.

Table 3.1. Chromosome characteristics (means).

	Chromosome Somatic No.	Length (μm)	Volume (μm^3)
A. auriculiformis	2n=26	31.47	18.91
A. mangium	2n=26	64.14	44.39
F_1-hybrid	2n=26	37.98	28.58
F_2-hybrid	2n=26	43.52	34.42

Source: Nor Aini et al. (in press)

Provenance Variation

Genetic variability within a species is the basis for any tree improvement program. Improvement programs should start by determining the amount, cause, and nature of the variation in the species, and how this variation can best be used. Studies of variation in natural populations are a good starting point, but tests in plantation are also needed since phenotypic expressions are controlled by environment as well as by genetics.

As described in Chapter 1, *A. mangium* has a fragmented natural distribution stretching from the Moluccan islands in Indonesia to the Western Province of Papua New Guinea and northeastern Queensland in Australia. Many provenances have been identified, highly adapted to their local habitats. Although most consist of small populations, studies have shown that they vary in many respects (Yang and Chen 1984; Atipanumpai 1989; Likitwunnawut 1990; Harwood and Williams 1991; Lawskul 1991; Hadi 1992), reflecting the overall range in the species' genetic composition.

Seed Characteristics

Seed characteristics are genetically controlled and can therefore be used as a tool for identifying seed origin (Bhumibhamon 1979). A study by Likitwunnawut (1990) involving 13 provenances from Queensland, Australia, 2 from Papua New Guinea, and 1 from Ceram, Indonesia shows that seed size within each of these geographic regions is fairly similar, but varies distinctly between the regions (Table 3.2). Seeds from Papua New Guinea (PNG) are generally oblong in shape and are the largest, while those from Indonesia are round and are the smallest of the three. Similar results were reported on the same seedlots by Salazar (1989) in Costa Rica.

Seedling Growth Characteristics

A. mangium seed can germinate well after various treatments (soaking in hot water or acid, or mechanical scarification). As discussed in Chapter 5, the hot-

Table 3.2. Characteristics of *A. mangium* seeds from three countries.

Country of Origin	Length (mm)	Width (mm)	Weight (1,000 seeds) (g)
Australia	2.8-4.3	2.0-2.6	5.3-12.2
Papua New Guinea	3.6-4.5	2.3-2.9	8.0-15.8
Indonesia	3.1-3.4	2.0-2.3	5.4-7.8

Source: Likitwunnawut (1990)

water pretreatment method generally promotes fastest seed germination. Because of this pretreatment, interspecific variation in germination rate may not be detected in a germination study.

Following germination, true leaves appear and later develop into phyllodes. There are differences among provenances in the time needed for this development.

Yang and Chen (1984) found significant differences in the 7-month seedling height growth under nursery conditions of 21 provenances of *A. mangium*, ranging from 26.34-58.95 cm. Two provenances from PNG (Oriomo River and West of Morehead) showed the best growth, followed by two provenances from Queensland (Ellerbeck Rd. Cardwell and Broken Pole Creek), with the Indonesian provenances (Piru, Ceram, and Sidei) among the poorest performers. While the relationship between seedling height and latitude of their origin did not show continuous variation, three scattered provenance groupings did emerge, following the same pattern as described above for seed characteristics (Salazar 1989; Likitwunnawut 1990).

Leaf Characteristics

After germination, *A. mangium* produces compound leaves made up of minute leaflets. Research on provenance variation in the true-leaf characteristics is relatively scarce because these compound leaves develop into phyllodes very quickly. Experience suggests differences in the period of this development among seedlings from different seed origins, but nursery practices also account in part for these differences.

While phyllode shape and size can be easily assessed, provenance variation is difficult to detect, probably again due to the compounding effect of site fertility. Nonetheless, these characters are used to identify hybrids of *A. mangium* and *A. auriculiformis*. Four main veins run longitudinally from the phyllode's base to its tip, kept widely separated in the middle of the phyllode. Generally, all provenances show this same pattern of vein distribution, even with secondary veins.

Atipanumpai's (1989) study on the stomatal characteristics of *A. mangium* phyllodes showed that the species is amphistomatous, with numerous stomata regularly distributed on both surfaces. Average stomatal density was 265-450 stomata/mm^2, tending to be greater at the base of the phyllode on both surfaces. Stomatal density varied significantly among provenances (Table 3.3): Trinity Inlet, Queensland showed the highest density; West of Morehead, PNG showed the lowest.

Physiological Characteristics

A tree's physiological processes constitute the machinery through which heredity and environment operate to control growth (Kramer and Kozlowski 1979).

Table 3.3. Average abaxial stomatal frequency of phyllodes from 16 provenances.

CSIRO Seedlot Number	Provenance	Stomatal Density (No./mm^2)
12992	Rex Range NR Mosson, Queensland, Australia	378.8 b
13229	Claudie River, Queensland, Australia	375.9 b
13232	Cowley Beach Road, Queensland, Australia	394.0 d
13233	Walsh's Pyramid, Queensland, Australia	397.4 d
13234	Trinity Inlet, Queensland, Australia	420.9 e
13235	Mourilyan Bay, Queensland, Australia	375.0 b
13236	Kurrimine, Queensland, Australia	401.4 d
13237	El Arish, Queensland, Australia	375.0 b
13238	Tully Mission Beach Rd., Queensland, Australia	389.9 cd
13239	Syndicate Rd., Tully, Queensland, Australia	392.8 cd
13240	Ellerbeck Rd., Cardwell, Queensland, Australia	375.6 b
13241	Broken Pole Creek, Queensland, Australia	383.7 c
13242	Abergowrie Sf.,Queensland, Australia	390.5 cd
13459	W. of Morehead, Papua New Guinea	353.5 a
13460	Oriomo River, Papua New Guinea	383.3 bc
13621	Piru, Ceram, Indonesia	401.1 d

Values in a column followed by the same letter are not significantly different at 0.05 level, using Duncan's New Multiple Range Test. *Source:* Atipanumpai (1989)

Understanding physiological differences among natural populations of a species can thus be useful for developing a successful tree improvement program. Atipanumpai (1989) examined transpiration, photosynthesis, respiration, and nutrient uptake for 6 of the 16 provenances at Lad Krating Plantation, Chachoengsao, Thailand listed in Table 3.3 (Seedlots 13229, 13236, 13240, 13459, 13460, and 13621). The results are summarized below.

Transpiration Rate

Transpiration rate varied daily depending on air temperature or soil moisture content. Differences among provenances were significant. The Ceram provenance from Indonesia (No. 13621) consistently showed the highest rates (7.2-15.2 mg/cm^2/h for a 12-h period), and the Claudie River provenance (No.13229) from Queensland the lowest (4.7-10.5 mg/cm^2/h).

Transpiration rates of all provenances decreased remarkably when seedlings were subjected to drought, with the effect of water deficit on transpiration rate quite similar for all provenances. The leaf water potential of *A. mangium* can be as low as -2 MPa without causing injury to seedlings, and transpiration rate may still be detectable in such a situation. The Morehead provenance from PNG (No. 13459) seemed to be the most drought-resistant; it showed the best ability to conserve water under stress conditions.

Net Photosynthesis

Net photosynthesis reached a maximum (7.2-10.1 mg $CO_2/dm^2/h$) at around 24°C with a photon flux density near 600 umol/m^2/s. Genetic differences among provenances appeared in the rates of net and total photosynthesis, and photorespiration (Table 3.4). The Morehead provenance (No. 13459) from PNG showed an extremely low total photosynthetic rate, while the Indonesian provenance from Ceram (No.13621) had a remarkably high rate.

Nutrient Uptake

Due to the geographic separation of the natural populations, each provenance may be expected to have adapted to different edaphic conditions and thus absorb and use various nutrients differently. Atipanumpai's study indicated differences among the 16 provenances in their ability to accumulate potassium, calcium, and magnesium, but not nitrogen, phosphorus, and micro-nutrients (Table 3.5). This is expected to vary with site fertility; nutrient accumulation and utilization characteristics should be considered in provenance selection.

Flowering and Seed Production Characteristics

Research on flowering and seed production of different provenances of *A. mangium* is negligible. The only known study, by Lawskul (1991), used the same trial at Lad Krating studied by Atipanumpai (1989) to compare flower development of two four-year-old trees from each of three provenances: Ellerbeck Rd. Cardwell, West of Morehead, and Piru, Ceram. Flower and seed development was faster in the Indonesian provenance.

This study also indicated significant differences among the 16 provenances at Lad Krating in terms of the quantity of flowers and seed produced (Table 3.6). The five most prolific seed-producing provenances were all from Queensland: Syndicate Rd. Tully, Walsh's Pyramid, Cowley Beach Road, Rex Range NR Mosson, and Abergowrie St.

Wood Characteristics

Despite the fact that variations in wood properties significantly affect utilization, studies on provenance variation in terms of wood characteristics are scarce.

Pipatwattanakul (1989) examined provenance variation in the wood density of a six-year-old *A. mangium* trial at Lad Krating. With values of 0.3-0.4, differences among the 16 provenances studied were not significant.

Similar results were obtained in the species network trials conducted at 10 sites in 4 countries by scientists in the Multipurpose Tree Species (MPTS) Research Network, supported by the USAID-funded Forestry/Fuelwood Research and Development (F/FRED) Project. In those trials, there were no significant difference in wood density between the PNG (Boite) and Queensland (Iron Range) provenances of *A. mangium*. However, values obtained at the generally

Table 3.4. Average net photosynthesis, total photosynthesis, photorespiration, and dark respiration (all in $mgCO_2dm^{-2}/h$) of *A. mangium* for six provenances at different temperatures (°C) under saturation light intensity.

	Total photosynthesis				Net photosynthesis				Photorespiration				Dark respiration			
Temperature	18	24	30	36	18	24	30	36	18	24	30	36	18	24	30	36
Claudie River, QLD (13229)	10.00ab	11.09b	11.87b	11.81b	9.09b	9.99b	10.09b	9.35b	0.92a	1.10a	1.78a	2.46a	0.53a	1.00a	1.41a	1.95a
Kurrimine, QLD (13236)	10.26b	11.33b	11.52b	11.42b	9.42b	9.98b	9.78b	9.03b	0.85a	1.36a	1.74a	2.38a	0.48a	0.82a	1.16a	1.77a
Ellerbeck Rd., QLD (13240)	9.70ab	10.64ab	10.91b	10.80b	8.83b	9.22b	9.05b	8.33b	0.87a	1.42a	1.86a	2.47a	0.44a	0.82a	1.16a	1.62a
W. of Morehead PNG (13459)	8.24a	9.14a	9.33a	8.88a	7.21a	7.70a	7.45a	6.27a	1.03ab	1.44a	1.87a	2.61a	0.50a	0.88a	1.31a	1.90a
Oriomo River, PNG (13460)	9.28ab	10.61ab	11.06b	10.98b	8.32ab	9.07b	8.88b	8.18b	0.96ab	1.55ab	2.18ab	2.80ab	0.41a	0.80a	1.10a	1.60a
Piru, Ceram, IND (13621)	9.74ab	11.49b	12.05b	12.24b	8.27ab	9.29b	9.38b	8.87b	1.47b	2.21b	2.68b	3.36b	0.51a	0.89a	1.22a	1.80a

QLD = Queensland; IND = Indonesia; PNG = Papua New Guinea. Values in a column followed by the same letter are not significantly different at 0.05 level, using Duncan's New Multiple Range Test. *Source:* Atipanumpai (1989)

Table 3.5. Mean foliar nutrient concentrations of 30-month-old *A. mangium* by provenances at Lad Krating, Chachoengsao, Thailand.

Provenance	N	P	K	Ca	Mg	Zn	Mn	Fe	Cu	Na
	----------% in dry wt.----------					----------ppm in dry weight----------				
12992	2.533[a]	0.091[a]	1.282[bc]	0.594[cdef]	0.124[abcd]	20.31[a]	225.00[a]	181.25[a]	3.13[a]	0.064[a]
13229	2.315[a]	0.080[a]	1.016[ab]	0.556[abcdef]	0.132[abcde]	25.00[a]	212.50[a]	314.06[a]	7.81[a]	0.056[a]
13232	2.284[a]	0.092[a]	1.376[c]	0.438[ab]	0.130[abcde]	18.75[a]	170.31[a]	168.75[a]	9.25[a]	0.069[a]
13233	2.341[a]	0.092[a]	1.141[abc]	0.500[abcd]	0.106[a]	21.88[a]	190.63[a]	185.94[a]	10.94[a]	0.063[a]
13234	2.459[a]	0.091[a]	1.281[bc]	0.456[abc]	0.111[ab]	21.88[a]	259.38[a]	190.63[a]	9.38[a]	0.055[a]
13235	2.450[a]	0.076[a]	1.000[ab]	0.663[ef]	0.153[ef]	18.75[a]	242.19[a]	248.44[a]	10.81[a]	0.063[a]
13236	2.503[a]	0.085[a]	1.078[abc]	0.694[f]	0.160[f]	25.00[a]	267.19[a]	243.75[a]	12.50[a]	0.071[a]
13237	2.424[a]	0.080[a]	1.157[abc]	0.588[bcdef]	0.149[def]	20.31[a]	240.63[a]	170.31[a]	9.38[a]	0.069[a]
13238	2.407[a]	0.085[a]	1.282[bc]	0.563[abcdef]	0.124[abcd]	21.88[a]	190.63[a]	204.69[a]	9.38[a]	0.062[a]
13239	2.556[a]	0.093[a]	1.344[c]	0.463[abc]	0.130[abcde]	23.44[a]	192.19[a]	192.19[a]	9.38[a]	0.071[a]
13240	2.538[a]	0.084[a]	1.282[bc]	0.425[a]	0.122[abc]	17.19[a]	215.63[a]	217.19[a]	9.38[a]	0.060[a]
13241	2.429[a]	0.088[a]	1.203[abc]	0.531[abcde]	0.136[bcdef]	21.88[a]	218.75[a]	150.00[a]	12.44[a]	0.058[a]
13242	2.743[a]	0.098[a]	1.235[abc]	0.500[abcd]	0.149[def]	25.00[a]	246.88[a]	162.50[a]	14.06[a]	0.068[a]
13459	2.345[a]	0.083[a]	1.110[abc]	0.619[def]	0.146[cdef]	21.88[a]	175.00[a]	165.63[a]	10.94[a]	0.055[a]
13460	1.995[a]	0.069[a]	0.969[a]	0.581[bcdef]	0.128[abcde]	20.31[a]	193.75[a]	159.38[a]	10.94[a]	0.053[a]
13621	2.490[a]	0.089[a]	1.281[bc]	0.481[abcd]	0.117[ab]	23.44[a]	300.00[a]	171.88[a]	10.94[a]	0.057[a]

Values in column followed by the same letter are not significantly different at the 0.05 level of significance using Duncan's New Multiple Range Test. *Source* : Atipanumpai (1989)

Table 3.6. Provenance variation in flower and seed production, with means (±SE).

	Flower			Seed		
Provenance	Inflorescences	Spikes	Florets	Pods/clump	Seeds/clump	Seeds/pod
12992	679.1 a	33.0 ab	213.2 de	19.1 abc	106.5 bcde	5.7 cde
13229	550.1 ef	18.9 f	224.7 c	17.9 bcde	94.7 def	5.3 e
13232	681.8 ab	32.4 ab	217.9 cd	19.8 ab	111.2 bcd	5.6 cde
13233	680.1 ab	30.2 bcd	223.0 c	19.7 ab	121.8 ab	6.2 bc
13234	600.1 cde	28.0 cd	186.9 g	16.1 def	90.0 ef	5.7 cde
13235	632.2 abc	32.1 ab	223.4 c	18.8 abc	107.9 bcd	5.9 cde
13236	620.0 bcd	28.1 cd	219.7 cd	16.8 cdef	110.4 bcd	6.6 b
13237	609.7 cde	27.3 d	221.0 c	15.2 f	105.5 bcde	7.2 a
13238	620.3 bcd	30.8 bcd	209.4 e	18.8 bc	113.8 abc	6.0 bcd
13239	653.6 abc	34.6 a	253.4 a	21.2 a	127.8 a	6.0 cd
13240	511.8 fg	18.0 f	195.2 f	18.9 abc	102.1 cde	5.4 de
13241	655.6 abc	28.4 cd	236.0 b	14.8 f	82.2 f	5.6 cde
13242	691.2 a	31.1 abc	222.7 c	18.4 bcd	103.8 cde	5.8 cde
13459	682.4 ab	19.8 f	242.0 b	18.0 bcde	98.9 cde	5.7 cde
13460	485.6 g	23.2 e	238.0 b	15.7 ef	99.9 cde	6.6 b
13621	556.7 def	16.9 f	189.8 fg	18.0 bcde	105.3 bcde	5.9 cde
Mean	619.4±72.1	27.0±6.1	219.8±18.3	18.0±2.2	105.1±14.4	5.9 ±0.6

Values in a column followed by the same letter are not significantly different at 0.05 level, using Duncan's New Multiple Range Test. *Source*: Lawskul (1991)

drier ustic sites (0.6) were substantially higher than those at wetter udic sites (0.4).

In terms of heartwood formation, Bhumibhamon et al. (1992) found significant variation among five-year-old trees of 23 families of *A. mangium* from 7 seed sources. Families from Capt. Billy in Queensland had the greatest heartwood area; families from Oriomo River, PNG had the least. The estimation of narrow-sense heritability indicated that this wood property is strongly heritable.

Growth Performance in Provenance Trials

The success of plantation establishment and productivity is determined largely by the grower's choice of species and seed source (Larsen 1954; Callaham 1964; Lacaze 1978). Provenance trials to evaluate growth performance, stem form, and susceptibility to pests and diseases is the first step in a genetic improvement program component of plantation establishment. The primary aim of such trials is to identify suitable provenances for large-scale planting locally.

Strictly speaking, provenance trials should consist of three phases: range-wide provenance screening, restricted provenance screening, and provenance proving. For *A.mangium*, trials established in almost all countries where it has been introduced are still in the range-wide screening stage. Results of trials established in the 1980s and coordinated by the Food and Agriculture Organization of the United Nations (FAO) and the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) have been reported from China

(Chung et al. 1990), Indonesia (Hadi 1992), Malaysia (Johari and Chew 1987; Khamis 1991), Thailand (Atipanumpai 1989; Lawskul 1991), and Vietnam (Huynh and Nguyen 1992). Most of these have shown substantial differences in growth performance of different natural provenances.

Harwood and Williams (1991) completed a more comprehensive intersite analysis of those trials involving 24 provenances (Table 3.7) on 19 sites in 7 Asia-Pacific countries (Table 3.8). Significant differences were found in performance (height and dbh) between experimental sites, between provenance regions, and among the provenances within each provenance region. Table 3.9 summarizes the performance of the 5 provenance regions; Figures 3.1 and 3.2 illustrate the differences for the 'non-Borneo' sites. Growth was generally faster at sites near the Equator (with mean annual increment in height around 3-4 m) and slower at sites further from the Equator in Bangladesh, southern China, Taiwan (Republic of China), and Fiji. PNG provenances consistently performed best.

Table 3.7. Provenances in the *A. mangium* international provenance trials.

Provenance Location (CSIRO seedlot no.)*	Provenance region**	Lat. (°S)	Long. (°E)	Alt. (m)	No. parents***
Julatten (12990)	QCR	16 34	145 35	400	10
Daintree (12991)	QCR	16 17	145 31	60	10
Rex Range (12992)	QCR	16 30	145 32	30	10
Claudie River (13229)	FNQ	12 44	143 13	60	6
Mission Beach (13230)	QCR	17 53	146 06	5	10
NW of Silkwood (13231)	QCR	17 42	145 57	40	5
Cowley Beach (13232)	QCR	17 41	146 05	5	10
NE Walshs Pyramid (13233)	QCR	17 06	145 48	20	10
E of Cairns (13234)	QCR	17 02	145 48	20	10
Mourilyan Bay (13235)	QCR	17 35	146 05	20	5
Kurrimine (13236)	QCR	17 46	146 05	10	5
El Arish (13237)	QCR	17 50	146 01	20	10
Mission Beach (13238)	QCR	17 56	146 02	70	10
Tully (13239)	QCR	17 55	145 52	50	10
Cardwell-Ellerbeck (13240)	QCR	18 14	145 50	60	5
Broken Pole Creek (13241)	QCR	18 21	146 03	50	5
Abergowrie S.F. (13242)	QCR	18 26	146 01	60	10
Daintree (13279)	QCR	16 17	145 31	60	25
Morehead (13459)	PNG	8 45	141 25	30	20
Oriomo River (13460)	PNG	8 50	143 08	10	18
Cassowary Range (13534)	QCR	16 32	145 25	60	70
Piru, Ceram (13621)	CERAM	3 04	128 12	150	99
Sidei (13622)	IRIAN	0 46	133 34	30	15
Mossman (13846)	QCR	16 31	145 24	60	75

*Seedlot identified number used by CSIRO's Australian Tree Seed Centre. **QCR = Queensland Cairns region; FNQ = Far North Queensland; PNG = Papua New Guinea; IRIAN = Irian Jaya, Indonesia; CERAM = Ceram, Indonesia ***Number of parent trees represented in provenance seedlot. *Source*: Harwood and Williams (1991)

closely followed by the Claudie River provenance from Far North Queensland (FNQ). Provenances from the Queensland Cairns Region (QCR)(16-18°30'S) and the CERAM and IRIAN provenance regions in Indonesia were almost always slower-growing than those from PNG and FNQ.

Form assessment at four sites (Table 3.10) indicates substantial differences between sites and among the provenances at each site.

Likewise, the multisite species trials of the MPTS Research Network revealed a significant genotype x environment interaction effect on total wood production (Table 3.11). The two provenances (Boite, PNG and Iron Range, Queensland) were not stable across sites, suggesting the need to take into account characteristics such as biomass production, tree form, and growth performance in provenance selection. Provenances may respond consistently across sites in terms of height (Figure 3.1) and diameter (Figure 3.2) but not in other characteristics (Tables 3.10 and 3.11). However, the ultimate choice of selection traits depends very much on the planting objective.

The existence of provenance x environment interaction can be exploited for higher genetic gain. This results in a choice related to site adaptability: one can select either a single provenance that is broadly adaptable over a range of sites, or the most productive provenance at each site. This choice depends on the relative costs and benefits, and the avail-

Table 3.8. Trial site descriptions.

Site Code	Location	Lat.	Long.	Alt. (m)	MAT (°C)	MAP (mm)
SbA	Sabah, Malaysia	5°N	115°30'E	100	26	3100
SbB	Sabah, Malaysia	n.a.	n.a.	500	24	3100
SbC	Sabah, Malaysia	n.a.	n.a.	650	23	3200
SbD	Sabah, Malaysia	n.a.	n.a.	1300	20	2000
Sfoda	Sabah, Malaysia	6°55'N	117°05'E	n.a.	26	2600
Sw1	Sarawak, Malaysia	1°03'N	109°55'E	35	26	n.a.
Sw2	Sarawak, Malaysia	2°13'N	111°30'E	30	26	n.a.
Sw3	Sarawak, Malaysia	2°17'N	112°00'E	30	26	n.a.
Sw4	Sarawak, Malaysia	3°22'N	113°37'E	35	26	n.a.
Sw5	Sarawak, Malaysia	3°45'N	113°49'E	170	26	n.a.
Skl+	S. Kalimantan,Indonesia	3°S	115°E	20	26	2100
Sum	S. Sumatra, Indonesia	3°45'S	103°55'E	75	26	2600
Thai	Lad Krating, Thailand	13°42'N	101°06'E	80	28	1220
ChiL	Leilin, China	20°38'N	110°31'E	50	22.6	1473
ChiH	Haikang, China	20°55'N	110°06'E	n.a.	22.9	1701
Taiw	Chung-Pu, Taiwan	22°23'N	120°31'E	250	22.1	3056
Melv	Melville Island,Australia	11°34'S	130°34'E	20	25	1750
Fiji	Nukurua, Fiji	17°50'S	178°20'E	50	25	3000
Bdsh	Keochia, Bangladesh	22°06'N	92°05'E	n.a.	24	2590

MAT = mean annual temperature; MAP = mean annual precipitation; n.a. = not available;
+ after site code indicates approximate values only *Source*: Harwood and Williams (1991)

Table 3.9. Mean annual increment (MAI) in height (m) and dbh (cm) of provenance regions and overall site mean at each trial site.

	SbA	SbB	SbC	SbD	Sfoda	Swk1	Swk2	Swk3	Swk4	Swk5	Skl	Sum	Thai	Chi L	Chi H	Taiw	Melv	Fiji	Bdsh
Height																			
CERAM	3.80		4.15	3.52		1.92	2.10	1.80	2.71	3.43	3.62		3.06	0.76	1.54	2.04		1.76	0.84
IRIAN	3.60		3.99	3.31	2.68	1.88	2.13	3.21	3.52	3.58				0.78		1.83		1.39	
QCR	3.13		3.92	3.44	2.98	1.42	2.74	2.11	3.32	3.34	4.44	2.96	2.92	0.91	2.10	2.29		2.29	0.96
FNQ	3.64		4.19	3.69		2.17						2.93	3.33	1.14	2.22	2.70		2.80	
PNG			4.22		3.27							3.46	3.44	1.12	2.28	2.56		2.81	1.33
Mean*	3.30		3.98	3.46	2.98	1.63	2.68	2.05	3.18	3.40	3.88	3.05	3.02	0.93	2.07	2.30		2.26	1.02
DBH																			
CERAM	3.35	2.50	4.04	3.80		1.62	1.55	1.70	2.53	2.93	3.26	4.77		0.84	1.46	1.48	2.76	1.73	
IRIAN	3.10	2.38	3.80	3.37	2.85	2.36	3.07	2.13	3.21	3.54	3.29			0.83		1.54	2.47	1.19	
QCR	2.78	2.16	3.91	3.76	2.96	1.85	2.83	2.33	3.47	3.19	4.64	3.35	5.09	1.22	2.15	2.83	3.19	2.34	
FNQ	3.30	2.29	4.46	4.48		2.83						3.96	5.56	1.31	2.15	3.44	3.42	2.91	
PNG			4.30+		3.23							4.23	5.84	1.39	2.60	3.01	3.80	3.07	
Mean*	2.92	2.23	3.97	3.79	2.98	2.01	2.62	2.16	3.23	3.21	3.73	3.65	5.20	1.20	2.12	2.75	3.23	2.31	

* Mean of all local provenances tested at site
\+ PNG seed source, but not one of the two listed in Table 3.7. Not included in computation of site mean or across-sites ANOVA. *Source*: Harwood and Williams (1991)

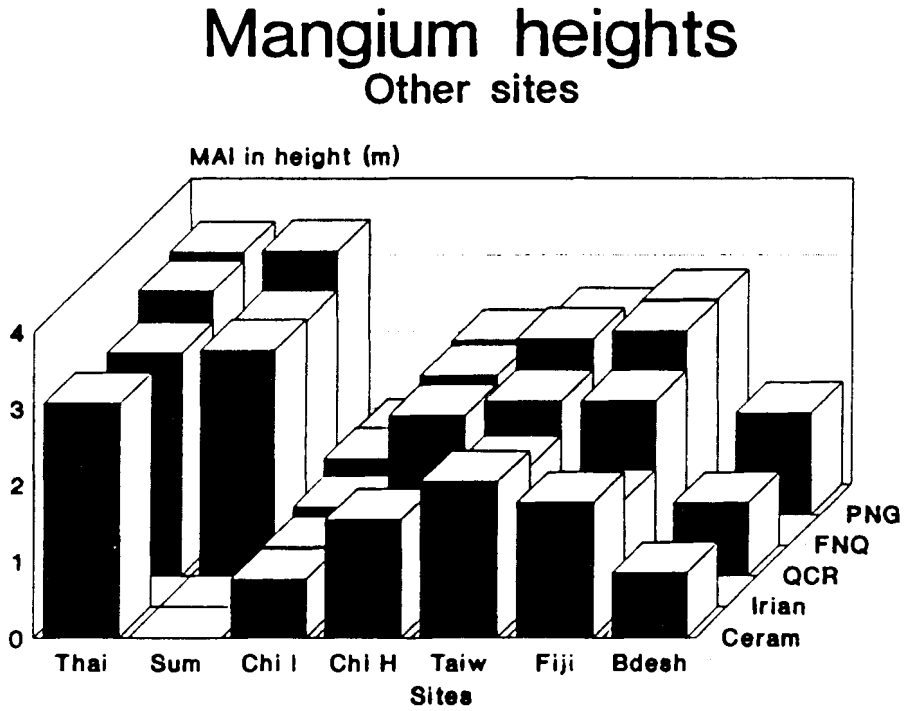

Figure 3.1. Mean annual increment in height of provenance regions at trial sites not on Borneo. *Source*: Harwood and Williams (1991)

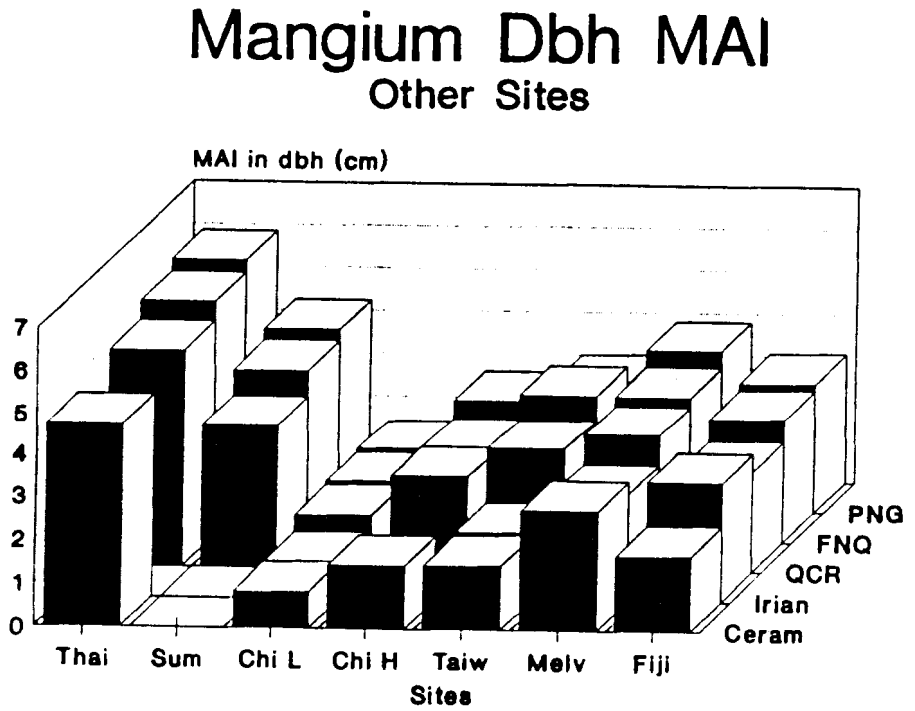

Figure 3.2. Mean annual increment in dbh of provenance regions for trial sites not on Borneo. *Source*: Harwood and Williams (1991)

Table 3.10. Percentage of trees with single stems at four trial sites, by provenance.

Prov. Region	Name	CSIRO seedlot no.	Sabah SbC	Sabah SbD	Melville Island Australia	Ivory Coast
QCR	Daintree	12991	34	18		
QCR	Rex Range	12992	51	13	41	
FNQ	Claudie River	13229	50	24	11	89
QCR	Cowley Beach	13232	44	22		
QCR	Walshs Pyramid	13233	47	26		84
QCR	E. of Cairns	13234			17	
QCR	Mission Beach	13238		48		17
QCR	Cardwell-Ellerbeck	13240		10		77
QCR	Broken Pole Ck	13241	45	33		76
PNG	Morehead	13459			22	
PNG	Oriomo River	13460			12	75
QCR	Cassowary Range	13534	51	37		
QCR	Mossman	13864				92
CERAM	Piru, Ceram	13621	42	23	1	56
IRIAN	Sidei	13622	66	33	12	69
PNG	n.a.*	-	47			
Sabah	(from plantation, Lahad Datu)	-	68		28	

*not available. *Source*: Harwood and Williams (1991)

ability of resources (Nickles 1991).

Undoubtedly, provenance affects the growth of a species at new sites where it is introduced. For example, Uddin (1990) showed that provenances of *A. mangium* collected from lower elevations performed very well at much higher elevations in the Philippines, a fact he attributed to higher rainfall. In contrast, provenances from higher elevations did not do well when planted at lower elevations.

Among the provenances of *A. mangium* planted in Vietnam, Kha and Nghia (1991) found that Kuranda and Bronted provenances grew best in La Nga where water drainage is very good during the rainy season. But in Bau Bang, where drainage is poor, the Kennedy provenance grew best.

Selection of Plus Trees

Selection of plus trees is an important step in tree improvement programs, particularly when interspecific provenance variation is relatively small. For industrial plantations (Plate 3.2), plus trees are commonly selected using the characteristics of:

Table 3.11. Mean total wood weight (kg) of two provenances of *A. mangium* at 36 months in multisite trials, for the interaction between sites and genotype under two moisture regimes.

Site	Site description	PNG	QLD
Udic			
Serdang, Malaysia	Soil: Coarse-loamy over clayey, siliceous, isohyperthermic Aqualfic tropofluvent; pH 5.3. Temp.: 22.0-32.8°C Rainfall: 2141 mm	10.24 (1.72)	5.63 (1.72)
Dramaga, Indonesia	Soil: Clayey, kaolinitic, isohyperthermic Typic Haplorthox; pH 5.0. Temp.: 21.3-31°C Rainfall: 3151 mm	16.05 (2.12)	14.04 (1.99)
Cikampek, Indonesia	Soil: Clayey, kaolinitic, isohyperthermic Rhodic Hapludult; pH 5.6 Temp.: 22.7-32.5°C Rainfall: 1385 mm	15.25 (2.52)	19.57 (2.13)
Hen Chun, Taiwan	Soil: n.a.*; Temp.: 21.8-28.3°C Rainfall: 2194 mm	12.65 (1.72)	10.86 (1.81)
Ustic			
Lad Krating, Thailand	Soil: Clayey-skeletal, kaolinitic, isohyperthermic Oxic Paleustult; pH 5.8 Temp.: 20.3-36.8°C Rainfall: 1244 mm	15.65 (2.85)	15.89 (2.85)
Ratchaburi, Thailand	Soil: Fine-loamy, mixed, isohyperthermic Ultic Hoplustalf; pH 5.8, Temp.: 23.4-35.0°C Rainfall: 983 mm	7.57 (2.99)	7.80 (2.85)
Uthai Thani, Thailand	Soil: Coarse-loamy, siliceous, isohyperthermic Typic Ustifluvent; pH 6.2 Temp.: 26.0-31.0°C Rainfall 1529 mm	24.78 (3.18)	21.51 (2.99)
Donglam, Thailand	Soil: Clayey, kaolinitic,isohyperthermic Oxic Paleustalf; pH 7.4. Temp.: 20.8-32.3°C Rainfall: 1612 mm	3.20 (2.85)	3.39 (2.99)

Values in parentheses respresent ± SE, using least square means. PNG = Papua New Guinea; Qld = Queensland, Australia. *Source*: Awang et al. 1992

- superior height
- greater diameter at ground level and breast height
- minimal stem taper
- straight stem
- small branches at a flat angle
- narrow, symmetrical crown
- few biotic enemies
- good pruning ability
- good wood properties, including high basic density

For urban planting, a wider crown and more persistent branches are preferable. Where fuelwood is a primary planting objective, multi-stemmed trees for maximum biomass are desirable.

Plus trees of *A. mangium* can be selected from natural stands, mature plantations, seed production areas, or even from provenance trials. Selection should start by identifying a large number of trees from which final plus trees are then screened. Ideally, clone or family banks are established from materials collected from the plus trees, followed by progeny testing. In practice, very few clone or family banks are established.

Systems of registering plus trees and testing their progenies vary from country to country. Both seeds and vegetative parts are used to raise plants for evaluating progeny performance. Such activities are currently underway in Indonesia, Malaysia, the Philippines, Taiwan (Republic of China), and Thailand. However, exchange of clonal or family materials among these countries is minimal.

Seed Stands, Seed Production Areas, and Seed Orchards

Improved seeds result in higher yields, good stem form, and/or resistance to identified pests and diseases. Still, most tree seeds planted in the Asia-Pacific region are collected from unclassified seed sources, and usually give variable performance and poor yields.

Some improvement in seed quality can be gained merely by collecting seeds from selected stands outside the species' natural range. For meeting

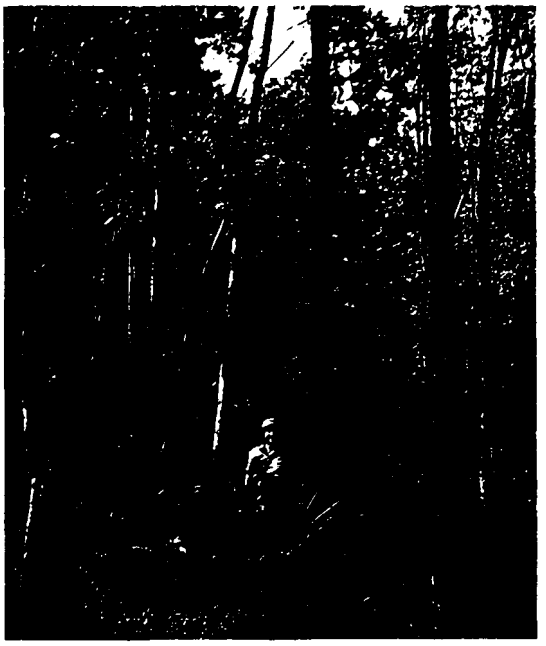

Plate 3.2. Potential plus tree at five years of age, Dramaga, Indonesia. *Photo*: K. Awang

current local demand for seeds, seed stands can be established in existing mature plantations by removing inferior phenotypes, controlling weeds, and applying fertilizer. Thinning stimulates the remaining trees to have large, healthy crowns for producing large seed crops. Isolating the stand from undesirable pollen sources can be difficult, but is desirable for better quality seed. Such improved stands can be classified as seed production areas.

Many existing plantations in the region have no registration of seed origin, and commonly have a narrow genetic base. To correct this for future seed demand, new seed production areas should be established using more seedlots from superior provenances. A new seed production area should be kept from outcrossing with outside pollen by completely surrounding it with an isolation zone or pollen dilution zone, and silvicultural treatments should begin at an early age. A seed production area thus established can provide better-quality seed than stands selected from existing plantations.

Three *A. mangium* seed production areas have been established in north Queensland, Australia using unselected individual-family seedlots from natural stands (Harwood et al. in press). Highly significant between-family differences have appeared, although family rankings were stable over the two FNQ sites. Stem form was generally poor, possibly due to intensive site preparation. Nonetheless, some genetic improvement over seed from natural stands may be anticipated for two reasons; reduced inbreeding, and removal of inferior phenotypes by selective thinning. The authors also noted that an initial spacing of 5 x 2 m would appear to be better for *A. mangium* than the 3 x 1.8 m spacing used at these sites.

The seed orchard approach is the standard method of producing genetically improved seed in operational quantities (Andersson 1960, cited by Zobel and Talbert 1984). Feilberg and Soegaard (1975) define *seed orchard* as a plantation of selected clones or progenies that is isolated or managed to minimize pollination from outside sources, and managed to produce frequent, abundant, and easily harvested crops of seed. Generally in Asia, the germplasm, budget, and qualified staff required for continuous and progressive seed orchard work are not available. Where this is the case, the ultimate goal of an intensive breeding program cannot be reached.

A few *A. mangium* seed orchards have been established in Australia (Harwood et al. in press), Indonesia (Wong in press; Suhaendi in press), Malaysia (Sim 1992), the Philippines (Pettersson and Havmoller 1984), Taiwan (Republic of China)(Pan, pers. comm.), and Thailand (Bhumibhamon and Atipanumpai 1992). Most of these are first-generation seed orchards from which high-quality seeds cannot be obtained easily. Often, pollination among clones or families in the seed orchard are not well synchronized.

The seedling seed orchard has been the most commonly established type in the past decade or so. Sabah Softwoods Sdn. Bhd. (SSSB) pioneered in this, starting theirs in 1980 (Sim 1984). Other early seed orchards of this type were

established by Swedish Match in the Philippines (Pettersson and Havmoller 1984) and PT Indah Kiat Pulp and Paper Corporation in Indonesia (Wong in press). With more intensive breeding underway and increasing use of vegetative propagation, clonal seed orchards are also being established. For example, SSSB has established bi-clonal seed orchards using selected and improved *A. mangium* and *A. auriculiformis* to produce naturally crossed hybrid seeds (Chia in press).

In Thailand, a seed orchard consisting of 20 selected, open-pollinated families (15 from Australia, 4 from PNG, and 1 from a plantation in the Philippines) has been established in Chachoengsao Province under a joint program by Thai Plywood Company and the Faculty of Forestry, Kasetsart University (Bhumibhamon and Atipanumpai 1992). The families have shown significant differences in height, diameter, crown growth, and flower production. Flowering occurred at only 28 months. The families from PNG were the most prolific flower producers. The narrow-sense heritability values obtained were quite high, indicating that the characteristics were strongly inherited and significant gains can be expected from selection. Height growth had the lowest heritability (0.19), while flowering was the most strongly inherited characteristic (0.98).

Elements of a Breeding Plan

For best results, a tree improvement program must define a breeding plan and follow it. A comprehensive plan will review achievements, consider all resources, and specify objectives and options that provide for:

- choice of species and provenances
- acquisition of potentially useful genetic material
- vigorous implementation of interim, simple measures for early, local production of improved propagules
- estimation of genetic parameters
- specification of selection criteria; selection, breeding, and propagation methods; and a schedule of operations
- control of inbreeding, and maintenance of variation and a large effective population size
- monitoring of genetic technologies
- establishment of systems for data collection, management analysis and interpretation, and communication of results
- assignment of responsibilities
- development of a suitable administrative framework and enhancement of human resources, skills, and technologies (Nickles 1991)

A breeding plan must consider the resources available, the appropriate level of effort for each of these resources, and the relative importance of individual

species being managed (Nickles 1985). Simple strategies are often most appropriate, especially in the early stages of a breeding program, and where several species are involved (Barnes 1984; Griffin 1989). Flexibility is an important element of such a plan, which should be revised from time to time on the basis of increasing knowledge and experience.

Various breeding strategies for *A. mangium* have been adopted in the Asia Pacific region, reflecting differences in available resources, program objectives, and stage of breeding. These plans range from simple strategies for mass production of *A.mangium* in Sabah (Monteuuis and Nasi 1992) to more integrated ones in the Philippines that include hybridization with *A. auriculiformis*, *A. crassicarpa*, and *A. leptocarpa* (Pettersson and Havmoller 1984).

Research and Development

Some progress has been made in the genetic improvement of *A. mangium* through the efforts of private and state agencies and state enterprises. For long-term benefits, these activities should be clearly defined by strategic breeding plans. Much remains to be done to realize the species' potential. The following are some suggestions.

1. Intensively explore more genetic materials from natural stands. Since little ecological genetic research has been done, collections could be combined with studies on stand structure and reproductive system under natural conditions.

2. For *ex situ* gene conservation programs, obtain more seed of the superior provenances for particular sites identified in the range-wide provenance trials already conducted. The materials can be used to establish new seed production areas. Large-scale industrial plantations should use the material for restricted provenance trials.

3. Select more plus trees for clone and family studies. This can be done from provenance trials, mature plantations, or *ex situ* gene conservation areas. Clones or families can also be used to establish clone or family banks for evaluating growth performance, flowering characteristics (including synchronization), controlled pollination, and seed ontogeny. This would be followed by more progeny testing.

4. Conduct physiological studies to determine: how *A. mangium* can produce great quantities of biomass when planted in *Imperata* grassland; the relationship between physiological processes and biomass productivity, and the influence of genetic factors; what physiological changes take

place when the species is planted in drought-prone, flooded, saline, or acidic areas. Also, more intensive work on the role of plantations as "carbon sinks" should be studied.

5. Establish advanced generation seed orchards using selected materials that have the combined characteristics desired for high-quality seeds.

6. Increase the exchange of genetic materials and experiences between countries for more cost-effective tree improvement with greater impact.

7. Conduct further studies on biotechnological research, particularly in combining superior genetic materials with selected strains of rhizobia and/or mycorrhizal fungi.

8. In all breeding strategies, emphasize development of materials that are resistant to heart rot.

Summary

A. mangium possesses a somatic chromosome number of 2n=26, with a greater proportion of the chromosomes of the short type.

Provenance differences exist in many characteristics, reflecting the variation in the total genetic composition of the species.

Seeds of Papua New Guinean provenances are generally oblong in shape and larger than those from Queensland and Indonesia; seeds of Indonesian provenances are round and relatively the smallest; Queensland provenances are intermediate. Seedling growth follows the same pattern.

In *leaf characteristics*, little provenance variation is found in terms of phyllode shape, size, and veination. However, stomatal density varies significantly.

Physiological processes of transpiration, photosynthesis, and nutrient uptake also vary. PNG provenances appear more drought resistant, but with lower photosynthetic rates than Indonesian provenances studied. Nutrient uptake differs in K, Ca, and Mg, but not in N, P, and micronutrients.

In terms of *flowering and seed production*, development time is shorter for Indonesian provenances, although those from Queensland produce the most seed.

Heartwood formation varies significantly with provenance, but not basic density.

Growth in provenance trials shows a significant interaction of site x provenance. In general, growth is faster near the Equator. PNG provenances consistently show better height, diameter, and form; they are closely followed by the Claudie River provenance from far north Queensland. Provenances from the Queensland Cairns region and Ceram and Irian Jaya, Indonesia are almost always slower-growing than those from PNG and far north Queensland.

Plus tree selection has taken place in several countries where *A. mangium* is planted on a large scale, and progeny testing of the selected materials is underway. There are country-by-country differences in how seed stands, seed production areas, and seed orchards are developed. Growth and flowering have been found to differ among different families in a seed orchard.

Research and development needs include the following: further seed collections from natural stands, both of unexplored provenances and those identified as superior in earlier range-wide studies; selection of plus trees; physiological studies; establishment of advanced-generation seed orchards; greater exchange of germplasm and results internationally; and breeding for resistance to diseases such as heart rot.

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References

Aupanumpai, L. 1989. *Acacia mangium*: studies on the genetic variation in ecological and physiological characteristics of a fast-growing plantation tree species. *Acta Forestalia Fennica* 206. 90 pp.

Awang, K., S. Bhumibhamon, B. Boontawee, K. MacDicken, M.L. Ngah, F.J. Pan, B. Purikorn, J. Quimio, R. Raros, K. Soemarna, D. Wahjono, and K. Wisupakarn. 1992. Draft 36-month intersite analysis of data from the 1987 humid/subhumid zone network trials. Report submitted to the MPTS Research Network Secretariat, Bangkok. Winrock International.

Barnes, R.D. 1984. A multiple population breeding strategy for Zimbabwe. In *Provenance and Genetic Improvement Strategies in Tropical Forest Trees*, eds. Barnes, R.D. and G.L. Gibson; 619-632. Oxford: Commonwealth Forestry Institute and Forest Research Centre, Harare.

Bhumibhamon, S. 1979. *Forest Tree Seeds in the Tropics*. Bangkok: Faculty of Forestry, Kasetsart University. (In Thai.)

Bhumibhamon, S., V. Thavorn, and R. Swatdipakdi. 1992. Variation in heartwood formation of *Acacia mangium*. *MPTS Research Notes* 2(3):1-2.

Bhumibhamon, S. and L. Atipanumpai. 1992. Family variation in growth and some morphological characteristics of *A. mangium* grown in Thailand. In *Biotechnology for Forest Tree Improvement*; 155-162. BIOTROP Special Publication No. 49. Bogor, Indonesia: BIOTROP.

Callaham, R.Z. 1964. Provenance research: investigation of genetic diversity associated with geography. *Unasylva* 18(2-3):73-74, 40-50.

Chia, E. In press. Recent developments in acacia improvement at Sabah Softwoods. In *Acacias for Rural, Industrial, and Environmental Development*, proc. of the Second Meeting of the Consultative Group for Research and Development of Acacias, February 15-18, 1993, Udorn Thani, Thailand. Bangkok: FAO and Winrock International.

Chung, J.D., Y.R. Hsui, T.Y. Chang, and J.C. Yang. 1990. Provenance variation of tree height, dbh and volume in *A. mangium* at young ages. *Qtrly J. Chinese For.* 23:77-86.

Darus Haji Ahmad. 1989. Growth performance and chromosome count of *Acacia mangium* plantlets derived from cultured nodal explants. *J. Trop. For. Sci.* 1(3):263-267.

Fellberg, L. and B. Soegaard. 1975. *Historical Review of Seed Orchards*. Forestry Comm. Bull. No. 54. London: Her Majesty's Stationery Office.

Griffin, A.R. 1989. Strategies for the genetic improvement of yield in *Eucalyptus*. In *Biomass Production by Fast-Growing Trees*, eds. Pereira, J.S. and J.J. Landsberg; 247-265. Amsterdam: Kluwer Academic Publishers.

Harwood, C.E., G. Applegate, K. Robson, and E.R. Williams. In press. Early growth of provenance and progenies in *Acacia mangium* seed production areas in north Queeensland, Australia. In *Acacias for Rural, Industrial, and Environmental Development*, proc. of the Second Meeting of the Consultative Group for Research and Development of Acacias, February 15-18, 1993, Udorn Thani, Thailand. Bangkok: FAO and Winrock International.

Huynh, D.C. and Q.D. Nguyen. 1992. *Acacia mangium* - what provenaces are the most promising. Forest Research Newsletter 1:16-17. Bai Bang-Vinh Phu, Vietnam: Forest Research Centre.

Johari Baharudin and T.K. Chew. 1987. Preliminary performance of *Acacia mangium* international provenance trial in Peninsular Malaysia. *Malaysian Forester* 50:9-28.

Kha, L. D. and N. H. Nghia. 1991. Growth of some *Acacia* species in Vietnam. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 173-176. ACIAR Proceedings No. 35. Canberra: ACIAR.

Khamis Selamat. 1991. Trials of *Acacia mangium* at the Sabah Forestry Development Authority. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 224-226. ACIAR Proceedings No. 35. Canberra: ACIAR.

Lacze, J.F. 1978. Advances in species and provenance selection. *Unasylva* 30(119-120):17-20.

Larsen, C.S. 1954. Provenance testing and forest tree breeding. In *Proc. 11th Congress of IUFRO*, Rome; 467-473.

Lawskul, S. 1991. Provenance trials of *Acacia mangium* Willd. at Lad Krating, Chachoengsao. M.Sc. (For.) Thesis, Kasetsart University, Bangkok, Thailand. 108 pp.

Likitwunnawut, U. 1990. Variability on seed morphological characteristics and seedling performances of *Acacia mangium* Willd. M.Sc. (For.) Thesis, Kasetsart University, Bangkok, Thailand. 95pp.

Monteuuis, O. and R. Nasi. 1992. Possible mass production options for *Acacia mangium* plantations in Sabah (Malaysia). Paper presented at IUFRO Symposium on Mass Production Technology for Genetically Improved fast Growing Forest Tree Species. September 14-18, 1992, Bordeaux, France. 14 pp.

Nickles, D.G. 1985. Tree improvement: genetic resources-strategies. In *Research for Forest Management*, eds. Landsberg, J.J. and W. Parsons; 159-174. Canberra, Australia: CSIRO, Division of Forestry Research.

_____. 1991. Developing successful forest tree plantations in Asia, with special reference to genetical aspects. In *Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia*; proc. of a regional symposium held June 5-9, 1989, ed. Sheikh Ali Abod et al.; 137-155. Serdang, Malaysia: Universiti Pertanian Malaysia.

Nor Aini Shukor, Mansur Rashid, and Khairuddin Itam. In press. Karyoptypic comparison of *Acacia mangium* Willd., *A. auriculiformis* A. Cunn ex Benth and their F1 and F2 hybrids. *Sylvae Genetica*.

Pettersson, H. and P. Havnoller. 1984. Provenance tests and breeding strategies for *Acacia mangium* and *Eucalyptus* spp. in Philippines and India. In *Provenance and Genetic Improvement Strategies in Tropical Forest Trees*, eds. Barnes, R.D. and G.L. Gibson; 432-435. Oxford: Commonwealth Forestry Institute and

Forest Research Centre, Harare.

Pipatwattanakul, D. 1989. Provenance variation in basic wood density of *Acacia mangium* Willd. at Lad Krating Plantation, Chachoengsao. M.Sc.(For.) Thesis, Kasetsart University, Bangkok, Thailand. 72 pp.

Salazar, R. 1989. Genetic variation of 16 provenances of *Acacia mangium* at nursery level in Turrialba, Costa Rica. *Commonwealth For. Rev.* 68(4): 263-272.

Sim, B. L. 1984. The genetic base of *Acacia mangium* Willd. in Sabah. In *Provenance and Genetic Improvement Strategies in Tropical Forest Trees*, eds. Barnes, R.D. and G.L. Gibson; 597-603. Oxford: Commonwealth Forestry Institute and Forest Research Centre, Harare.

Suhaendi, H. In press. *Acacia mangium* improvement for industrial forest plantation in Indonesia. In *Acacias for Rural, Industrial, and Environmental Development*, proc. of the Second Meeting of the Consultative Group for Research and Development of Acacias, February 15-18, 1993, Udorn Thani, Thailand. Bangkok: FAO and Winrock International.

Tjuk Sasmito Hadi. 1992. A study on provenance variation in *Acacia mangium* Willd. at Riam Kiwa, South Kalimantan, Indonesia. M.Sc. Thesis, Faculty of Agriculture and Forestry, University of Helsinki, Finland. 70 pp.

Uddin, Md. F. 1990. Provenance trials of mangium (*Acacia mangium* Willd.) in the Philippines. Ph.D. Dissertation, University of the Philippines at Los Baños, College of Forestry (unpublished).

Williams, W. 1964. *Genetical Principles and Plant Breeding*. Oxford: Blackwell Scientific Publications.

Wong, C.Y. In press. Acacias for industries. In *Acacias for Rural, Industrial, and Environmental Development*, proc. of the Second Meeting of the Consultative Group for Research and Development of Acacias, February 15-18, 1993, Udorn Thani, Thailand. Bangkok: FAO and Winrock International.

Yang, J. C. and Z. Z. Chen. 1984. Seedling height growth of *Acacia mangium* from different provenances. Taiwan Forestry Research Institute Bulletin No. 423. Taipei: TFRI.

Zobel, B. and J. Talbert. 1984. *Applied Forest Tree Improvement*. New York: John Wiley and Sons.

Chapter 4

Vegetative Propagation

Darus Hj. Ahmad

Introduction

Where conditions permit, macropropagation (from stem cuttings) and micropropagation (from aseptically germinated seedlings) offer several advantages over traditional nursery propagation from seed. For suitable species, it is a valuable short cut to genetic gain in breeding programs, and in plantations can increase product homogeneity and growth. Use of clones is also an advantage when seed is difficult to handle or short-lived. Horticulturists have practiced macropropagation of woody plants by stem cuttings for many centuries, rooting cuttings from healthy plant stock to multiply plants of known characteristics. Micropropagation of woody species has been employed increasingly in the last two decades, using adventitious shoots, callus cultures, somatic embryogenesis, and multiplication of existing meristem. *Acacia mangium* shows promise for both macropropagation and micropropagation for commercial-scale plant production.

This chapter describes various techniques of these two methods of asexual propagation of *A. mangium* and examines principal factors that affect their success.

Macropropagation and Factors Affecting Rooting

Macropropagation generally uses cutting materials excised from healthy, moderately vigorous stock plants growing in good environmental conditions and having ample food reserves to nourish root and shoot development until the new plant can sustain itself. Stem cuttings from weak stock (thin stems and long internodes) usually root slowly and poorly, and should be rejected.

Of the many factors that affect the success of rooting of stem cuttings, choice of species appears to be the main one (Girouard 1974; Komissarov 1964). Other factors include type of cutting materials, time of year when cuttings are excised, and such environmental factors as air temperature and humidity (Hartmann and

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Kester 1983). Suitable age of cutting materials, rooting medium, and application of growth substances are also essential for good rooting (Whalley 1979).

Stock Plants

Stock plants are commonly raised in black polythene bags. However, for a continuous supply of cutting materials, stock plants should be permanently planted in a bush garden at a planting distance of 1 x 1 m. They should be fertilized every two to three months using commercial compound fertilizers such as NPK Blue, and need regular pruning to induce multiple leaders. Occasional tilling of the planting site avoids soil compaction around the plants.

Cutting Materials

Stem cuttings of selected *A. mangium* seedlings are cut into single-node cuttings approximately 4-5 cm long and 0.5-1.5 cm in diameter, depending on the age of the seedling. Every portion of the stem within this diameter range is normally used for rooting. Each stem cutting should have one phyllode, either whole or cut transversely into half size. Terminal nodes are succulent and liable to rot in the rooting bed, and should be avoided. The basal portion of cuttings should be cut at an oblique angle to increase wound surface area for greater absorption of water and applied growth substances.

Environmental Conditions of Rooting Chambers

Cuttings should be placed in a humidified rooting chamber in which air temperature is maintained at an average of 28°C during both day and night. Intermittent mist sprayers, controlled by an electronic "leaf," can be installed in the rooting chambers to maintain high humidity. Stem cuttings of *A. mangium* require about 70-90% air humidity.

Effect of Seedling Age

The age of stock plants from which cuttings are taken is the most important single factor affecting root formation. Cuttings of difficult-to-root species are normally rooted more easily from younger stock plants than from older stock. For *A. mangium*, rooting percentage decreases significantly with older stock plants. For example, cuttings taken from 6- and 12-month-old seedlings give a higher rooting percentage than those taken from 18- and 24-month old seedlings (Table 4.1). Similar results are reported for *A. catechu* and *A. decurrens* (Nanda et al. 1970) and some tropical hardwood species, including *Shorea bractoelata*, *S. leprosula*, and *Dipterocarpus chartaceus* (Srivastava and Penguang Manggil 1981).

Table 4.1. Rooting percentage of *Acacia mangium* stem cuttings (n=80) in relation to the age of stock plant (±SE of mean).

Age of stock plants at time of cutting	Total rooted cuttings	Rooting percentage	
6 months	57	71.3	(4.6)
12 months	52	65.0	(5.2)
18 months	25	31.3	(2.1)
24 months	12	15.0	(1.7)

Source: Darus (1990)

The decline in percentage of rooting of stem cuttings from older stock plants may be due to anatomical features such as sclerenchymatous cells, which obstruct adventitous root initiation and are always present in older trees. Histological studies of one-year-old *A. mangium* seedlings clearly showed the presence of a continuous layer of sclerenchymatous cells (Darus 1989). At that age it did not affect rooting of cuttings, but as seedlings get older this layer may become thicker and a barrier to the initiation and emergence of adventitous roots. Other possibile causes are physiological changes (for example, lack of balance between growth regulator level and certain growth co-factors) and the presence of growth inhibitors.

Effect of Phyllode Number and Trimming

The presence of phyllodes on stem cuttings of *A. mangium* is very important to successful rooting. Table 4.2 shows that stem cuttings with either one phyllode or with a half phyllode tend to root better than cuttings with two or no phyllodes. Similar findings are reported for *Eucalyptus camaldulensis* (Geary and Harding 1984) and *Liquidambar stryracifolia* (Bilan 1974).

The failure of leafless cuttings to root well may be due to a lack of carbohydrate production required by the stem tissues involved in root formation, as found

Table 4.2. Rooting percentage of one-year-old *A. mangium* stem cuttings (n=50) in relation to phyllode presence (±SE).

Number of phyllodes	Total rooted cuttings	Percentage	
0	6	12.0	(2.1)
0.5	38	76.0	(7.5)
1	33	66.0	(9.3)
2	23	46.0	(2.4)

Source: Darus (1990)

by Leakey et al. (1982) in the case of *Triplochiton scleroxylon* leafless cuttings. On the other hand, although leaves are important for rooting, the high mortality of *A. mangium* cuttings with two entire phyllodes may be due to a higher loss of water from phyllodes through transpiration, resulting in death before root formation could take place. Avidan and Lavee (1978) reported that leaves on stem cuttings also produce a higher concentration of growth inhibitor which can depress root formation.

Influence of Growth Substances

Synthetic growth substances (for example, indole-butyric acid, or IBA) can enchance rooting of cuttings of many woody species. For many tree species, stem cuttings treated with hormones respond better than cuttings without hormones. Table 4.3 shows that growth substances generally improve the rooting performance of *A. mangium* stem cuttings. Cuttings treated with 500 and 1,000 ppm of IBA and Seradix 3, a hormone rooting powder, showed better rooting.

Table 4.3. Rooting percentage of one-year-old *A. mangium* stem cuttings (n=50) with and without hormone treatments (±SE).

Treatment	Total rooted cuttings	Total non-rooted cuttings	% rooted cuttings	
Control	18	8	36.0	(2.3)
Rooting powder	33	5	66.0	(8.9)
500 ppm IBA	38	7	76.0	(6.5)
1,000 ppm IBA	34	5	68.0	(3.6)
1,500 ppm IBA	30	6	60.0	(8.6)
2,000 ppm IBA	23	7	46.0	(7.3)
500 ppm IBA	25	7	50.0	(5.2)
1,000 ppm NAA	30	7	60.0	(12.8)
1,500 ppm NAA	26	7	52.0	(4.7)
2,000 ppm NAA	17	8	34.0	(6.5)

Source: Darus (1991)

The effectiveness of these growth substances, especially at lower concentrations, might be caused by an initiation of morphological changes on the tissues responsible for root formation at the base of the cuttings. It may also be due to increased transportation of photosynthates and other products (for example, endogenous growth regulators) from leaves to tissues involved in root formation. The effect-iveness of Seradix 3 may be related to the following facts:

its constituents 0.8% IBA and a small amount of fungicide protect cuttings from fungal attack and

- when the cuttings are dipped into the powder, the bottom ends remains covered, possibly giving a longer-lasting effect for root formation.

Effect of Rooting Medium

A good rooting medium should have:

- high water-holding capacity
- a suitable pH value for rooting
- sufficient porosity to allow efficient aeration
- good drainage
- no harmful pathogens

The most commonly used rooting media for stem cuttings of woody species are sand, vermiculite, and peat. They are best when used in combination.

For *A. mangium* , the most suitable medium for rooting is a mixture of river sand and Irish sphagnum peat in equal proportion (Table 4.4). Although river sand was the least successful medium for this species,some reports note that this medium is quite suitable for stem cuttings of *Araucaria hunsternii* (Darus 1982), *Shorea bracteolata* (Srivastava and Manggil 1981), and *Gmelina arborea* (Zakaria and Ong 1982).

The differences in performance of different rooting media are probably due to differences in pH and water-holding capacity (moisture content)(Table 4.5). Howland (1975) demonstrated the importance of higher pH values (5.8- 7.4) for

Table 4.4. Rooting percentage of one-year-old *A. mangium* stem cuttings (n=50) in four different rooting media (±SE).

Rooting medium	Total rooted cuttings	Total non-rooted cuttings	Dead cuttings	Rooting percentage	
River sand	8	16	26	16.0	(4.0)
River sand: Irish sphagnum peat (1:1)	33	5	12	66.0	(9.2)
River sand: Vermiculite (1:1)	15	19	16	30.0	(5.5)
River sand: Irish sphagnum peat: Vermiculite (1:1:1)	8	9	33	16.0	(4.0)

Source: Darus (1988)

Table 4.5. Moisture content and pH value of four rooting media (±SE).

Testing medium	Moisture content (%)		pH	
Sand	6.3	(0.3)	4.8	(0.1)
Sand : Peat (1:1)	22.2	(0.5)	5.7	(0.1)
Sand : Vermiculite (1:1)	25.0	(0.8)	4.7	(0.1)
Sand : Peat : Vermiculite (1:1:1)	44.6	(1.6)	5.2	(0.1)

Source: Darus (1988)

rooting in *Triplochiton* stem cuttings by showing that media with low pH values of 4.0-4.8 (such as 100% peat or a 1:1 mixture of sand and peat) gave rooting percentages of only 15-50%, while adjustment of media pH to 5.8 or near to neutral improved rooting to 80%.

A medium's water-holding capacity is clearly correlated to both rooting success and mortality rate (Tables 4.4 and 4.5). Low moisture content in 100% sand can induce water stress in cuttings, slows root formation, and increases mortality rate. On the other hand, when moisture content is too high, cuttings tend to rot and root formation is slowed.

Potting and Maintenance of Rooted Cuttings

Rooted cuttings are usually transplanted into polythene bags immediately after some lignification has taken place in the roots. If transplanting is done before this, the non-lignified roots can be easily broken and the plants will die. The time required to reach this stage of root lignification varies with species. For many dipterocarps, it is about 10-12 weeks. For *A. mangium*, 4-5 weeks are sufficient (Darus and Aminah 1993).

For potting, the medium commonly used at Forest Research Institute of Malaysia is a 1:3 mixture of sieved river sand and forest top soil. Ground magnesium limestone (at a rate of 1.6 kg/m^3) and triple superphosphate (46% P_2O_5)(at a rate of 1.2 kg/m^3) are added to the mixture.

The potted cuttings are weaned in shade for one month before being transferred to transplanting beds with 50-60% light intensity. When they reach 3-4 months of age, they are fully exposed to sunlight. Compound fertilizers, such as NPK Blue (15:15:15) are applied at a rate of 1 g/plant per month, starting one month after potting.

Micropropagation and Factors Affecting Shoot Development

Although micropropagation techniques are considered new in forestry and are still in the development stage, a number of forest species including four acacias—*A. koa* (Skolmen and Mapes 1976), *A. melanoxylon* (Mayer and Staden 1987), *A. nilotica* (Mathur and Chandran 1983), and *A. albida* (Dohoux and Davies 1985)—have been successfully propagated through *in vitro* cultures.

The four main micropropagation techniques are: multiplication of existing meristem, multiplication by adventitious shoot production, multiplication through callus cultures and shoot regeneration, and somatic embryogenesis. Of these, production of plantlets from existing meristem is the most commonly used, especially on a commercial scale. It is easy to carry out and requires less time to mass produce genetically stable plantlets identical to the mother plants.

Aseptically Germinated Seedlings

A. mangium seeds are normally pretreated with hot water (80-90°C) and left at room temperature for 24 hours. For culture of nodal explants, they are subsequently surface-sterilized with 10% (v/v) Domestos for 30 minutes and washed with sterile-distilled water before culturing into sterilized bottles containing a half-strength Murashige and Skoog's basal medium (MS)(Murashige and Skoog 1962). These bottles are normally placed in a controlled environment culture room with air temperature around 20°C and a photoperiod of 18 hours at a light intensity of 30,000 lux from white fluorescent tubes.

Culture Medium

In micropropagation of *A. mangium* using nodal in initial cultures, a premixed MS basal medium is supplemented with 3% (w/v) sucrose and 0.6% (w/v) bacteriological agar. A growth substance is added to the medium for either shoot multiplication or root initiation, depending on the treatment. The pH of the medium should be adjusted to 5.8 using 1N NaOH prior to autoclaving. The medium is then sterilized by autoclaving at 121°C and 15 p.s.i for 20 minutes.

Establishment of Aseptic Cultures

Nodal explants of one-month-old *A. mangium* aseptically germinated seedlings are cut into small segments 2-3 mm in length and then placed in full-strength MS medium supplemented with 3% sucrose (w/v), 0.6% bacteriological agar (w/v), and growth substances. They should be incubated in a controlled environment culture room at 20°C with a photoperiod of 18 hours. One month after inoculation explants should be transferred onto fresh medium of the same composition.

Effect of Cytokinins

Cytokinins can help induce better shoot multiplication and elongation. The growth hormone 6-benzylamino purine (BAP) has frequently been reported to be particularly effective for this in tree species. Its effectiveness has been shown with both juvenile and mature tissues of *Calophyllum inophylum, Eugenioa grandis, Fragraea fragrans* (Rao and Lee 1982), *Bougainvillea glabra* (Sharma et al. 1981), *Prunus serotina* (Tricoli et al. 1985), and *Eucalyptus* spp. (Gupta et al. 1981).

In nodal cultures of aseptically germinated *A. mangium* seedlings, adventitious shoots appear within two weeks of inoculation. They are green with small, juvenile compound leaves. For shoot multiplication of *A. mangium* nodal cultures, BAP is more effective than other cytokinins such as kinetin and zeatin. An MS basal medium supplemented with 0.5 or 1.0 mg/l of BAP yields the highest number of shoots per explant (Table 4.6 and Plate 4.1), with an average length of developed shoots greater than 0.5 cm (except for shoots in MS basal medium with a high concentration of BAP).

Plate 4.1. Shoot multiplication of nodal explant of one-month-old, aseptically-germinated seedling on MS basal medium, supplemented with 0.5 mg/l BAP after 2 months in culture. *Photo*: Darus Ahmad

Effect of Culture Cycle

Culture cycle is a term used to describe repeated subculturing of nodal explants excised from developed shoots of previous cultures. Table 4.7 shows the average

Table 4.6. Effect of BAP concentration on shoot multiplication and shoot length of cultured nodal explants after two months in culture (±SE).

BAP concentration (mg/l)	Average shoot length (cm)		Average number of shoots per explant	
0.0	0.67	(0.06)	1.2	(0.43)
0.1	0.61	(0.06)	4.6	(0.33)
0.25	0.62	(0.03)	7.1	(0.53)
0.5	0.68	(0.33)	25.4	(1.90)
1.0	0.59	(0.03)	24.6	(1.28)
2.0	0.55	(0.03)	19.3	(0.78)
4.0	0.43	(0.03)	15.8	(1.46)

Source: Darus (1989)

number of shoots for each cycle of nodal explants. Initially the number of shoots increases with each subsequent culture cycle, but after the fourth cycle there is a sharp decline in shoot multiplication.This has been observed in recycle cultures of several tree species. According to some reports (Standardi 1982; Ryynanen and Ryynanen 1986), this decrease in shoot multiplication and shoot length in later culture cycles is probably due to an adaptation of the species to *in vitro* culturing conditions. However, other reports claim that shoots can be continuously regenerated over a longer period without losing their potential for shoot generation of, for example, cultured shoot tips of *Bougainvillea glabra* (Sharma et al. 1981), *Dioscorea floridunda* (Chaturvedi 1983), and *Eucalyptus* spp. (Gupta et al. 1981 and Mehra Palta 1982).

Table 4.7. Effect of culture cycle on shoot multiplication and elongation (±SE).

Culture cycles	No. of shoots per explants		Average shoot length (cm)	
1	21.6	(3.4)	0.61	(0.10)
2	n.a		n.a	
3	21.1	(3.4)	0.69	(0.31)
4	26.4	(8.5)	0.82	(0.11)
5	25.7	(7.0)	0.80	(0.15)
6	30.2	(5.9)	0.82	(0.30)
7	33.1	(9.5)	1.30	(0.31)

n.a = not available *Source*: Darus (1988)

The findings in Table 4.7 suggest that explants from aseptically germinated *A. mangium* can be continuously recultured to produce several generations of shoots, with good shoot induction even after six recycled cultures of 2 months each. It is estimated that more than 219 million shoots >0.5 cm in length could be obtained from a single one-month-old aseptically germinated seedling in one year.

Effect of Gibberellic Acid

Shoot proliferation and elongation of nodal cultures are influenced by gibberellic acid, which inhibits multiple shoot formation and induces greater elongation of developed shoots (Table 4.8). The inhibition of shoot formation might be caused by increased auxin synthesis and its activities, which in turn depresses exogenous cytokinin activities. Lane (1979) reported the negative effect of gibberellic acid on shoot proliferation in cultures of *Linum usitatissimum*.

The increase in shoot length is clearly due to elongation of internodes (Plate 4.2) rather than an increase in their number. According to Wareing and Phillips (1973), increase in internode length is a consequence of cell extension and cell division by the direct effect of gibberellic acid. De la Guardia and Benlloch (1980) mentioned that the increased shoot length is due to an increased transport

Table 4.8. Effect of gibberellic acid on shoot multiplication and elongation (±SE).

Gibberellic acid (GA3) (mg/l)	Average no. of shoots per explant		Average shoot length (cm)	
0.0	25.4	(0.6)	0.43	(0.02)
0.5	7.2	(1.2)	0.76	(0.05)
1.0	6.0	(0.8)	0.87	(0.06)
2.0	5.6	(0.8)	0.92	(0.14)
4.0	4.4	(0.7)	1.04	(0.07)

Source: Darus (1988)

of potassium (K) ions to the parts of the plant where cell division and elongation take place. Higher potassium and sugar levels in the elongation area, together with a high endogenous auxin activity, increases growth rate. Franclet and Boulay (1982) note that gibberellic acid also causes greater elongation of shoots of *Eucalyptus* nodal cultures.

Plate 4.2. Effect of gibberellic acid on shoot development of cultured explant. *Photo*: Darus Ahmad

Effect of Position of Nodal Segments

The portion of the excised nodal segments for initial cultures affects shoot multiplication and varies by species. In the case of *Betula pendula* cultures, shoot tip explants are preferred in order to avoid the inhibiting effect of apical dorminance on the growth of explants from axillary buds (Ryynanen and Ryynanen 1986). Nodal explants taken from apical meristems usually respond better than those taken from the plant base (Tisserat 1985).

For *A. mangium*, Yang et al. (1989) reported that shoot tips produce more shoots than axillary buds; however, Table 4.9 indicates that mid-portions of stems of one-month-old, aseptically germinated seedlings are the most productive explants in shoot formation. Reduced shoot multiplication of the apical portion and basal nodes of one-month-old seedlings may be due to:

- shoot tip responds less to cytokinins and is influenced by the endogenous auxin normally produced by the young leaf
- apical dominance

Table 4.9. Effect of position of nodal stem segments on shoot multiplication and elongation (±SE).

Nodal position	Average no. of shoots per explant		Average shoot length (cm)	
1 (shoot tip)	18.0	(1.5)	0.54	(0.04)
2	19.0	(1.6)	0.50	(0.03)
3	24.8	(2.3)	0.50	(0.03)
4	21.8	(1.5)	0.55	(0.04)
5	18.4	(1.1)	0.51	(0.03)

Source: Darus (1988)

Influence of Auxins and Hormone Rooting Powder on Root Formation

While excised shoots of *A. mangium* nodal culture root easily *in vivo*, rooting percentage is influenced by growth substance and concentration (Table 4.10). A low concentration of NAA is very effective; increasing concentrations gradually reduce the rooting percentage. IBA has the reverse effect: rooting percentage increases with higher concentrations. Of the three hormones tested (IBA, NAA and Seradix 3), Seradix 3 promoted rooting best, probably for the same reasons given above.

Although it is difficult to root most woody species *in vitro* (Hu and Wang 1983), three *Acacia* species have been rooted easily to date: *A. koa* (Skolmen and Mapes, 1976), *A.melanoxylon* (Meyer and Staden, 1987) and *A. albida* (Duhoux and Davies, 1985). In comparison to these, *A. mangium* shoots rooted much more easily *in vivo* and produced higher rooting percentage using commercial rooting powder. The advantages of the *in vivo* technique over the *in vitro* technique are:

- more shoots can be rooted in a misted rooting chamber
- aseptic techniques are not required
- it is easy to transplant rooted shoots into pots

For rooting, it is essential to use only healthy, elongated shoots with relatively normal leaf morphology and pigmentation. As mentioned earlier in the section on macropropagation, the presence of leaves is important to produce and supply carbohydrates and endogenous auxins to the stem tissues involved in root formation. Smaller shoots (<0.5 cm long) with few, small leaves frequently die in the rooting beds. It is possible that smaller shoots are unable to perform sufficient net photosynthesis, and as a result shoots do not initiate roots. This suggests that smaller shoots do not have sufficient internal food reserves to support them

Table 4.10. Rooting percentage (±SE) of excised shoots (n=40) with and without growth substances in a misted rooting chamber.

Treatment	Total rooted shoots	Rooting %	
Control	7	17.5	(3.1)
Seradix 3	34	85.0	(2.5)
100 ppm NAA	16	40.0	(2.5)
250 ppm NAA	14	35.0	(4.7)
500 ppm NAA	9	22.5	(2.5)
1,000 ppm NAA	5	12.0	(0.0)
100 ppm IBA	7	17.5	(3.1)
250 ppm IBA	13	32.5	(5.0)
500 ppm IBA	16	40.0	(6.1)
1,000 ppm IBA	15	37.5	(5.6)

Source: Darus (1988)

through the rooting process and autotrophic growth. Ryynanen and Ryyanen (1986) report similar results with shoots of *Betula pendula*.

Conditions in a rooting chamber can be harsh, with almost hourly variations in relative humidity, temperature, and light intensity that, combined, can kill off small tissue-cultured shoots (John 1986). The high mortality of small shoots might also be due to handling damage.

Effect of Culture Cycles on Rooting

Shoots treated with Seradix 3 can be planted in nonsterile, misted rooting chambers containing a mixture of Irish sphagnum peat and sand in equal proportion. Environmental conditions in rooting chambers should be similar to those of rooting beds used for stem cuttings (see above). The rooting percentage of shoots from recycled cultures of explants from one-month-old, aseptically germinated seedlings decreases with increasing number of culture cycles (Table 4.11).

Table 4.11. Effect of culture cycle on rooting percentage of excised shoots (±SE).

Culture cycle	Percentage rooting	
1	60.0	(10.5)
2	n.a	
3	73.0	(14.9)
4	66.0	(12.6)
5	51.0	(8.7)
6	50.0	(12.5)

Source: Darus (1988)

This may be due to the aging effect of these shoots *in vitro*, despite their juvenile shoot morphology; prolonged culture cycles may become unfavorable for rooting. However, results of this experiment contrasted with reports on rooting of shoots of *Eucalyptus citriodora* (Gupta et al. 1981), *Prunus* (Tricoli et al. 1985), and *Actinadia chinensis* (Standardi 1982), in which repeated subculturing increased the rooting percentage or did not decrease it significantly.

Potting and Maintenance of Rooted Plantlets

Two-month-old rooted plantlets can be lifted from rooting chambers for potting. Usually plantlets bearing incipient roots are kept in water-filled containers before they are transplanted into black polybags containing 100% forest topsoil. The newly potted plantlets need to be placed in nursery beds under 50% Sharlon shade for about one month, after which the shade should be removed to enable the plants to harden. Survival rate can be 80-90%.

Potted plantlets should be watered regularly in the morning and fertilized using compound fertilizer such as NPK blue (15:15:15) at the rate of about 0.5 g/plant/month, starting two months after potting. Normally, plantlets are ready for planting in the field 6-8 months after potting.

Future Research

Further research is needed on the following topics:

- the effect of environmental factors (such as air and medium temperatures, photoperiod, light intensity, and air humidity) on rooting performance of stem cuttings

- the effect of carbohydrate content and different position of stem nodes on rooting performance of stem cuttings

- the cause of mortality of stem cuttings in rooting beds

- the anatomy of stem cuttings at different ages of stock plants to observe development of the sclerenchymatous ring on older stock plants and its effects on root development

- the coppicing habits of *A. mangium* seedlings and rooting performance of stem cuttings taken from coppiced shoots, and evaluation of the number of rooted cuttigs that can be produced from one seedling in one year

- growth performance of vegetatively propagated stock plants produced from stem cuttings and from tissue culture

- tissue culture techniques for mature *A. mangium* trees, especially important for mass-producing genetically improved plus trees

- protoplast culture of *Acacia* species

Summary

A. mangium stem cuttings can be easily rooted, following these considerations:

- cutting materials from 6- to 12-month-old seedling stock are best; rooting percentage declines with older stock plants

- high air humidity (70-90%) and fairly constant temperature (28°C) should be maintained in the rooting chamber

- use of cuttings with one half or one phyllode improves rooting

- application of auxins such as 500-1,000 ppm IBA or a hormone rooting powder such as Seradix 3 improves rooting

- use of a rooting medium with relatively high pH (5.8 or neutral) and high water-holding capacity is best; the combination of river sand and Irish sphagnum peat has given best results in experiments

A micropropagation technique for *A. mangium* has also been successfully developed. For optimum induction of multiple shoots, Murashige and Skoog basal medium supplemented with 0.5 mg/l of benzylamino purine (BAP) is best. This medium gives an average of 25.4 shoots per explant. Excised shoots longer than 0.5 cm can easily be rooted in a humidified rooting chamber. Number of shoots per explant and shoot length increase with increasing culture cycles. An estimated 219 million shoots of greater than 0.5 cm in length can easily be produced from a single germinated seedling, but the rooting percentage decreases with increasing numbers of culture cycles.

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References

Avidan, B. and S. Lavee. 1978. Physiological aspect of rooting ability of olve cultivars. *Acta. Hort.*79:93-97.

Bilan, M.V. 1974. Rooting of *Liquidambar styraciflua* cuttings. *N.Z. J. For. Sci.* 4(2):177-180.

Chaturvedi, H.C. 1983. Plant tissue culture. Paper presented at the 15th International Congress of Genetics, New Delhi, India.

Darus Ahmad. 1982. Vegetative propagation of *Araucaria hunsternii* by cuttings. *Malaysian Forester* 45(1):81-83.

_____. 1988. Vegetative propagation of *Acacia mangium* Willd. by stem cuttings and tissue culture techniques. Ph.D. thesis submitted to the University of Aberdeen, Scotland. 298 pp.

_____. 1989. Anatomical study on root formation in *Acacia mangium* stem cuttings. *J. Trop. Sci.* 2(1):20-24.

_____. 1990. Vegetative propagation of *Acacia mangium* by stem cuttings: the effect of age and phyllode number on rooting. *J. Trop. For. Sci.* 2(4):274-279.

_____. 1991a. Micropropagation of *Acacia mangium* from aseptically germinated seedlings. *J. Trop. For. Sci.* 3(3):204-208.

_____. 1991b. Multiplication of *Acacia mangium* by stem cuttings and tissue culture techniques. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 32-35. ACIAR Proceedings No. 35. Canberra: ACIAR.

De la Guardia, M.D. and M. Benllock. 1980. Effect of potassium and gibberellic acid on stem growth of whole sunflower plants. *Physiology Plantarium* 49:443-448.

Dohoux, E. and D. Davies. 1985. Shoot production from cotyledonary bud of *Acacia albida* and influence of sucrose on rhizogenesis. *J. Plant Path.* 121:175-180.

Franclet, A. and M. Boulay. 1982. Micropropagation of pest resistant *Eucalyptus* clones. *Australia For. Res.* 13:83-89.

Geary, T.F. and W.G. Harding. 1984. The effect of leaf quantity and trimming on rooting success with *Eucalyptus camaldulensis* Dehn. cuttings. *Commonwealth For. Rev.* 63(3):225-230.

Girouard, R.M. 1974. Propagation of spruce by stem cuttings. *N.Z. J. For. Sci.* 4(2):140-149.

Gupta, P.K., A.F. Mascarenhas, and V. Jogannathan. 1981. Tissue culture of forest tree clonal propagation of mature tree of *Eucalyptus citriodora* Hook. by tissue culture. *Plant Science Letters* 20:195-201.

Hartmann, H.T. and D.E. Kester. 1983. *Plant Propagation: Principles and Practices*, 4th. edition. Engleword, Cliffs, New Jersey: Prentice-Hall, Inc.

Howland, P. 1975. Vegetative propagation methods for *Triplochiton scleroxylon* K. Schum. In Proc. Symposium on Variation and Breeding System of *Triplochiton scleroxylem* K. Schum; 99-109. Ibadan, Nigeria: IITA.

Hu, C.Y. and P.J. Wang. 1983. Meristem, shoot tip and bud cultures. In *Handbook of Plant Cell Culture: Techniques for Propagation and Breeding*, eds. D.A. Evans, W.R. Sharp, P.V. Ammirato and Y. Yamada; 177-227. New York: MacMillan Publishing Co.

John, A. 1986. Test-tube trees: potential of micropropagation. *Forestry and British Timber* :10-11.

Komissarov, D.A. 1964. *Biological Basics for Propagation of Woody Plants by Cuttings*, trans. by Z. Shapido. 1969. Jerusalem: Israel Program for Scientific Translations.

Lane, W.D. 1979. Influence of growth regulators on roots and shoots initiation from flex meristem-tips and hypocotyl *in vitro*. *Physiology Plantarium* 45:260-264.

Leaky, R.R.B., V.R. Chapman, and K.A. Longman. 1982. Physiological studies for tropical tree improvement and conservation. Factors affecting root initiation in cuttings of *Triplochiton scleroxylon* K. Schum. *For. Ecol. Manag.* 4:53-56.

Mathur, I. and N. Chandran. 1983. Induced regeneration in stem explants of *Acacia nilotica*. *Current Science* 18(52):882-883.

Mehra Palta, A. 1982. Clonal propagation of *Eucalyptus* by tissue culture. *Plant Science Letters* 26:1-11.

Meyer, H.J. and J.V. Staden. 1987. Regeneration of *Acacia melanoxylon* plantlets *in vitro*. *S. African J. Botany* 53(3):206-209.

Murashige, T. and F. Skoog. 1962. A revised medium for rapid growth and bioassays with tobacco tissue cultures. *Physiology Plantarium* 15:473-495.

Nanda, K.K., V.K. Anand, and P. Kumar. 1970. Some investigations of auxin effects on rooting of stem cuttings of forest plants. *Indian Forester* 96(3):171-178.

Pain, S.K. and B.K. Roy. 1981. A comparative study of the root forming effect of indole propionic acid (IPA), indole butyric acid (IBA) and naphthalene acetic acid (NAA) on stem cuttings of *Dalbergia sissoo* Roxb. *Indian Forester* 44(2/4):301-313.

Rao, A.N. and S.K. Lee. 1982. Importance of tissue culture in tree propagation. In *Plant Tissue Culture*, ed. A. Fujiwara; 715-718. Tokyo: The Japanese Association for Plant Tissue Culture.

Ryynanen, L. and M. Ryynanen. 1986. Propagation of adult curly birch successes with tissue culture. *Silva Fennica* 20(2):139-147.

Sharma, A.K., R.N. Prasad, and H.C. Chaturvedi. 1981. Clonal propagation of *Bougainvillea glabra* 'Magnifica' through shoot apex culture. *Plant Cell Tissue Organ Culture* 1:33-38.

Skolmen, R.G. and M.O. Mapes. 1976. *Acacia koa* grey plantlets from somatic callus tissue. *J. Heredity* 67:114-115.

Srivastava, P.B.L. and P. Manggil. 1981. Vegetative propagation of some Dipterocarps by stem cuttings. *Malayan Forester* 44(2/3):301-313.

Standardi, A. 1982. Effect of repeated subcultures in shoots of *Actinidia chinensis* (P1). In *Plant Tissue Culture*, ed. A. Fujiwara; 737-738. Tokyo: The Japanese Association for Plant Tissue Culture.

Tisserat, B. 1985. Embryogenesis, organogenesis and plant regeneration. In *Plant Cell Culture: A Practical Approach*, ed. D.A. Dixon; 79-105. Washington D.C.: IRL Press.

Tricoli, D.M., C.A. Maynard, and A.P. Drew. 1985. Tissue culture of propagation of mature trees of *Prunus serotina* Barh. I. Establishment, multiplication and rooting *in vitro*. *For. Sci.* 31 (1):201-208.

Whalley, D.N. 1979. Propagation of ornamental trees and shrubs by dormant leafless (hardwood) cuttings. *Arboriculture J.* 3(7):499-511.

Yang, J.C., M.C. Lu, J.Y. Tsay, S.H. Chang, and C.K. Ho. 1989. *In vitro* culture of *Acacia auriculiformis*, *A. mangium* and their interspecific hybrid. In *Proc. of the Sixth International Congress of SABRAO*; 865-868. Malaysia: SABRAO.

Zakaria, I. and T.H. Ong. 1982. Vegetative propagation of yemane (*Gmelina arborea*) by stem cuttings. *Malaysian Forester* 45(2):282-284.

Chapter 5

Nursery Practices

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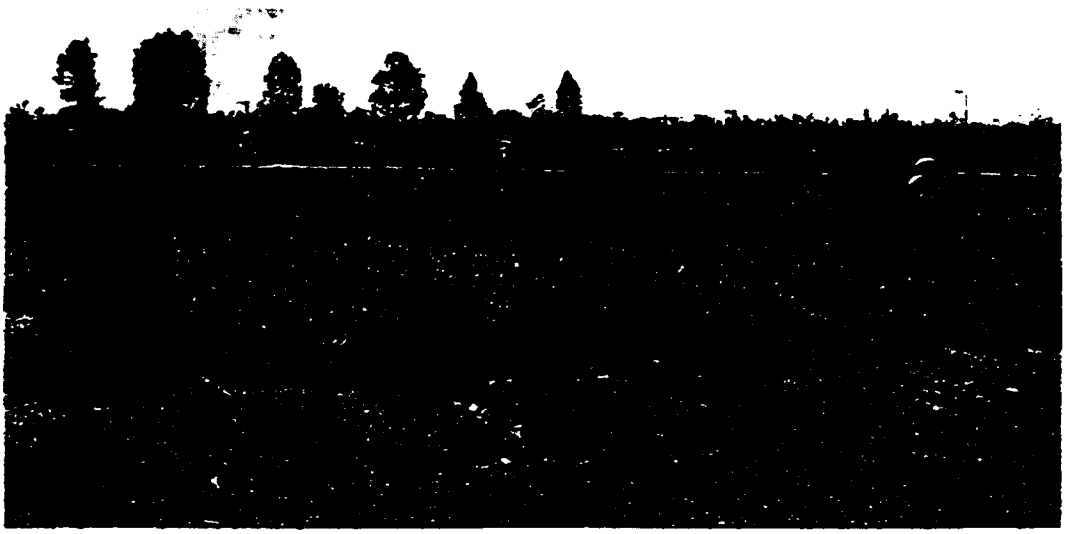

Plate 5.1. Overview of a large nursery producing *A. mangium*. *Photo*: Enso Forest Development, Ltd.

Introduction

While use of vegetative propagation for *Acacia mangium* is increasing, nursery propagation of seedlings is still the most common method. Reproduction from seeds maintains a broad genetic base and is often still the cheapest technique. Nursery practices for *A. mangium* are not very demanding, and seeds are now easily available (see Appendix 1).

Seed Collection and Handling

Seed Collection

From Natural Stands

Collecting seeds from natural stands of *A. mangium* is a costly enterprise. The Departments of Forest of Papua New Guinea (PNG) and Indonesia and the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) have mounted a number of seed collection expeditions to wild and virgin populations of a number of distinct provenances of *A. mangium* in North Queensland (Australia), Indonesia, and Western Province of Papua New Guinea (Doran and Skelton 1982; Turnbull et al. 1983). Recently, additional collections have been made in the region north of the Claudie River (Queensland), Lake Murray (PNG) and Muting (Irian Jaya) (Gunn et al. 1989, 1990; Morse et al. 1991; Gunn and Midgley 1991). The ecology of this area in Western Province (PNG) is described by Skelton (1986). In Indonesia, seeds were collected by locally hired climbers who cut off branches and stripped the fruits into bags. After air drying, the pods were hand threshed and the seeds were cleaned by village women using bamboo trays.

The Western Province of PNG is remote, with many rivers and swamps but few roads. Most of the Oriomo plateau is accessible only by walking from small air strips. The high cost of aircraft hire, payload and space and the lack of road transport combine to make seed collection tedious and expensive. The 1982 expedition used a vehicle and light aluminum barge to reach collection sites on the Oriomo River's shores and in the Morehead area. The expedition took 42 days: 16 days in Port Moresby and Daru to organize the trip, 7 days travel by barge, 5 days travel by vehicle, and 14 days collecting and extracting seeds in the field.

Some problems have been eased in subsequent trips, due in part to the attraction of revenue for landowners there (the forests are owned by the people in PNG); nonetheless, collection of *Acacia* spp. seeds from Western Province is time consuming and expensive. Therefore there is a trend to establish seed production stands and seed orchards of this species in each country with large reforestation and afforestation programs using *A. mangium*.

A 0.308-caliber rifle with 110-grain, soft-nosed ammunition was used to collect the seeds. This was supplemented by a chainsaw for felling trees where there were sufficient trees in the population.

From Plantations

It is common practice now in most countries where *A. mangium* is a priority species for reforestation and afforestation to collect seeds from seed production stands or seed orchards that have been created from general plantations by careful thinning, or especially established from seeds obtained from wild popula-

tions (see Chapter 3). Seed collection starts when the pods turn very dark green to light-brown in color (Emmeric Devige, personal communication).

In both Sabah (Malaysia) and PNG, *A. mangium* is observed to flower and produce viable seeds early in its life. In PNG, although plants as young as two years have been found to flower, seeds are not collected before the trees reach 3.5-4 years.

Trees at different sites (for example, Sabah and PNG) have shown wide variation in flowering and fruiting patterns (see Chapter 2). Despite a common tropical climate with little seasonal variation, significant diurnal fluctuations in temperature differ among these sites; such temperature fluctuations are further influenced by the surrounding seas.

At Ulu Kukut in Sabah, seeds are collected in the middle of February. Ripe seeds are available for about three weeks, although a few trees fruit until at least the beginning of August. At Sook and other locations on the western side of the island, beyond the Crocker Range of mountains, trees follow the same pattern of flowering and fruiting. However, at Sapilok the first pods are collected in early May and fruiting continues until mid-July. At Gum-Gum, 6 km north of Sapilok, trees bear ripe pods in late May, but at Lungmanis, 75 km further north of Sapilok, collection does not begin until mid-June.

At a number of sites in Sabah (Sook, Brumas), trees produce two crops of fruits annually. Generally the period of seed availability is one month; only small quantities of seeds are available six weeks after harvest begins. However, in some locations (including Sapilok), seed is available over a three-month period (Bowen and Eusebio 1981).

In Gogol, PNG, flowering begins in early February and continues until April, or even into the seed collection period. Fruiting begins in March and continues until September; seed is collected from late June or early July to October, and occasionally until mid-November.

This information indicates the need for detailed phenological observations even within the tropics. It may also be useful to determine the factors responsible for the variation in flowering and fruiting patterns from year to year under the different sets of conditions. Such information would help to make the seed collection process more economical and productive in terms of obtaining the best-quality seeds from known populations.

Seed Extraction and Cleaning

The *A. mangium* pods must be processed as soon as possible after collection. During transport, some fresh pods and seeds will lose viability due to heat and humidity build-up. If pods and seeds are not thoroughly dried, the best storage during transport is cloth bags; tight containers build up heat and humidity and encourage the development of fungi.

Many techniques have been used to separate *A. mangium* seeds from their pods. In the field where transport space is a limiting factor, seeds are extracted

manually after sun drying for several days, until the pods turn brown/black and split. Pods and seeds should not be left to dry in the sun for too long. Drying temperatures should not exceed 43°C to avoid loss of seed viability (FAO 1987). Seed moisture content should be reduced below 13% to prevent molding. In Sabah, Malaysia, *A. mangium* pods are dried in a simple drying chamber equipped with an electric heater and a domestic fan (Bowen and Eusebio 1981).

Seeds can be separated from the pods after drying by rotating them for 10-15 minutes in a cement mixer together with blocks of hard timber (10 x 10 x 15 cm dimension)(Bowen and Eusebio 1981). Another rather crude method is to put the dried pods into sacks and then lightly beat them and toss them around. In Australia, the pods are dried and broken down in a mechanical thresher.

In cleaning the seeds, one should aim for a compromise between the desired seed quality and quantity; rigorous cleaning will cause more seeds to be discarded, especially small seeds. In Australia, seeds are cleaned in a Kurt Pelz Saatmeister separator as described by Doran et al. (1982).

Threshing of pods and seeds of many tropical acacias produces a highly irritating dust from which workers need protection. A helmet fitted with a device to blow filtered air over the face of the operator is satisfactory for this purpose (Turnbull et al. 1983).

Seed Storage

Hard, impermeable seed coats of many legumes, including *A. mangium*, confer long seed viability under almost any conditions, provided they are kept dry and free from insect or rodent damage (Evans 1982). Proper storage protects the seeds from high temperatures, light, and excessive oxygen. In spite of the easy storage of *A. mangium* seeds, one should take special care during storage. FAO (1987) recommends storing *A. mangium* seeds in sealed, air-tight containers in a refrigerator between 0-5°C. Supriadi and Valli (1988) recommend using clean jerry cans or small jars that can be closed tightly for storing *A. mangium* seed. These jars can be stored in a dry, cold storage especially designed for forest tree seeds. This technique has been used to store seeds of *A. mangium* for several years, with no serious problems.

Seed Yield and Size

Seed Yield per Tree

Skelton's (1980) collection from natural stands in the Western Province of PNG yielded an average of 150 g per tree (highest 1,148 g). These trees were of mixed

age, estimated between 8 and 30 years. Some collections from this area have been very poor due to attack by insects and birds; trips should be timed carefully to avoid these losses.

In Sabah, Malaysia, studies indicated that 14-year-old trees at Gum Gum yielded 51-1,312 g of seeds per tree. At Sook, where the trees were 3 years old and 10-12 m in height, yields of 300 g per tree were common (maximum 675 g). Yields from both 7- and 3-year-old trees at Lungmanis averaged about 230 g per tree with no appreciable difference between age groups (Bowen and Eusebio 1981).

Seed Yield per Unit Weight of Pods

The amount of seed yielded per kg of pods depends on the ripeness of the pods at the time of harvest, and can vary from 56 g/kg at Gum Gum to 86 g/kg at Sepilok in Sabah. The pods harvested at Sapilok were almost all black (that is, fully mature), whereas the Gum Gum harvest contained a relatively high percentage of green and brown pods. In one of the PNG collections, 1 kg of pods yielded only 16 g of seed (Bowen and Eusebio 1981).

Seed Weight

The number of seeds in 1 kg of pure (100% clean) seed varies markedly among trees. This should be kept in mind when calculating the amount to sow. To a certain extent, this depends upon the moisture content at the time of measurement. The figures in Table 5.1 have been adjusted to 5% moisture (wet-weight basis) for comparison.

For the Sabah collections derived from the original importation from Lacey's Creek, Queensland in 1966, the number of seeds per kg from individual trees

Table 5.1. Mean number of seeds per kg.

Collection	Seeds per kg	
Australia		
Queensland	98,159	
Sabah, Indonesia		
Ulu Kukut	155,717)	
Sepilok	123,206)	
Gum Gum	123,296)	Mean about 125,000
Lungmanis	130,421)	
Sook	78,605	
Papua New Guinea	76,922	

Source: Bowen and Eusebio (1981)

varied from approximately 95,000 to 158,500, with a mean of around 125,000. Seed from the Australian collections was distinctly larger, ranging from 77,850 to 115,900 for each tree collection, with a mean of 88,200 per kg (around 27% fewer seeds per kg than Sabah). Seeds collected at Sook were even larger than the Australian seeds, ranging from 72,000-91,000 per kg, with an average of 78,600. PNG seeds were also large, with collections from individual trees varying between 57,200 and 105,200 per kg, with an average of 76,922.

Seed from different-colored pods did not appear to differ significantly in weight, regardless of whether they were obtained from black, brown, or green pods.

Seed Dimensions

For the results shown in Table 5.2, a batch of seeds from typical Sabah, Australia, and Papua New Guinea collections were cleaned of funicles and debris. Each batch was passed through a series of test sieves of decreasing mesh size and the percentage, by weight, of the sample retained in each sieve was determined.

Table 5.2. Percentage of seed (by weight) retained in sieves of decreasing mesh size, by provenance region.

Mesh size (mm)	Sabah	Australia	Sook	PNG
2.36	0.0	0.9	6.6	14.4
2.00	26.8	35.9	66.8	74.4
1.70	58.4	46.1	24.4	9.1
1.40	14.0	16.8	2.3	2.2

Source: Bowen and Eusebio (1981)

As might be expected from the results concerning seeds per kg, the Australian seeds have a somewhat greater diameter than the general Sabah collections: 36% were retained by the 2.00-mm sieve, as opposed to 27% of the Sabah seeds. The Australian seeds also appear to be somewhat longer, on average. The Sook seeds were even larger than the Australian imports; almost 67% were retained in the 2 mm sieve. The PNG seeds were larger still, with 14% retained by a 2.36-mm mesh and nearly 75% by a 2.00-mm mesh.

Seed Treatment

Germination of *A. mangium*, like that of most acacias, is inhibited by the hard and water-impermeable seed coat (Doran and Gunn 1987). While this assures seed longevity, it also makes germination slow, unpredictable, and difficult. To

Table 5.3. The effects on germination and seed imbibition of heating dry seeds at 100°C for increasing intervals of time.

Treatment Time	Precentage germination	Precentage not imbibed
Control (100°C soaking 30 secs)	92	3
5 minutes	67	20
10 minutes	8	7
15 minutes	79	4
30 minutes	70	3
60 minutes	48	5
Unheated (cold water imbibition)	3	96

Source: Bowen and Eusebio (1981)

obtain even and quick germination in the nursery, it is necessary to use scarification or some other pretreatment that will make the testa permeable to moisture.

A number of methods have been used to break the dormancy of *A. mangium* seeds caused by the hard seed coat. One way of scarifying seeds is to crack the testa at one edge (away from the plumule) using a scalpel. However, this method is time-consuming, especially with *A. mangium*'s small seeds. Scarification using sulphuric acid has been tried with variable success. However, there seems to be little advantage in using acid or other dangerous chemicals (such as H_2O_2), when a more convenient and better method is available through hot-water treatment.

Still another method for scarifying *A. mangium* seeds is described by Bowen and Eusebio (1981). The seeds were exposed to dry heat in an oven at 100°C for 5, 10, 15, 30, and 60 minutes. These seeds were then imbibed in cold water at 30°C for 18 hours before sowing. The results are shown in Table 5.3.

Exposure to dry heat was nearly as effective in overcoming seed dormancy as the hot water treatment. Seeds heated for 10 minutes followed by soaking in water gave 83% germination, compared with 92% in hot water treatment. This explains the profuse natural regeneration of *A. mangium* after fire in clear-felled areas. However, there are obvious difficulties involved with heating large amounts of dry seeds uniformly in an oven, and the method is not recommended.

The most common and practical pretreatment method now in use in almost all nurseries for *A. mangium* seeds is the hot water treatment. Bowen and Eusebio (1981) described the experiment which standardized this method.

Seven half-sib seedlots were chosen and three replicates of 100 seeds were selected at random for testing at eight different pretreatment temperatures. The seeds were dropped into 10 times their volume of heated water for 30 seconds. After this, the water was poured off and the seeds immersed in 20 times their volume of cold water, where they imbibed for 18 hours. They were then sown on damp tissue paper at 30°C, and germination recorded. The results are shown in Table 5.4.

Table 5.4. Percentage germination of seven half-sib seedlots pretreated with 10 times their volume of hot water for 30 seconds.

Pretreatment temperature (°C)	Seedlot number SEP 125	SEP 144	SEP 153	SEP 149	SEP 155	SEP 129	SEP 145	Mean germination (%)
30	5	2	5	17	1	1	1	5
40	3	3	5	3	6	7	2	6
50	15	28	13	16	7	11	11	15
60	26	37	17	19	10	17	16	20
70	29	34	48	25	61	12	33	34
80	40	71	84	48	53	25	26	50
90	65	98	88	84	84	80	89	84
100	96	98	88	79	94	89	96	91

Source: Bowen and Eusebio (1981)

The results are clear. Germination is particularly poor if the seed is not heated to more than 80°C. Pretreatment with hot water at 90°C for 30 seconds is effective, but germination was significantly better following the 100°C treatment.

The following pretreatment is therefore recommended:

1. Measure the volume of seed to be sown.
2. Heat five times this volume of water in a glass or light metal container until it is boiling vigorously.
3. Remove the water from the heat source.
4. Immediately pour the seed into the water at 100°C.
5. Stir the seed and water for exactly 30 seconds.
6. Pour off the hot water.
7. Add 20 times the seed volume of cold water (room temperature).
8. Let stand overnight to imbibe.
9. Sow the seed in the laboratory or nursery beds.

Failure to follow all measurements and timing exactly will result in poor germination. These results have been confirmed by other workers (Newman 1989b). Pretreated seeds can either be immediately sown or dried, repacked, and stored (or transported) for later use with no further pretreatment required before sowing (Udarbe and Hepburn 1986). Bowen and Eusebio (1982) reported that germination after three days was as good (about 80%) as when seeds were sown immediately after treatment. This is very helpful when using temporary or satellite nurseries.

Sowing and Pricking Out

Sowing is one of the most important nursery operations. Low germination rates can jeopardize not only a nursery's production targets but also a whole reforestation program.

Germination Tests

Before sowing seed in the nursery to produce the required planting stock, it is helpful to know the percentage of germination expected from a particular seed lot. If germination is low, either (a) much extra time and labor (hence additional cost) will be wasted on non-viable seed, or (b) larger quantities of seeds must be procured and sown in order to obtain the same required number of seedlings.

A good seed supplier generally informs the buyer (user) about the germination rate, but if there is any doubt it is best to perform germination tests. These tests also yield other useful information, such as time required for germination, which will be useful in planning nursery operations.

Germination tests can be conducted either under normal sowing conditions in the nursery or in a seed-testing laboratory. A germination house equipped with mist irrigation is ideal for such tests (Supriadi and Valli 1988). For hard-coated seeds (like *A. mangium*), sow seeds after the standardized pretreatment (see above). Sow a random sample of 100 seeds in at least three replications in seed boxes (one box per replication) using river sand as a substrate. In a seed laboratory, the test is carried out on moist filter papers in petri dishes under controlled conditions of normal temperature and moisture. Detailed procedures for performing germination tests are given in FAO (1985) and proceedings of the International Seed Testing Association.

Sowing into Seed Trays or Seed Beds

Failures in sowing add extra cost, and in the worst case delays the nursery operations. Pretreated *A. mangium* seed should be sown in a seed box filled with sterilized, sieved (5-mm mesh size) river sand.

Sand substrate is most easily sterilized by heating it in an oil drum cut in half to 100°C for 15-30 minutes. After heating, the substrate should be covered and stored to avoid contamination (Jackson 1987). Chemicals such as methyl bromide and formalin have also been used for soil sterilization, but these chemicals are dangerous and are not recommended.

Conventionally, *A. mangium* seedlings were raised in seed beds and pricked into polybags at the 2-leaf stage. The recovery rate using this procedure was poor (around 37%) because:

- seed germination was affected by soil characteristics (including texture, fertility, acidity), sowing depth, and watering frequency and intensity,

- a number of seeds were damaged or carried away by ants attracted by oily funicles, and

- seedlings were damaged during pricking out.

In a method developed in Malaysia, seeds are sown in germination trays (wet-towel method) and, when the radicle appears after 6-10 days, pricked using forceps directly into polybags. According to Sim (1986), the advantages of this method are:

- a high recovery rate (over 85%)
- a shorter and more precise pricking method, and
- a high productivity in terms of seedlings transplanted per person per hour.

A box (or a tray) can contain 250-300 seedlings of *A. mangium*. The ideal box size is 30 x 40 cm, which can be carried from the germination house to the pricking-out area. Larger boxes are heavy and unmanageable.

It is an advantage to house the sowing operation in a permanent germination house with a roof of glass or plastic and a concrete or gravel floor. In some nurseries, the germination boxes (or trays) are placed on raised tables to control insect and rodent attacks, and to make weeding and watering more convenient. Watering is more easily organized in a germination house, especially if an irrigation system is installed. The best watering system in a germination house uses mist irrigation nozzles.

If seed beds are used for sowing, the substrate should be sandier than the media used in the containers. Jackson (1987) recommends a 1:1 ratio of forest topsoil:sand. Compost should not be used in seedbeds or seed trays. Seeber (1976) and Jackson (1987) provide detailed guidelines on the preparation of seedbeds.

Damping off, caused by a wide range of fungi (including *Pythium* spp, *Phytophtophera* spp., *Fusarium* spp., and *Rhizoctonia* spp.), is the most serious disease affecting *A. mangium* seedlings in nurseries (see Chapter 7). It can be overcome by appropriate use of fungicide. Two types of damping off are recognized: pre- and post-emergence. The first type attacks the seedling's radical, which starts to rot. Post-emergence damping off attacks the stem tissue, causing seedlings to collapse, shrivel, and dry. It occurs first in patches, and spreads quickly, and can easily cause large losses if not controlled. The chemical Thiuram is very effective in controlling the disease. To prevent this disease in the nursery, avoid over-watering, over-shading, poor ventilation, and dense spacing.

Rodents like young seedlings of *A. mangium* and can also become a problem. Netting the seed during sowing prevents damage by rodents.

Sowing Seeds Directly into Containers

Large seeds can be easily sown directly into containers. Although not particularly big (50,000-100,000 seeds/kg) *A. mangium* seeds can be sown directly. Direct sowing has two main advantages: reduced cost of seedling production, and minimal risk of root deformation. Direct sowing, however, requires good-quality seeds with a high germination percentage. Seeds with a germination percentage of less than 70% are better sown in seed boxes (Supriadi and Valli 1988).

If a grower still prefers direct sowing despite poor germination, sowing several seeds in each container can compensate. A rule of thumb based on known germination percentage is (FAO 1987):

if germination is	then sow
35-50%	three seeds per container
51-80%	two seeds per container
over 81%	one seed per container

Sowing several seeds in each pot may result in a number of containers with more than one seedling. The surplus seedlings can be removed at a proper time and used to fill empty pots. This operation requires additional labor and funds, and thus may nullify the advantage of direct sowing.

Direct sowing methods tend to waste seeds. For expensive seed lots, therefore, broadcast seeding and pricking-out is favored.

Direct sowing of *A. mangium* should be carried out under a shading net. In Indonesia, nets transmitting 50% light have been extensively used (Supriadi and Valli 1988). Schroeder (1987) notes that only light shade is suitable for *A. mangium*. In general, it is more difficult to supervise tending of direct-sown seedlings in the early stages, partly because outdoor conditions are more extreme. Droplets from the irrigation system must be smaller if using direct sowing. At P.T. Indah Kiat Pulp and Paper Corporation in Sumatra, about 10-12 million *A. mangium* seedlings are produced annually by direct sowing in greenhouses (Werren 1991). With proper watering and germination percentage greater than 80%, direct sowing has yielded good nursery results in South Kalimantan (Valli and Rusmana 1990), although it has not yet been implemented on a commercial scale there.

Covering Seed

After sowing, seeds should be covered. This applies both to direct and broadcast sowing. Seed should not be pressed into the media, but left on the top and covered with a suitable material. Covering with a 3-5 mm layer of coarse, washed sand, crushed rock, or gravel:

- provides excellent air exchange and water drainage
- allows rapid emergence of the cotyledon, and
- prevents damping off (FAO 1987).

Supriadi and Valli (1988) recommend covering *A. mangium* seed with a 2 mm layer of fine sand. In PNG, fine, old sawdust (about 1 cm thick) has been used. In a direct-sowing trial, peat and sand were compared as covering material. Both substrates yielded good germination (>80%) and no significant difference was observed between the treatments (Valli and Rusmana 1990).

Pricking Out

Plate 5.2. Seedlings ready for pricking out. *Photo*: Enso Forest Development, Ltd.

Transplanting or pricking-out means that seedlings from seed boxes or seed beds are planted into another container or growing place. *A. mangium* seedlings require no special measures during pricking-out; normal procedures, as described by Supriadi and Valli (1988) and Seeber (1976), are appropriate.

The best time for transplanting is immediately before the first lateral roots appear and after the stem tissue has hardened (Seeber 1976). *A. mangium* seedlings are ready for pricking-out about 6-10 days after sowing (Supriadi and Valli 1988). At this age, seedlings are 2-4 cm tall with a root 3-6 cm long (Plate 5.2). If the tap root is too long it can be clipped using fingernails. In case of uneven germination, seedlings have to be selected and transplanted in stages.

A vertical hole should be made in the substratum of the container to which the seedlings will be planted. A simple tool, such as a bamboo stick with a sharp point, can be used for this. Adjust depth and width of the hole to the length of the root of the seedling. The root must be carefully placed into the hole so that it is not twisted. Close the hole by making another hole beside it and by pushing the substrate towards the roots. At the same time, lift the seedling gently to straighten the root. After this, the substrate should be lightly compacted. It is important not to place the seedling too deep into the hole—so that the root collar is about 0.5 cm above the soil surface. It is also important to keep the seedlings moist before, during, and after transplanting.

Care should be taken in pricking-out to avoid bruises on the stem and not to plant the seedlings too deep in order to discourage fungal attacks (damping-off)

after transplanting. Pricking should not be done in direct sunlight. For this, shading nets transmitting 50% light have been used extensively in Indonesia (Supriadi and Valli 1988).

In South Kalimantan, the work output for a pricking-out operation has been 1,500-2,000 seedlings per 7-hour working day (Supriadi and Valli 1988).

Potting

Container Type and Size

Planting stock of *A. mangium* is raised in containers with a suitable medium for better growth and survival. Various types of containers can be used for growing potted seedlings. The best type to use depends on the species growth habit, substrate, and cost.

A. mangium is not particularly demanding regarding the type of container. Several types and sizes of plastic polythene bags, tin and plastic cans, and different sizes of pot trays have been used. Polythene bags are the most common containers in the tropics (Jackson 1987). Their advantages are low cost and ready availability.

The larger nurseries have conducted many trials to optimize the size of these containers and reduce the requirements for medium and labor, which would result in less expensive seedling production. Solutions must balance between biological and economical ideals. For example, the Sabah Forest Development Authority (SAFODA) reduced the size of the polythene bags from 700 cc soil volume to 330 cc with no significant difference in growth after 3 months, but with great savings in soil collection, transport, and planting costs (Poole 1987). A container trial with three container sizes (90, 183, and 462 cc) was conducted in a nursery in South Kalimantan. Although *A. mangium* seedlings grew better in the larger containers, no statistically significant differences were noticed in terms of height, diameter, dry weight, or survival percentage (Table 5.5) at the end of the 12-week nursery phase (Adjers and Luukkanen 1985).

Table 5.5. Effect of container volume on seedling growth after 12 weeks in the nursery.

Container volume (cm^3)	Height (cm)	Diameter (mm)	Dry weight (g) shoot	Dry weight (g) root	Survival (%)
90	14.0	2.3	0.43	0.22	89
183	15.3	2.4	0.44	0.27	92
462	16.2	2.6	0.76	0.36	88

Note: This trial was conducted in the rainy season; seedlings grew slowly due to frequent rains and leaching of nutrients from the substrate. *Source:* Adjers and Luukkanen (1985)

The P.T. Indah Kiat Pulp and Paper Corporation's central nursery in Sumatra, however, with a target of 10-12 million *A. mangium* seedlings annually, is phasing out the polythene nursery system, replacing it with 50 cm^3 plastic root trainer tubes. These tubes hang in trays on raised seedling production lines. Pretreated *A. mangium* seeds are sown directly in the tubes, and roots are air-pruned. As many as 30,000 seedlings can be transported on a 6-ton truck with considerable savings in transportation cost (Werren 1991).

In Kalimantan, Sumatra, and Sulawesi, the Central Nursery Establishment Project, with its 8 large nurseries aiming to produce 6-10 million seedlings each year, is designed to use square-shaped pots arranged in trays. The pot-trays have outer dimensions of 30 x 49 cm and their volume varies from 90-300 cc. Each pot-tray contains 28, 45, or 77 individual cavities (Malmiraara 1992, personal communication)(Plate 5.3). The pots have a single 1.5 cm hole in the bottom and the four 90° angles prevent the seedling roots from winding. The main advantage of several containers arranged into a tray is that these can replace single containers as the handling units, with considerable savings in labor and transportation cost.

Plate 5.3. Seedlings grown in square Enso pot-trays. Space between rows discourages fungal infections and encourages stem diameter growth. *Photo*: Enso Forest Development, Ltd.

Potting Substrate

The supply of potting substrate in adequate quantity and quality is a major problem in many large nurseries, which can require huge amounts. Several substrates have been used for raising *A. mangium* planting stock, including topsoil, vermiculite, perlite, different types of compost, and tropical peat. These

substrates can be used as a mixture or in pure form. Vermiculite or perlite should be mixed with a less expensive substrate (for example, bagasse).

A medium for container-grown seedlings should drain well and at the same time have good water-holding capacity, aeration, and firmness. The optimum pH of the nursery substrate is 5.5-7.0 (FAO 1987). *A. mangium* seedlings do not seem to be particularly sensitive to low pH-values of the nursery substrate; in trials these have been successfully grown in peat substrates with a pH as low as 3.1 (Adjers et al. 1988). In the field, *A. mangium* tolerates moderately acidic soils with pH as low as 4.0 (FAO 1987).

In Indonesia, tropical peat in different mixtures has been used extensively. Tropical peat is usually highly humified and its aeration is poor. By mixing the peat with a suitable material, aeration can be increased (Adjers 1987). Rice husk is widely used with peat in large-scale production of *A. mangium* (Plate 5.4), employing a proportion of 70-80% peat with 20-30% rice husk (Supriadi and Valli 1988; Suomela et al. 1988; Hendromono 1988). Sumatran experience indicates that the proportion of rice husk can be lower (10-30%), depending on the peat (Valli 1993, pers. communication).

The pH of tropical peat substrate can be quite low. Low pH is usually corrected by liming. Also, the pH of peat increases in storage. In South Kalimantan, the peat is lifted during the dry season and stored for at least 3 months (Supriadi and Valli 1988). During storage, the pH increases by 1 to 1.5 units. Drying in the dry season is carried out in open fields. During the rainy season, the peat should be covered with canvas or plastic to prevent soaking and kill weeds.

With *A. mangium*, Adjers et al. (1988) found high liming doses (15 kg/m^3) to have a negative effect with three peat sources in South Kalimantan. The pH varied from 3.1 to 6.3 in the trial after application of 8 and 15 kg of dolomite lime. Liming increased the pH relatively little.

The most common nursery substrate is topsoil. Sandy loams are the best, but heavier soils can be modified by adding sand, peat, vermiculite, perlite, shredded bark, sawdust, wood shavings, coconut coir, or rice husk, in proper proportion (FAO 1987). Even when using top soil, for uniform growth of *A. mangium*, soil collection should be standardized to get more uniform and fertile soils, rather

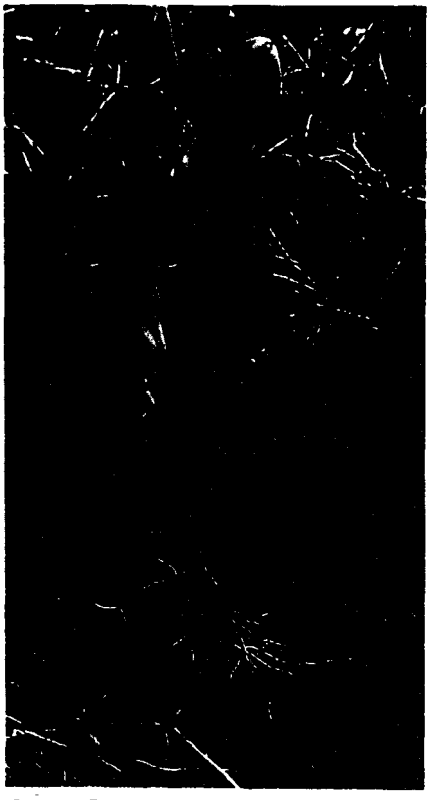

Plate 5.4. *A. mangium* grown in a medium of tropical peat and rice husk. Note new root development. *Photo*: Enso

than haphazard collection from different locations (Poole 1987).

Different types of compost have also been used as seedling media. Trials in South Kalimantan tested 13 different compost substrates with *A. mangium*. Compost of rice straw, maize stems, and leaves, mixed with 50% or 30% topsoil, produced the best growth and survival. Bagasse yielded good height but poor diameter growth. Pure compost media (maize and rice straw), excluding bagasse, yielded poor survival. In the same trial, peat and rice husk (70:30) yielded moderate growth but highest survival (Rusmana 1993, pers. communication). Newman (1989a) reported the results of using sawdust as germination medium for *A. mangium* at SAFODA's nursery. Two seedlots of this species were germinated outside in trays in the shade in three media: soil/sand (2:1), old (mixed species) sawdust, and fresh (mixed species) sawdust. Control seeds were germinated in petri dishes in a germinating cabinet. Germination reached 80% in the control and in the soil/sand and old sawdust media but did not occur at all in fresh sawdust.

Tropical peat and compost have the additional advantage of light weight for transport and planting.

Filling Pots

For direct sowing, substrate should be filled to 2-5 mm below the edge of the container in order to allow additional spreading of the cover material (for example, sand) over the seeds. The compaction of different substrates varies and should be considered in each case.

When pricking-out is practiced, the container should be completely filled with substrate and leveled to the edge.

Regardless of substrate or container, the growth media should be neither too compact nor too loose. Compacting the substrate too much is likely to create anaerobic conditions and inhibit absorption of water by the media. This generally results in bad-quality seedlings with poor root and shoot growth. On the other hand, filling the substrate too loosely decreases the container volume when the pots are watered, and causes the substrate to dry quickly. If seedlings are transported to the field without the container, loosely filled rootballs do not retain adequate strength.

A. mangium seems to be somewhat sensitive to compact substrate and poor aeration, which results in stunted growth and yellowish seedlings. Care must also be taken when mixing the substrates. An unevenly mixed substrate results in irregular seedling growth.

Bare-Rooted Seedlings

Advantages of bare-rooted seedlings are that they:

- are cheaper to produce in the nursery,
- make for compact and light seedling transport,
- are easy and quick to plant, and
- form better root system after planting (Schroeder 1987).

However, careless handling of the seedlings may lead to heavy losses. Higher risks during transport and planting discourage the use of this system, especially in the tropics.

Little information is available on growing *A. mangium* as bare-root seedlings. Schroeder (1987) records successful trial and pilot plantations with bare-rooted *A. mangium* in the Philippines, where the growth time was 15 weeks, compared to 12 weeks for potted planting stock. The bare-rooted plants also required a longer conditioning time.

Watering

Adequate moisture during the nursery stage is essential for proper seedling growth. Insufficient watering leads to wilting and stunted seedlings (FAO 1987; Supriadi and Valli 1988). On the other hand, excessive watering results in tender, overgrown succulent plants with poor root development.

There are no fixed rules about how often to water or how much water is required. The watering schedule depends on temperature, air humidity, wind velocity, rainfall, evaporation, tree species and size, and the substrate. The only way to find the optimum watering regime is through observation and experience. Supriadi and Valli (1988) describe a practical method for determining the need for watering when using pot trays and peat substrate with *A. mangium*: measure the periodic loss of water in evapotranspiration on a weight basis. (In a nursery trial in South Kalimantan, the average evapotranspiration loss was 9.6 l in the open and 5.5 l in shade.)

The substrate should be checked daily. In addition to having the right amount of moisture, the root ball should be evenly wet. Manual watering requires more intensive supervision. Seeber (1986) describes various types of irrigation.

Fertilizer Application

A suitable source of fertilizers is essential for good seedling growth in the nursery. *A. mangium* appears to be an easy species to manage in the nursery from the point of view of nutrition and fertilization. Both chemical and organic fertilizers (for example, cow dung, chicken manure, or compost) have been used. If organic fertilizers are applied, they should constitute about 20% of the total media (FAO 1987).

The need for different fertilizers varies with the type of the substrate and probably also with climate. Generalizations are dangerous; local trials are necessary to find the most suitable type and method of nursery application.

Large-scale production of *A. mangium* seedlings in South Kalimantan has used locally available chemical fertilizers. The following procedure and doses have been used with local peat and rice husk (70:30) as the main substrate.

Basic Fertilization

Before pricking out, a basic dose of fertilizers is applied using TSP (Triple Super Phosphate, P_2O_5 45-48% P). A dose of 10g/m^2 is applied manually in 1% solution using watering cans. Basic fertilization takes place 2-3 days before pricking out.

Fertilization During the Growing Period

In addition, NPK fertilizer (15:15:15) is applied twice weekly (19 times in all), for a total dose of 225 g/m^2 during the nursery period. The first fertilization is done 10 days after pricking out. The concentration of the solution is gradually increased from 0.5% to 1.5%. Doses vary according to the growth, from 5 g during the first two weeks to 10-15 g in the subsequent period. Generally, the fertilizer is dissolved in water and applied through the irrigation network, or manually using watering cans. The dosage mentioned here is applicable to peat and rice husk substrate, which is generally low in nutrients.

After applying fertilizers, a light watering is necessary to wash away the fertilizer's residue from the leaves.

Discontinue fertilization 15-25 days before delivering the seedlings in order to improve their lignification (Supriadi and Valli 1988). Table 5.6 shows the fertilization regime for the whole nursery period.

Heavy rainfall can leach nutrients from the substrate, and may necessitate additional fertilization. An instrument for measuring the electrical conductivity (EC) of the water pressed out from the substrate can help in determining the need for additional fertilizer treatment by providing a quantitative measure of salt content. Monitoring the EC of the irrigation water and of the leachate from the containers permits recognition of sudden changes. A rule of thumb is that the EC

Table 5.6. Fertilization regime using local tropical peat and rice husk as medium.

Phase*	Days after pricking	Frequency	Interval (days)	Grams/ m^2	Concentration (%)
BF	2-3	1		10	1
F	10-16	3	3	5	0.5
	19-36	5	3	10	1
	39-55	8	3	15	1.5
	58-64	3	3	10	1
	> 65, no fertilization		-	-	-

*BF = Basic fertilization with Triple Super Phosphate (TSP, 48 P); F = Fertilization during the nursery growing period with NPK (15:15:15). *Source:* Supriadi and Valli (1988)

of the leachate should be 1.5-2 mm hos. Tinus and MacDonald (1979) provide detailed definitions and an explanation of the use of an EC meter. Daily visual inspection of the seedlings is important.

Fertilization trials conducted with *A. mangium* indicate that it is not specifically sensitive to high doses of fertilizers. Adjers (1987) found that doses of up to 20 g NPK/m^2/week still increased seedling height and diameter growth with no significant decrease in survival. The differences among the four treatments, ranging from 0-20 g/m^2, yielded a significant difference both for height and diameter growth, but only when comparing the control and the fertilized treatments.

Role of Rhizobia

Like other legumes, *A. mangium* lives in symbiosis with nitrogen-fixing organisms in the soil. In its natural habitat it is infected with *Rhizobium*. Some strains of *Rhizobium* are more effective than others with *A. mangium* (NFTA 1989). Dart et al. (1991) report that in nursery trials with *A. mangium* in the Philippines, different *Rhizobium* strains accounted for large increases in biomass (32-1,120%) and plant height (64-270%)(see Chapter 6).

A. mangium nodulates easily in the nursery in a tropical peat and rice husk mixture. In South Kalimantan, millions of *A. mangium* seedlings have been produced with no additional inoculation (Supriadi and Valli 1988).

Root Pruning and Weeding

Advantages of root pruning in the nursery are that it:

- activates the development of lateral roots
- reduces damage to the root ball and seedlings during lifting

- reduces damage to reusable containers
- speeds up packing of seedlings (Supriadi and Valli 1988)

The need for root pruning depends on the substrate and type of containers and their volume. In larger containers, root pruning can be done less frequently.

Roots should be pruned before they become too big and penetrate deep into the soil. Root pruning can be done manually with fingers. Scissors are also an option but they get blunt quickly.

Using pot trays (45 pots per tray, with 180 cm^3 volume) with a peat and rice husk substrate (70:30), as in South Kalimantan, two root prunings are usually required during the 3- to 4-month nursery period. The first root pruning is carried out 6-8 weeks after pricking; the last takes place 7-10 days before seedling dispatch (Supriadi and Valli 1988). Even if seedling delivery is delayed, root pruning is carried out as scheduled.

The need for root pruning can be avoided or greatly reduced by raising the containers from the soil surface. When the roots grow out of the containers and become exposed, they die ('air-pruning'). Air pruning is used at the nursery of P.T. Indah Kiat Pulp and Paper Corporation (Werren 1990).

Proper weeding is important for good growth and health of *A. mangium* seedlings in the nursery. In seedbeds and containers, weeds can be pulled by hand, and should be done regularly to prevent weeds from growing too large.

For keeping the nursery surroundings clean from weeds after seedling dispatch, herbicides are safe to use and less costly than manual weeding.

Optimum Seedling Size and Hardening Off

Attempts have been made to reduce the nursery period to the minimum for achieving proper-sized *A. mangium* seedlings for planting out. A target size of 25-40 cm height (Plate 5.5) has been achieved in 12 weeks (Poole 1987; Udarbe and Hepburn 1986). Although establishment and subsequent growth in these cases was good, the seedlings were "soft" and easily damaged by handling and desiccation. This is avoided by extending the nursery period by 3-4 weeks to harden the seedlings. Generally, when fertilizers are used in the nursery it is essential to harden off seedlings before they are dispatched to the planting site.

Hardening off is achieved by progressively reducing nitrogen fertilization and watering. Seedlings should also be exposed to full sunlight. This procedure is designed to slow growth, reduce lush foliage, and encourage woodiness (FAO 1987). In South Kalimantan, fertilization is completely discontinued 15-25 days before the anticipated delivery day (Supriadi and Valli 1988).

Plate 5.5. Three-month-old seedlings ready for planting in the field. *Photo*: M. Temmes

Lopping Seedlings

Generally, the ideal height of an *A. mangium* seedling ready for planting is 25-40 cm. However, if seedlings have grown larger than this in the nursery due to unavoidable reasons, they can be lopped (Perkins 1992). This has been done with no adverse effect on seedling development in a planting trial in South Kalimantan. A new leader forms within a relatively short period and does not affect the plant's form in subsequent growth (Adjers and Luukkanen 1988).

Grading

No poor-quality seedlings should be used as planting material. Extra costs of replanting and weeding can be avoided by planting only high-quality seedlings. Before dispatch, the seedlings should be graded at the nursery. Important factors in grading the seedlings in the nursery are:

1. *Health*. Seedlings should be free from diseases and insect infestation.

2. *Freshness*. Wilted or half dry seedlings should be rejected outright. Before lifting and during temporary storage at the nursery or field site, always keep the seedlings moist. Although *A. mangium* appears not to be sensitive to drying, die-back of dry seedlings may occur after planting.

3. *Root system.* Seedlings should have a well-developed lateral root system, rather than a long tap root. A compact root system makes planting easier and prevents breakage of the root ball.

   When using pot trays, the protective container is not sent to the field. Then it is essential to have a well-developed root system which will prevent the root ball from breaking.

4. *Stem.* The most important aspect here is the stem diameter; it should be relatively thick and woody (cf. age and size). A regular, well-shaped crown is preferred.

5. *Shoot/root ratio.* The best indicator of plant quality is the ratio between shoot and root weight, which should be well balanced. In general, the quality of the seedling is better if the root system is larger relative to the crown. A plant with a favorable shoot/root ratio will resume growth faster and have little chance of mortality.

6. *Size and age. A. mangium* seedlings can be outplanted three months after sowing, by which time they should be 25-40 cm high and have a minimum diameter of 3 mm at the root collar (Supriadi and Valli 1988).

When using pot trays, seedlings can be lifted in two turns. The best seedlings are taken during the first lifting and the suppressed ones are left for about 3-4 more weeks in the nursery. One trial showed that *A. mangium* seedlings of the second lift grew nearly at the same rate as the first one. The seedlings from the first lift were nonetheless taller and thicker in diameter after 14 months in the field (Adjers 1988).

Cost of Seedling Production

While *A. mangium* is not demanding in the nursery, it is important to keep the cost of seedling production to a minimum, especially in planning large plantation projects. Reliable information on seedling production costs is difficult to obtain. Generally in the region, estimates vary from US$0.02 to $0.031 per seedling, depending on the nursery type and size.

There is a growing tendency to switch from the conventional system using polythene bags toward mechanized root-retainer nursery systems. Although root-retainer systems are more expensive to establish and maintain, especially in the initial years, high initial investments in infrastructure and facilities have little impact on the long-term cost of seedling production, and reports show that the root-trainer system can give better seedling growth and survival.

The Central Nursery Establishment Project in Indonesia illustrates the magnitude of investment. The nurseries in this project use the ENSO root-trainer system to produce millions of seedlings of *A. mangium* and other fast-growing species. The price per seedling calculated was US$0.053. In two smaller nurseries with annual production of 6 million seedlings, seedling production was slightly more expensive: US$0.061 and $0.066 (Mantyla in press). Although slightly higher than conventional poly-bag nurseries, the better growth and survival of seedlings in the field are judged to fully compensate this difference.

Summary

Nursery practices for *A. mangium* are not very demanding. The species' ease of management in the nursery probably accounts for the scarcity of information on specific nursery practices.

With the establishment of seed production stands and seed orchards in many countries where *A. mangium* is grown on a large scale, seeds are now easily available. However, there remains a need to collect good-quality seeds of specific, potentially better provenances from virgin populations.

Seeds should be collected when the pods turn very dark green to light brown.

Seeds must be pretreated; following the procedure for hot water pretreatment precisely gives the best germination results in seed trays or containers.

Damping off, the most serious disease during the nursery stage, can be controlled by use of fungicide and cultural practices.

For best results, use the most suitable seedling containers of up to 300 cc.

Use a standard, uniform substratum in the containers; either topsoil mixed with compost or a mixture of tropical peat and rice husk (between 70:30 and 90:10, depending on the characteristics of the peat).

The optimum height of seedlings for outplanting is 25-40 cm; this can be achieved in 12 weeks with proper fertilizer application, allowing another 3-4 weeks for hardening. Only the best seedlings should be planted out after proper grading.

In the Asia-Pacific region, the cost of seedling production varies between US$0.02 to $0.066.

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References

Adjers, G. 1987. Tropical peat in Southeast Asia and its use as growth substrate in a forest tree nursery in South Kalimantan, Indonesia. M.Sc. thesis, Department of Peatland Forestry, Faculty of Forestry, University of Helsinki, Finland.

Adjers, G., S. Huurinainen, and O. Luukkanan. 1988. Effect of different Indonesian peats and dolomite lime dosages on *Acacia mangium* seedlings in a forest tree nursery in South Kalimantan. Mechanized Nursery and Plantation Project in South Kalimantan (ATA-267) Research Paper No. 1. Jakarta, Indonesia: Ministry of Forestry of Indonesia, Enso Gutzeit, Finnish International Development Agency and University of Helsinki.

Adjers, G. and O. Luukkanen. 1985. Experiments in a forest nursery in South Kalimantan, Indonesia. Performance Review No. 4. Mechanized Nursery and Plantation Project in South Kalimantan (ATA-267). Jakarta: Ministry of Forestry of Indonesia, Enso Gutzeit Ltd, FINNIDA and University of Helsinki, Department of Silviculture.

———. 1988. Field comparison of *Acacia mangium* seedlings with damaged and intact top shoots. In Trials established in 1986-1987 in the Mechanized Nursery and Plantation Project in South Kalimantan. Research Paper No. 2. Mechanized Nursery and Plantation Project in South Kalimantan (ATA-267). Jakarta: Ministry of Forestry of Indonesia, Enso Gutzeit Ltd, FINNIDA and University of Helsinki, Department of Silviculture.

Bowen, M.R. and T.V. Eusebio. 1981. *Acacia mangium*: Updated information on seed collection, handling and germination testing. Occasional Tech. and Scientific Notes: Seed Series No. 5. Sepilok, Sabah: Forest Research Centre Pub. 26 pp.

———. 1982. Seed handling practices for fast growing hardwoods for humid tropical plantations. *Malay. For.* 45(4): 534-547.

Dart, P., M. Umali-Garcia, and A. Almendras. 1991. Role of symbiotic associations in nutrition of tropical acacias. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 13-19. ACIAR Proceeding No. 35. Canberra, Australia: Australian Council for International Agricultural Research.

Doran, J.C. and B.V. Gunn. 1987. Treatments to promote seed germination in Australian acacias. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 57-63. ACIAR Proceedings No. 16. Canberra, Australia: ACIAR.

Doran, J.C., J.W. Turnbull, D.J. Boland, and B.V. Gunn. 1982. *Handbook on Seeds of Dry-zone Acacias*. Rome: FAO.

Evans, J. 1982. *Plantation Forestry in the Tropics*. Oxford: Clarendon Press.

FAO. 1985. *A Guide to Forest Seed Handling with Special Reference to the Tropics*. FAO Forestry Paper 20/2. Rome: FAO.

———. 1987. *Nitrogen Fixing Trees: A Training Guide*. RAPA Publication 1987/15. Bangkok, Thailand: Regional Office for Asia and the Pacific (RAPA), Food and Agriculture Organization of the United Nations.

———. 1988. *Nitrogen Fixing Trees for Wastelands*. RAPA Publication 1988/9. Bangkok, Thailand: RAPA, FAO.

Gunn, B.V., M.W. McDonald and C. Gardner. 1989. *1988 Seed Collections of Tropical Acacias in Papua New Guinea and North Queensland*. Canberra, Australia: Australian Tree Seed Centre, CSIRO.

Gunn, B.V. and S.J. Midgely. 1991. Exploring and accessing the genetic resources of four selected tropical acacias. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 57-63. ACIAR Proceedings 35. Canberra, Australia: ACIAR.

Gunn, B.V., J. Morse and L.A.J. Thompson. 1990. *1989 Seed Collections of Tropical Acacias in Papua New Guinea and North Queensland*. Canberra: ATSC, CSIRO.

Hondromono. 1988. Improvement of growth and quality of *Acacia mangium* seedlings by using several types of medium. *Bulletin Penelitian Hutan* No. 502: 17.26. Bogor, Indonesia: Pusat Penelitian Pengembangan Hutan.

Jackson, K.F. 1987. *Manual of Afforestation in Nepal*. Nepal-United Kingdom Forestry Research Project. Kathmandu, Nepal: Forest Survey and Research Office, Department of Forests.

Malmivaara, E. 1992. Team-leader, Central Nurseries Establishment Project, Jakarta. Personal communication.

Mantyla, J. In press. *Nursery Manual for Central Nursery Establishment Project.* Jakarta: Ministry of Forestry and ENSO Forest Development, Ltd.

Morse, J., M.W. McDonald and T.K. Vercoe. 1991. *1990 Seed Collections of Tropical Acacias in North Queensland and Papua New Guinea.* Canberra: ATSC, CSIRO.

National Academy of Sciences. 1983. Innovation in tropical reforestation. In *Mangium and Other Fast Growing Acacias for the Humid Tropics.* Washington, DC: National Academy Press.

Newman, V. 1989a. Occasional Technical & Scientific Notes: Results of media trials using saw dust on germination of *Acacia mangium* (Willd.) seedlings. Forest Res. Centre Pub. No.2/89. Sandakan, Sabah: Forest Research Centre. 17pp.

———. 1989b. Occassional Technical & Scientific Notes: Effects of pretreatments on germination of *Acacia mangium* (Willd.) seeds in Sabah. Forest Research Centre Publ. No 3/89. Sabah: Forest Research Centre. 14 pp.

Nitrogen Fixing Tree Association. 1989. *A Guide to the Establishment of Research and Demonstration Plantings of Nitrogen Fixing Trees.* Waimanolo, Hawaii: NFTA.

Perkins, L.A. 1992. Queensland Forestry Service, Ingham Nursery, Byfield, Queensland, Australia. Personal communication.

Poole, B.R. 1987. Nursery and establishment practices for *Acacia mangium* in Sabah. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 170-172. ACIAR Proceedings No. 16. Canberra: ACIAR.

Rusmana, E. 1993. Trials Supervisor, Reforestation and Natural Forest Management Project (ATA-267), personal communication.

Schroeder, P.F. 1987. *Nursery Procedure Manual.* Manila, Philippines: ASEAN-New Zealand Afforestation Project.

Seeber, G. 1976. Nursery techniques. In *Manual of Reforestation and Erosion Control for the Philippines*, ed. H.J. Weidelt. Eshborn, Germany: Schriftenreihe der Deutchen Gasellshaft fur Technische Zusammenarbeit (GTZ).

Sim, B.L. 1987. Research on *Acacia mangium* in Sabah. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 164-166. ACIAR Proceedings No. 16. Canberra, Australia: ACIAR.

Skelton, D.J. 1987. Distribution and ecology of Papua New Guinea acacias. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 38-44. ACIAR Proceedings No. 16. Canberra, Australia: ACIAR.

Suomela, K., O. Luukkanen, and G. Adjers. 1988. Local peat as growth substrate in a forest tree nursery in South Kalimantan. Research Paper No. 4, Mechanized Nursery and Plantation Project in South Kalimantan (ATA-267). Jakarta: Ministry of Forestry of Indonesia, Enso Forest Development, FINNIDA and University of Helsinki, Department of Silviculture.

Supriadi, G. and I. Valli. 1988. *Nursery Manual.* Mechanized Nursery and Plantation Project in South Kalimantan (ATA-267). Jakarta: Ministry of Forestry of Indonesia, Enso Forest Development, and FINNIDA.

Tinus, R.W. and S.E. MacDonald. 1979. *How to Grow Tree Seedlings in Containers in Greenhouses.* Washington, D.C.: USDA Forest Service Gen. Tech. Rep. RM-60.

Udarbe, M.P. and A.J. Hepburn. 1986. Development of *Acacia mangium* as plantation species in Sabah. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 157-159. ACIAR Proceedings No. 16. Canberra: ACIAR.

Valli, J. 1993. Assistant Team Leader, Central Nurseries Establishment Project, Jakarta, personal communication.

Valli, I. and E. Rusmana. 1990. Trial of direct sowing into containers with *Acacia mangium, Cassia siamea* and *Paraserianthes falcataria.* Mechanized Nursery and Plantation Project in South Kalimantan (ATA-267) Technical Report No. 5/IV. Jakarta: Ministry of Forestry of Indonesia, Enso Forest Development and FINNIDA.

Werren, M. 1990. The improvement programme yielding results: P.T. Indah Kiat pulp wood plantations project. *Know-how Wire, Jaakko Poyry Client Magazine* No. 3.

———. 1991. Plantation development of *Acacia mangium* in Sumatra. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 107-109. ACIAR Proceeding No. 35. Canberra, Australia: ACIAR.

Chapter 6

Symbiotic Associations

Reynaldo E. de la Cruz and Kovith Yantasath

Introduction

Acacia mangium's popularity is partly due to its ability to establish well on adverse sites. *A. mangium* can grow successfully in degraded grasslands where it competes well with noxious grasses such as *Imperata cylindrica*. Once established, the excellent canopy of *A. mangium* can shade out these grasses. Introduction of *A. mangium* is not always successful, however. This points to the fact that, like all other species, *A. mangium* has growth limitations related to problems with site adaptation.

The last 12 years have seen great scientific interest in mycorrhiza as a key to enhancing tree growth on degraded grasslands for reforestation of these areas in the Asia Pacific region. Two Asia-wide Conferences on Mycorrhiza in India and Thailand have assembled mycorrhiza researchers in the region. Research on biological nitrogen fixation, particularly by *Rhizobium*, has also experienced advances, having begun even before the growth of mycorrhiza studies. The new field of biotechnology has further added to the momentum of both mycorrhiza and *Rhizobium* research.

A. mangium forms natural associations with both *Rhizobium* bacteria and vesicular-arbuscular mycorrhizal (VAM) fungi. This chapter reviews existing knowledge about site adaptation of *A. mangium* related to its symbiosis with rhizobia and mycorrhiza.

Tree Growth and Symbiotic Associations

Like other leguminous trees, *A. mangium* can grow well on infertile soils, including those under grasslands, in part because of its association with symbiotic soil organisms, including mycorrhiza and *Rhizobium* (dela Cruz and Garcia 1991) (Plate 6.1). The tree roots provide these organisms with excess carbohydrates and

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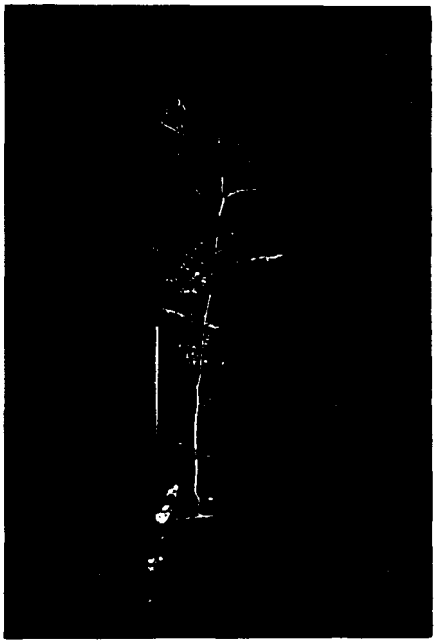

Plate 6.1. *A. mangium* seedling with *Rhizobium* nodules on the roots. *Photo*: Kovith Yantasath

other metabolites; in turn, the mycorrhiza and rhizobium make soil nutrients available to the tree, particularly nitrogen and phosphorus (Supriadi and Valli 1988). Many trees require rhizobia and/or mycorrhiza in order to survive and grow in natural forest ecosystems.

Rhizobia are soil micro-organisms found in root nodules of leguminous trees and plants that can "fix" atmospheric nitrogen. Most *Acacia* species nodulate with *Rhizobium* to fix nitrogen (Nakos 1977). For most of their existence, rhizobia live as free-living bacteria in soil, surviving and growing in the absence of a host legume. The legume plant root recognizes only selected kinds of *Rhizobium* among other bacteria (including other rhizobia in the vicinity). Likewise, the nodulating *Rhizobium* recognizes only the selected legume roots among all the other roots which may occur in that environment (Schmidt 1978).

Many nitrogen-fixing tree species particularly depend on mycorrhiza for absorbing nutrients required for plant growth and efficient nitrogen fixation.

As with rhizobia, studies have shown that under some conditions, mycorrhizal fungal inoculation can increase growth of trees in plantations (Marx 1980; Garbaye and LeTacon 1986). In the tropics, however, the potential for improving growth of hardwoods through mycorrhizal inoculation has often been neglected (Mikola 1980). Most of the increase in tree growth related to mycorrhizal inoculation can be attributed directly to increased nutrient uptake, but mycorrhiza may also benefit trees by reducing the effects of stress related to drought and transplantation (Parke et al. 1983), extreme soil conditions of high soil temperatures, high Aluminum, and low soil pH (Bowen 1980), and some soil-borne pathogens (Marx 1973).

Rhizobium and Nitrogen Fixation

Annual nitrogen fixation rates for cultivated legumes range from 10-40 kg/ha/year (Nutman 1976); pasture legumes fix 100-200 kg/ha/year (Date 1973); and woody legumes range from 1.8-18.8 kg/ha/year (Langkamp et al. 1979). Nitrogen fixation rates for acacias are reported to be 10-32 kg/ha/year (Adams et al. 1981).

Nodulation with Interaction with Other Treatments

In a nursery experiment on the effect of liming and inoculation of *A. mangium* in the presence or absence of NPK fertilizer, Cali (1991) reported that inoculation independently improved height, shoot biomass, nodule weight, and nitrogen content and uptake of *A. mangium*. The relationship between shoot biomass and nodule number, nodule weight, and N-uptake was highly significant.The study used Annam clay with pH 5.9 and 0.74% OM and Adtuyon clay loam with pH 6.2 and 5.31% OM. In Adtuyon clay loam, the local *Rhizobium* isolate Am_2 could replace about 91% of the N requirement for *A. mangium* growth.

In that study, Cali (1991) also found that liming did not improve seedling growth and nodule development. The seedlings grew well in both soils when fertilized with 200 kg N/ha + 100 kg PK/ha; the second best treatment was inoculation with *Rhizobium* in the presence of only P and K. Height, diameter, and nodule weight were significantly affected by the interaction of lime, inoculation, and fertilizer treatments.

Cabahug (1991), studying early growth of *A. mangium* in a grassland soil (0.05% N, 23.12 me Ca/100 g, 6.34 me Mg/100 g, 0.85 me K/100 g, 10.53 ppm P, 1.04% OM, pH 6.4, and a cation exchange capacity (CEC) of 30 me/100 g), found that increasing levels of N gave a general trend of improved growth performance and nodulation. In the presence of N at the rate of 100 kg/ha, inoculation improved nodulation by 193.6% over the unfertilized inoculation treatment. Application of 300 kg N/ha decreased nodulation but did not affect nodule weight. The soil used in this study had high populations of native rhizobia, so that N-amendments of 30-100 kg N/ha improved infection of roots by these native rhizobia. However, inoculation with a more effective strain could enhance growth of *A. mangium* even more.

Identifying Effective Strains

Acacia species can be classified into three groups according to effective nodulation response patterns with fast and slow growing tropical strains of *Rhizobium*. The first group nodulates effectively with slow-growing, cowpea-type strains; the second group nodulates with tropical, fast-growing strains; and the third group nodulates with both fast- and slow-growing strains (Dreyfus and Dommergues 1981).

Souvannavong and Galiana (1991) collected, isolated, and characterized *Rhizobium* strains from *A. mangium* natural range in Australia, as well as in Côte d'Ivoire, Senegal, Congo, China, and French Guyana, where it had been introduced. Of the 42 strains isolated, those nodulating *A. mangium* were all found to belong to the *Bradyrhizobium* group. *In vitro* and greenhouse tests, as well as nursery and field trials established in Benin, Côte d'Ivoire, and the Cook Islands, indicated variable efficiency among the strains, with the Australian strains being the most efficient.

Dart et al. (1991) isolated 12 *Rhizobium* strains from *A. mangium*. None of the 12 strains nodulated *A. auriculiformis* effectively, leading the authors to conclude that *A. mangium* was more specific in its *Rhizobium* affinities than *A. auriculiformis*. Their studies suggest that many of the strains naturally present in soils are only partially effective with many *Acacia* species, and that responses to inoculation can be obtained with young seedlings. After outplanting, the competition between inoculant strains and native rhizobia population changes as the inoculant strains need to colonize new roots formed. This report stresses the need to inoculate seedlings with *Rhizobium* that are effective in fixing atmospheric nitrogen and aggressive enough to compete with less-efficient native strains.

Technologies for the mass production of rhizobial inoculants are available. Inoculants containing effective strains of *Rhizobium* for *A. mangium* are available from the Nitrogen Fixation in Tropical Agricultural Legumes (NiFTAL) Project in Hawaii, USA; the Biological Nitrogen Fixation Resource Center for South and Southeast Asia in Thailand; and from BIOTECH, at the University of the Philippines at Los Baños (UPLB).

Combined Effects of Mycorrhiza and *Rhizobium*

It is difficult to isolate the effect of mycorrhiza on the growth of *A. mangium* without also considering the effect of *Rhizobium*. Thus, many reports in the literature include dual effects of mycorrhiza and *Rhizobium*.

Reddell and Warren (1987) reported that *A. mangium* forms associations with VAM fungi, and subsequent research suggests that this is the tree's dominant mycorrhizal association. Yantasath (1989) and Poonsawad and Yantasath (1991) reported that *Acaulospora* spp. and *Glomus* spp. were some of the dominant strains of VAM found in large numbers in acid sandy soils (pH 4.3-5.0) associated with *A. mangium*. Among ectomycorrhizal fungi, fruiting bodies of *Thelephora ramariodes* have been observed under plantations of *A. mangium* in Malaysia (Gibson 1981; Lee 1990) and the Philippines. However, this fungus probably does not form a true ectomycorrhizal association because it does not show typical symptoms, including fungal sheath and Hartig net. Nor are there demonstrated growth increases from inoculation with *Thelephora*. More studies of possible ectomycorrhizal associations in *A. mangium* are warranted.

Only plants dependent on mycorrhiza for their growth show positive responses to inoculation with VAM fungi in growth and nutrient uptake (Yantasath and Poonsawad 1991). Chemical fertilizers can improve tree growth, but once the fertilizer is exhausted, growth will cease. Fortunately, native VAM populations where trees are planted (especially in logged-over areas and degraded grasslands) are often adequate for at least minimal growth. Tambalo-Zarate and dela Cruz (1991), in screening 18 crops (6 agronomic, 6 fruit species, and 6 reforestation species) for their responses to VAM inoculation, found *A. mangium* to be mycorrhizal-dependent; that is, it would not survive in soils of marginal fertility with-

out forming VAM associations. Introduction of *A. mangium* in some parts of the tropics has thus been successful partly due to the presence of native VAM fungi. VAM fungi are not specific in their associations with crops.

The major factor limiting the large-scale use of mycorrhiza in the establishment of *A. mangium* has been the scarcity of cheap but effective mycorrhizal inoculants. Unlike ectomycorrhizal fungi, VAM fungi have not been isolated *in vitro* in the laboratory, making mass production of inoculants for nursery use difficult. The standard practice is to isolate the spores of VAM fungus by wet-sieving and decanting techniques, and inoculating these to the roots of trap plants (grown in soil) such as corn, sorghum, or other grasses. The spores germinate around the roots of the trap plant, sending out numerous mycelia which later invade the roots where they proliferate and sporulate. After 4-5 months, the potting soil—together with spores and infected roots—are harvested and used as inoculants.

Commercial VAM inoculants have been available on the market. Earlier, an important inoculant was NUTRI-LINK, which was produced in Salt Lake City, Utah, USA, and contained a single VAM fungus species. However, this product was phased out due to failed attempts to enhance growth of target crops, and contamination problems. Other inoculant technologies incorporated VAM into expanded clays, but use of this, too, has been limited due to contamination problems. Limited quantities of inoculants are produced by the nutrient film technique in UK, aerophonics in Florida, USA, and by root tissue culture in the USA.

In the Philippines, two VAM inoculants are produced by BIOTECH at UPLB under the commercial names MYKOVAM 1 and MYKOVAM 2. For MYKOVAM 1, three species of VAM fungi are grown separately in trap plants (Pensacola Bahia grass) using sterilized 3:1 soil:sand mixtures. After 4-5 months, the roots are harvested and the soil mixtures of the 3 VAM species are mixed thoroughly. The three species of VAM fungi in MYKOVAM 1 were earlier screened for effectiveness in promoting growth and yield of target crops. Spore counts determine the number of VAM propagules. MYKOVAM 1 is then added to target plants to give an inoculum potential of 50 spores/plant for container-grown seedlings and 200 spores/plant for field-grown seedlings. Most study results presented below are responses to inoculations with MYKOVAM 1.

MYKOVAM 2 is a granulated form of MYKOVAM 1 which resembles granular chemical fertilizers. It is easier to handle than MYKOVAM 1 and has a longer shelf life (6-8 months, as opposed to 3-4 months for MYKOVAM 1). MYKOVAM 2 can also be stored at room temperature.

Some VAM fungi are more effective than others in promoting *A. mangium* growth. Dela Cruz et al. (1988) found that *Glomus fasciculatus* + *Rhizobium* and *Gigaspora margarita* + *Rhizobium* were most effective. These promoted higher N concentration and N uptake of seedlings, higher P content and uptake, and higher nodule weight and nitrogen fixation rates. Treatments yielding consistently poor growth included inoculation with the VAM fungus *Sclerocystis*

Table 6.1. Periodic height growth (cm) of *Acacia mangium* inoculated with three VAM species in the nursery and outplanted in a degraded grassland.

	Nursery		Field (months)					
VAM species	2 mo	% incr.	2.5	5	7	10	15	24
Uninoculated	5.0	---	10.73	11.10	11.89	15.40 c	26.73 b	All dead
Glomus etunicatum	14.0	180	23.17	30.51	33.69	45.40 a	82.90 a	136.30
Gl. macrocarpum	13.5	170	23.52	31.96	37.73	49.20 a	78.59 a	126.78
Gigaspora margarita	11.11	22	22.93	31.46	37.50	42.20 a	75.22 a	111.70

Numbers in the same column followed by the same letter are not significantly different at p = 0.05. *Source:* Dela Cruz et al. (1991)

clavispora + R, inoculation by *Rhizobium* alone, and uninoculated control.

Table 6.1 summarizes the results of another study testing inoculation of *A. mangium* with three VAM species in the nursery, followed by outplanting in a degraded grassland. Inoculation with any of the three VAM species resulted in very significant increases in both height and diameter. Uninoculated seedlings were shortest and showed symptoms of nutrient deficiency. Seedlings inoculated with any of the 3 VAM species grew significantly taller than the uninoculated seedlings. After 24 months in the field, all uninoculated seedlings were dead.

Lorilla et al. (1992) tested inoculation of *A. mangium* in the nursery using *Glomus etunicatum*, *G. margarita*, or *Scutellispora calospora*. After 5 months, seedlings were outplanted in a degraded grassland. Five levels of chemical fertilizer (14-14-14) were applied (0, 5, 10, 25, and 50 g per plant) at planting. In the nursery, seedlings inoculated with *S. calospora* performed best of all the treatments (Table 6.2). In the field, Lorilla et al. (1992) reported that mycorrhizal treatments significantly increased seedling growth in terms of height and diameter. The most efficient VAM fungus remained *S. calospora* (Table 6.3). Interaction between VAM and fertilizer levels proved significant, with best growth obtained by seedlings inoculated with *S. calospora* in the nursery and fertilized with 50 g complete fertilizer per plant in the field. *G. margarita* replaced 54%,

Table 6.2. Height of *A. mangium* inoculated with VAM after 5 months in the nursery.

Mycorrhizal treatment	Height (cm)	Increase (%)
Uninoculated	19.9 b	---
Gl. etunicatum	16.3 b	-18
G. margarita	13.6 c	-32
S. calospora	30.7 a	54

Numbers in the same column followed by the same letter are not significantly different at p = 0.05. *Source:* Lorilla et al. (1991)

Table 6.3. Height growth (cm) of *A. mangium* in the field following inoculation with VAM fungi in the nursery and different chemical fertilizer treatments at outplanting.

VA mycorrhiza treatments	Fertilizer levels (g per plant)					Treatment means
	0	5	10	25	50	
Uninoculated	38.4 h	64.2 gh	91.6 efg	151.8 cd	147.0 cd	98.6 b
Gl. etunicatum	102.2 ef	146.6 cd	149.4 cd	170.4 c	216.5 b	157.0 ab
G. margarita	72.6 fg	120.2 de	121.3 de	212.4 b	218.8 b	149.1 ab
S. calospora	112.2 e	167.2 c	178.4 c	216.4 b	249.7 a	184.8 a
Fertilizer means	81.4 c	124.6 b	135.2 b	187.8 a	208.0 a	

Numbers in the same column followed by the same letter are not significantly different at p = 0.05. *Source:* Lorilla et al. (1992)

Gl. etunicatum 88%, and *S. calospora* 100% of the chemical fertilizers required for growth in the field.

Research in the Philippines is now incorporating VAM into traditional silvicultural technologies for growing *A. mangium*. In direct-seeding experiments, Dela Cruz et al. (1992b) placed *A. mangium* seeds into fabricated direct-seeding blocks (DSB) and inoculated them with either *Gl. macrocarpum, G. margarita* or combinations of the two fungi. Seeds received one of three pre-soaking treatments (soaked for 1 minute in hot water, 90°C; soaked overnight in tap water; soaked for 1 minute in hot water, then soaked overnight in tap water) to overcome seed dormancy. The DSB tested various combinations of agricultural waste materials (sugarcane bagasse, coconut coir dust, and sawdust) compressed into blocks about 2.5 cm high x 2.5 cm diameter. At one end, a 1.2 cm hole is punched in which the seeds and inoculants are placed. The DSB was directly seeded into pots containing soils collected from a degraded grassland. Seeds inoculated with *G. margarita* alone attained best height and diameter growth (Table 6.4).

Seeds inoculated with *G. margarita* alone attained best height and diameter growth. *A. mangium* seeds need to be pre-soaked for 1 minute in hot water (90°C) and then soaked overnight in tap water for best germination. Inoculation of the DSB with *Gl. macrocarpum* or combinations of *Gl. macrocarpum* + *G. margarita* also gave better height and diameter growth responses than the uninoculated control or DSB without mycorrhizal treatments.

MYKOVAM 2, the granulated form of VAM inoculant containing *G. margarita*, has also increased height growth of *A. mangium* , with inoculated seedlings averaging 10.6 cm taller than uninoculated seedlings after 4 months (17.5 cm compared to 6.9 cm, respectively)(Dela Cruz et al. 1992a). Nursery workers accustomed to handling chemical fertilizers appreciate the granular nature of MYKOVAM 2.

Table 6.4. Height and diameter growth of *Acacia mangium* in response to seed pre-soaking and DSB-VAM treatments.

Pre-soaking treatments	DSB-VAM treatments*					Pre-soaking treatment means
	U	DSB-M	DSB+M1	DSB+M2	DSB+M12	
			Height growth (cm)			
No treatment	0.0 g	0.0 g	0.0 g	0.0 g	0.0 g	0.0 c
Hot water	13.5 ef	19.2 de	18.0 def	42.3 b	15.3 ef	21.6 b
Soaked overnight	0.0 g	0.0 g	0.0 g	0.0 g	0.0 g	0.0 c
Hot water + soaked overnight	12.9 f	14.2 ef	22.1 d	49.8 a	38.0 c	26.6 a
DSB-VAM Treatment means	13.2 d	16.7 cd	20.1 bc	46.0 a	24.6 a	
			Diameter growth (mm)			
No treatment	0 e	0 e	0 e	0 e	0 e	0 c
Hot water	170 d	230 d	220 d	455 ab	200 d	255 b
Soaked overnight	0 e	0 e	0 e	0 e	0 e	0 c
Hot water + soaked overnight	175 d	180 d	305 c	525 a	425 b	322 a
DSB-VAM treatment means	172 d	205 cd	262 bc	490 a	312 b	

*U = Uninoculated with VAM; DSB-M = Direct-seeding block without mycorrhiza; DSB+M1 = Direct-seeding block with *Gl. macrocarpum*; DSB+M2 = Direct-seeding block with *G. margarita*; DSB+M12= Direct-seeding block with *Gl. macrocarpum* and *G. margarita*
Numbers in the same column followed by the same letter are not significantly different at p = 0.05. *Source:* Dela Cruz et al. (1992b)

Future Research

To obtain greater benefits from these symbiotic relationships, research should:

1. identify superior strains of *Rhizobium* that are effective in fixing nitrogen and aggressive enough to compete with less efficient native strains

2. determine the efficiency of selected *Rhizobium* strains under varying site conditions of soil fertility, soil texture, moisture regime, pH, and temperature

3. study the occurrence of ectomycorrhizal associations and their beneficial effects on *A. mangium*

4. combine superior strains of rhizobia, mychorrizal fungi, and highly improved *A. mangium* materials

Summary

A. mangium's success in the tropics is partly due to its ability to adapt to adverse sites, particularly *Imperata* grasslands, acidic soils of less than pH 4, areas subjected to periodic drought, and soils low in nitrogen and phosphorus. The species' ability to grow in degraded grasslands, where nutrients—particularly nitrogen and phosphorus—are deficient, may be attributed to its dual symbiosis with the nitrogen-fixing bacterium *Rhizobium* and VAM fungi.

A. mangium appears to be more specific in its associations with *Rhizobium* than other *Acacia* species, meaning that many *Rhizobium* strains isolated from *A. mangium* do not cross-inoculate other acacias. Some rhizobial strains are more effective than others in promoting *A. mangium* growth.

VAM fungi found to be more efficient in promoting *A. mangium* growth are *Gigaspora margarita, Glomus etunicatum*, and *Scutellispora calospora.*

Used together, effective *Rhizobium* strains and effective VAM fungi can increase early seedling growth in areas of marginal fertility and can economically substitute for large portions of early chemical fertilizer requirements in such areas. Technologies for commercial production of rhizobial and VAM inoculants are now available in the Asia region.

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References

Adams, M.A. and P.M. Attiwill. 1981. Role of *Acacia* sp. in regenerating *Eucalyptus regnans* F. Muel.: temporal changes in biomass and nutrient content. *Aust. J. Bot.* 32:205-215.

Bowen, G.D. 1980. Microorganisms and tree growth. In *Research for Forest Management*, eds. J.J. Landsberg and W. Parsons; 180-201. Melbourne, Australia: CSIRO.

Cabahug, R.D. 1991. Nodulation and seedling growth of kakawate (*Gliricidia sepium* (Jacq.) Steud.) and mangium (*Acacia mangium* Willd.) grown on a grassland soil from Batac, Ilocos Norte. MS thesis, University of the Philippines at Los Baños (unpublished).

Cali, C.A. 1991. Assessment of growth and nodulation of *Acacia mangium* Willd. and *Sesbania grandiflora* (L.) Pers. in two Philippine soil types. Ph.D. Dissertation, University of the Philippines at Los Baños (unpublished).

Dart, P., M.U. Garcia, and A. Almendras. 1991. Role of symbiotic associations in nutrition of tropical acacias. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 13-19. ACIAR Proc. No. 35. Canberra, Australia: ACIAR.

Date, R.A. 1973. Nitrogen, a major limitation in the productivity of natural communities, crops and pastures in the Pacific Area. *Soil Biochem.* 5:5-18.

Dela Cruz, R.E. 1979. Mycorrhiza: indispensable allies in forest regeneration in the tropics. In Proc. on Forest regeneration. Bogor, Indonesia: BIOTROP.

Dela Cruz, R.E., N.S. Aggangan, E.B. Lorilla and J.T. Zarate. 1991. Application of mycorrhizal fungi and *Rhizobium* for advanced silviculture. Paper presented at the Second Asian Conference on Mycorrhiza, Chiang Mai, Thailand, February 1991.

Dela Cruz, R.E. and M.U. Garcia. 1992. Nitrogen fixation and mycorrhizae in acacias on degraded grasslands. In *Tropical Acacias in East Asia and the Pacific*, eds. Kamis Awang and D.A. Taylor; 59-71. Bangkok, Thailand: Winrock International.

Dela Cruz, R.E., N.S. Aggangan, J.T. Zarate, and B.E. Lorilla. 1992a. Application of mycorrhizal technologies for agriculture and forestry. Paper presented in the Ninth International Biotechnology Conference,Washington D.C., USA, August 19-22, 1992. Sponsored by the American Chemical Society.

Dela Cruz, R.E., B.E. Lorilla, and J. Zarate. 1992b. Application of mycorrhiza in barerooting and direct-seeding technologies for reforestation. Paper presented at BIO-REFOR workshop, Tsukuba, Japan, May 19-21, 1992.

Dela Cruz, R.E., M.Q. Manalo, N.S. Aggangan, and J.D. Tambalo. 1988. Growth of three legume trees inoculated with VA mycorrhizal fungi and *Rhizobium*. *Plant and Soil* 108:111-115.

Dreyfus, B.L. and Y.R. Dommergues. 1981. Nodulation of *Acacia* species by fast and slow growing tropical strains of *Rhizobium*. *Appl. and Environ. Microb.* 41:97-99.

Garbaye, J. and F. Le Tacon. 1986. Effects de la mycorhization controlée apres transplantation. *Revue Forestiere Francaise* 3:258-263.

Gibson, I.A.S. 1981. Forest mycology. FAO/UNDP, Malaysia Consultant Report No. 3. Rome: FAO. 45 p.

Langkamp, P.J., L.B. Swinden, and M.J. Dalling. 1979. Nitrogen fixation (acetylene reduction) by *Acacia pellita* on areas restored after mining at Groote Eylandt, Northern Territory. *Aust. J. Bot.* 27:353-361.

Lee, S.S. 1990. The association of *Thelephora ramarioides* Reid with *Acacia mangium* Willd. In Proc. Third Int. Conf. Plant Protection in Tropics. Vol. IV, Genting Highlands, Malaysia: 171-173.

Lorilla, E.B., R.E. dela Cruz and J.T. Zarate. 1992. Growth of three reforestation species in response to inoculation with VA mycorrhizal fungi and fertilization. Paper presented at BIO-REFOR Workshop Conference, Tsukuba, Japan, May 19-21, 1992.

Marx, D.H. 1973. Mycorrhizae and feeder root diseases. In *Ectomycorrhizae, Their Ecology and Physiology*, eds. G.C. Marks and T.T. Kozlowski; 351-382. New York: Academic Press.

———. 1980. Ectomycorrhizal fungus inoculations: a tool for improving forestation practices. In *Tropical Mycorrhiza Research*, ed. P. Mikola; 13-71. New York: Oxford University Press.

Mikola, P. 1980. *Tropical Mycorrhiza Research*. New York: Oxford University Press.

Midgley, S.J. and K. Vivekanandan. 1987. Australian acacias in Sri Lanka. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 132-135. ACIAR Proc. No. 16. Canberra, Australia: ACIAR.

National Research Council. 1983. *Mangium and other Fast-growing Acacias for the Humid Tropics*. Washington, D.C.: National Academy Press.

Nokos, G. 1977. Acetylene reduction (N_2-fixation) by nodules of *Acacia cyanophylla*. *Soil Biochem.* 9:131-133.

Nutman, P.J. 1976. IBP field experiments on nitrogen fixation by nodulated legumes. In *Symbiotic Nitrogen Fixation in Plants*, ed. P.S. Nutman; 211-237. London: Cambridge University Press.

Parke, J.L., R.G. Linderman, and C.H. Black. 1983. The role of ectomycorrhizas in drought tolerance of douglas fir seedlings. *New Phytologist* 95:83-95.

Poonsawad, S. and K. Yantasath. 1991. Vesicular-arbuscular mycorrhiza in legumes cultivated soils in Thailand. Paper presented at the Second Asian Conference on Mycorrhiza, March 12-17, 1991, Chiang Mai, Thailand.

Reddell, P. and R. Warren. 1987. Inoculation of acacias with mycorrhizal fungi: potential benefits. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 50-53. ACIAR Proc. No. 16. Canberra, Australia: ACIAR.

Schmidt, E.L. 1978. Legume symbiosis: An ecology of the legume root bacteria. In *Interactions Between Non-pathogenic Soil Microorganisms and Plants*, eds. Y.R. Dommergues and S.V. Krupa; 269-304. Amsterdam: Elsevier and Oxford.

Souvannavong, O. and A. Galiana. 1991. *Acacia mangium-Rhizobium* symbiosis: selection and propagation of the host plant and the microorganism. In *Research on Multipurpose Tree Species in Asia*, eds. D.A. Taylor and K.G. MacDicken; 216-222. Bangkok, Thailand: Winrock International.

Supriadi, G. and I. Valli. 1988. *Nursery Manual: Mechanised Nursery and Plantation Project in South Kalimantan* (Indonesia-Finland) ATA-267. Umatra, Finland: Enso-Gutzeit OY, Forest Group, SF-55800.

Tambalo-Zarate, J.D. and R.E. dela Cruz. 1991. Inoculation of VA Mycorrhiza for the improvement of growth and yield of agricultural crops, fruit trees and forest tree species in a grassland soil. Paper presented at the 13th Annual Scientific Meeting, National Academy of Science, Philippines, July 9-10, 1991.

Yantasath, K. 1989. A new hope from mycorrhiza. *Sci. and Tech. J.* 3:2-4. Chatuchak, Thailand: Thailand Institute of Scientific and Technological Research. (In Thai.)

Yantasath, K. and S. Poonsawad. 1991. Effects of vesicular-arbuscular mycorrhiza on mineral nutrition and yield of plants. Paper presented at the Second Asian conference on Mycorrhiza held 12-17 March 1991, Chiang Mai, Thailand.

Chapter 7

Silvicultural Practices

P.B.L. Srivastava

Introduction

Acacia mangium is versatile in its growth and tolerance of varied site conditions and its adaptability to different planting objectives. While it shows most vigorous growth on well-drained, fertile soils in high rainfall areas (>2000 mm annually) in the humid tropics, it grows reasonably well on difficult sites with pH as low as 4.5, even on degraded forest sites and denuded catchments, and grasslands dominated by *Imperata cylindrica*, provided that rainfall and temperature are favorable. The species is successfully grown for pulpwood on 6- to 8-year rotations in Sabah, Malaysia and Sumatra, Indonesia, and can be grown for saw logs following proper silvicultural prescriptions on a longer rotation of 15-20 years (Chai 1984; Udarbe and Hepburn 1987; Werren 1991; Raymond Tan 1992). Mangium has also been tested as a potential agroforestry species for supplying fuelwood and timber (Kanua and Sitipai 1992; Gessesse 1992) as well as soil enrichment and afforestation of grasslands with marginal soils. The silvicultural practices therefore vary considerably, depending on the grower's objective and the trees' end use. This chapter deals mainly with current knowledge of silvicultural practices for industrial plantations.

Site Preparation

The following seven factors affect the initial growth, survival, and cost of establishment, and must be considered in preparing a site for *A. mangium* plantations:

- past and present vegetation
- climate
- topography
- soil type

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- soil fertility
- equipment
- availability of labor

In plantation forestry and land rehabilitation, the objectives of site preparation are to achieve high percentage of survival and initial uniform fast growth in order to capture the site.

When logged-over forest is to be converted to plantations, Mead and Miller (1991) recommend clear-felling followed by burning, instead of windrowing and then burning. The latter practice results in variable, uneven growth with comparatively lower yield. Results in Kemasul, Peninsular Malaysia show that windrowing and burning resulted in only 35% of the area being covered by ash beds, compared to over 90% in an adjacent broadcast-burnt area (Plate 7.1). Despite the application of fertilizers at planting, plants over the windrowed area as a whole averaged only 80 cm in height at age 4-5 months, compared to 120 cm on the broadcast burnt site. As is well known, a good broadcast burn has the advantages of:

- making available nutrients such as P, K, Ca, and Mg in the "A" horizon
- killing seeds and coppice shoots of weeds, resulting in reduced competition
- easy access during planting

A broadcast burn is a standard practice in rubber and oil palm plantations establishment.

Plate 7.1. Burn site after windrowing and mechanical clearing. *Photo*: Kamis Awang

From the management viewpoint, successful site preparation involves:

- avoiding loss of volatile nutrients, increased erosion, and nutrient run-off in high-rainfall areas.

- coinciding the burning operation with the dry season, which may be quite short in some places.

- minimizing the gap between burning and planting. If for some reason (unavailability of labor or planting stock) this period stretches out, the area could quickly be covered by weeds and require costly re-weeding before actual planting (Mead and Miller 1991).

In the event of a poor burn, further site preparation is needed; this can be carried out either manually or semi-mechanically. In manual preparation, woody materials taller than 15 cm, as well as all vegetation along the lines, are cut, heaped, and reburnt. In semi-mechanical preparation following broadcast burn, all remaining material is stocked by tractors or light bulldozers (less than 13 tons) with blades positioned 10 cm above ground level. The stacked material is reburnt, producing a clean planting site (Thang and Zulkifli 1992).

For planting *A. mangium* on poor secondary forests or scrubs, Mead and Speechly (1989) recommend two methods. On flatter areas (slopes <30%) at Bengkoka (in Sabah), managers at Sabah Forestry Development Agency (SAFODA) have successfully used a twin-drum Marden Chopper-roller. This requires a D-6 or preferably a D-7 tractor, results in well chopped and compacted material, and takes 2-3 machine hours per ha with a D-6 tractor. Burning after roller crushing produces a cleaner site for planting with less weed growth than an unburnt site; however, the value of retaining the vegetation as a mulch to improve soil fertility on such sites instead of burning it has not been investigated.

The second method, most practical for slopes >30%, is to slash the vegetation manually and burn; this requires 20-26 working days per ha. Even then, the site is not usually as uniformly clean as after the roller crushing operation. It may also require more weedings during or immediately after planting. However, the preference depends on the relative cost and availability of laborers and machines. Both these methods for site preparation are also used in Sumatra on the two types of sites (Werren 1991).

In grasslands dominated by *Imperata* and/or broad-leaf weeds (for example, *Eupatorium* spp.), burning to clear the site followed by chemical treatment is one option. At Bengkoka, trials have shown that spraying with Roundup (glyphosphate) at 4 l/sprayed ha gives 6 months effective control of *Imperata* grass. This chemical is less effective on broad leaves, but may give 3 months control if a pre-emergent spray, such as simazine, is included in the mix. Another chemical, imazapyr, has been found to be very effective on these weeds but has

caused residual side affects on *A. mangium* itself. Arif et al. (1990) describe a schedule for controlling *Imperata* in newly established *A. mangium* plantations based on field trials conducted in South Kalimantan from 1982 to 1989. *Imperata* was totally eradicated by site preparation during March-June, followed by spraying with glyphosphate in October, planting in February-March of the following year, and spot spraying with glyphosphate at the time of planting and for the following two years to prevent regrowth. According to the authors, benefits of this technique are:

- soil moisture conservation and erosion control provided by the mulch of dead *I. cylindrica*
- easy applicability in hilly terrain
- lack of herbicide residue in the soil
- non-toxicity to the environment and workers.

It is also cheaper than the mechanical method (US$150-245/ha up to one year after planting).

Another successful method is total ploughing with a farm tractor or bulldozer. In South Kalimantan, disc ploughing twice and harrowing once is carried out on sites free of stones and stumps (Plate 7.2). This achieves best results if the area is left to dry for two weeks between each treatment. However, mechanized site preparation is expensive.

Plate 7.2. Planting at a twice-disc-plowed and once-harrowed *Imperata cylindrica* site. *Photo*: Marku Temmes.

For agroforestry in Papua New Guinea, the most common technique is manual slash and burn, whether in logged-over forests or grasslands, followed by planting.

Planting and Initial Spacing

The usual practice in Southeast Asia and Papua New Guinea is to plant nursery-grown seedlings manually on a freshly prepared site after it has been marked out at recommended spacing, with planting spots indicated by bush sticks. Seedlings are planted in contour lines on slopes, and in straight lines on flat land. The lines are laid out approximately at right angles to the road that serves as the main access for the supply of seedlings. The seedlings (together with the pot soil) are

carefully introduced in the planting holes after removing the polythene bags. Generally, the polythene bag is hung on the stick near the hole to indicate the completion of planting. The planting hole should be about 13 cm in diameter and 20 cm in depth, and dug using a post-hole digger or *penggali*—a tool consisting of a 22-cm half-round blade with a 1-m wooden handle (Thang and Zulkifli 1992).

The seedlings are transported to the field in the early morning, tightly packed in wooden, plastic, or wire baskets (Plate 7.3). The vehicle carrying the seedlings should be covered to prevent desiccation and wind damage. Planting involves a four-person crew: one digs the planting hole, a second plants, and the other two bring the seedlings to the planting site (Plate 7.4).

One month after planting a survival count is made. If less than four seedlings survive for every five consecutive planting spots, refilling is carried out on these five consecutive spots. Generally, *A. mangium*'s survival after planting is very high, over 90% on favorable sites.

In some nurseries, root pruning and hardening off of the seedlings is a standard practice before planting out (Rahim 1987; Werren 1991). See Chapter 5.

Direct seeding in the field has not been tried commercially anywhere due to insufficient data on the survival and initial growth rate of direct-seeded plants. A trial in Sabah (Rahim 1987) gave 66% survival for direct seeding after 3 months,

Plate 7.3. Seedlings ready for dispatch to the field. Grown in Enso pot-trays, they are shipped in ordinary plastic bags with a bare rootball. *Photo*: Marku Temmes

Plate 7.4. Field transport of *A. mangium* seedlings. *Photo*: Enso Forest Development

compared with 97% for containerized seedlings. After 6 months these rates fell to 30% and 90%, respectively. In spite of this high mortality during the first 3-6 months following the direct-sowing treatment, Rahim (1986) suggested that this could be a viable method provided that proper silvicultural treatments (weeding, fertilizer application, etc.) are applied during this critical period. More trials are needed, particularly to compare the costs of the two operations.

The choice of initial spacing is determined mainly by the end use of the plantation material, and to some extent by the tree form. It is commonly observed that *A. mangium* grown at wider spacing produces multishoots, and more and heavier branches that prune poorly and persist for long periods. For chipwood and fuelwood, form may not be important; in fact, production of multishoots and heavier branches may even result in higher volume, although it may increase harvesting costs. Plantings intended for saw logs need sufficient numbers of trees to enable selection for excellent form at the end of the rotation. According to Mead and Miller (1991), density may vary with site (and even among microsites) and with seed source.

In agroforestry trials, spacing within rows and between rows must consider the effect of shade and root competition on the yields of nearby cereal crops.

Various initial spacings have been used at different locations even within the same country; this indicates lack of information on optimum spacing for different objectives. It appears that very few trials on spacing have been conducted to yield reliable information on the form and growth rate of *A. mangium*.

In Sabah, 3 x 3 m is the most common spacing used for *A. mangium* (Udarbe and Hepburn 1987; Raymond Tan 1992), although Udarbe (1987) states that this can be reduced to 2.5 x 2.5 m to take advantage of fast initial growth. SAFODA adopted a spacing of 4 x 2 m (1,250 stems/ha), moving away from square to rectangular spacings after their trials at Bengkoka found little difference in growth between the two options, with considerable cost savings due to fewer lines per ha. Table 7.1 shows the results of a spacing trial by SAFODA.

Although there was no significant difference in diameter growth among the different treatments, comparison of mean heights using least significant difference (LSD) indicated that spacing of 2 x 2 m and 2.5 x 2.5 m are significantly different from the control at 1 and 5% levels, respectively.

Table 7.1. Mean diameter and height growth of *A. mangium* spacing trial at Nahaba, Sabah, Malaysia at 2 years.

Treatment	Mean diameter (cm)	Mean height (m)
2 x 2 m	6.7	8.4
2.5 x 2.5 m	6.5	7.6
3 x 3 m (cont)	6.2	6.9

Source: Khamis (1991)

Again in Sabah, the Sabah Softwoods Sendirian Berhad (SSSB) plants trees at 1,075 stems/ha on better sites and 1,680 stems/ha on poorer sites (Tan and Dougles 1989). On the other hand, in Peninsular. Malaysia, in the Compensatory Forest Plantation Project (CFPP), trees planted at 3 x 3.7 m (900 stems/ha) result in good site occupancy within the first year (Mead and Miller 1991). Weinland and Zuhaidi (1992), however, recommend higher intial planting density to maintain strong lateral competition for producing thin, self-pruning branches. According to them, a sequence of slow initial diameter growth under strong lateral competition, followed by relatively late fast diameter growth under minimal competition, is probably the key to reduced fungal infection and enhanced log quality.

In Papua New Guinea, the two timber companies that have taken up *A. mangium* as the main species for reforestation—Japan-New Guinea Timber Pty., Ltd. (JANT) and Stettin Bay Lumber Co. (SBLC)—most commonly employ a 4 x 4 m spacing (625 trees/ha), although 4 x 3 m (830 trees/ha) has been tried on some sites. In both cases, the management objective is to produce pulpwood.

Weeding

The importance of weeding, especially for a fast-growing species like *A. mangium*, has probably not been fully realized. This is due in part to the high cost involved in weeding. There is a lack of reliable, quantitative information on the effect of various types of weeding (such as blanket treatment, circle weeding, selective weeding, or any other non-blanket weeding), their cost, and resulting rates of survival, initial growth, and form of *A. mangium*. However, each country appears to follow a tentative schedule. The method and frequency of weeding varies with site, composition of weeds, and plantation objective. Weinland and Zuhaidi (1992) recommend some kind of selective weeding in which only obnoxious weeds are removed (climbers, creepers and vines). According to them, this helps to maintain some lateral competition, which induces development of small branches in young trees that shed easily and leave only small wounds on pruning. This needs to be confirmed through proper trials.

In Sabah, Udarbe and Hepburn (1987) recommend a first weeding at about 2 months after planting; otherwise growth suffers. Experience in Peninsular Malaysia indicates that a clean burn of logged-over forests may need only one ring weeding, but a poor burn requires more weedings, especially the removal of climbers. Mead and Speechly (1989) recommend removing wild bananas by hand cutting or herbicide injection.

On dry grasslands, two hand weedings should take place in the first year, according to Udarbe and Hepburn (1987). *Imperata* grass is a strong competitor, however, on wetter sites with heavier soils in parts of South Kalimantan and Sumatra. Under these conditions, this weed should be eradicated before planting

and again later by frequent weeding operations.

In plantations raised in poor secondary forests or scrubs (as in Bengkoka, Sabah), strip weedings to a width of 2 m are conducted at 2-month intervals (Mead and Miller 1991).

Mechanical weeding is practiced in pure *Imperata* grasslands in South Kalimantan, using farm tractors equipped with a harrow or rotator. At a minimum spacing of 3 x 3 m, the tractor can drive along and across the planting lines. The work output is approximately 0.5 hour per ha. This method has also been found useful from the perspective of fire protection, but is not recommended in stands older than 1.5 years. A "roller" made of oil drums welded together and pulled by a tractor has also been used to control weeds. The heavy roller, with oil drums filled with concrete, effectively tramples the *Imperata*, which dies gradually. Older plants seem to be particularly sensitive to trampling. Such a roller can be used both for weeding (width adjusted to spacing) and site preparation before the area is ploughed.

In Papua New Guinea, a weeding schedule of 4-3-2 in the first three years after planting is general practice, consisting of:

Year 1	4 x (3 line + 1 clear)
Year 2	3 x (2 line + 1 clear)
Year 3	2 x (1 line + 1 cut and release)

Line weeding removes grasses manually using bush knives within 1 m of the planted lines. In clear weeding, the whole planted area is cleaned of weeds by the same method. The first weeding is carried out two months after planting. The last weeding in Year 3 removes climbers in order to release the trees from competition. On favorable sites, *A. mangium* plants emerge and dominate the weeds within two years, thus not requiring any further weed control in subsequent years. Herbicides are not used to control weeds in Papua New Guinea (PNG).

Soils and Fertilizer Requirements

Relationship Between Soil Properties and Growth of *A. mangium*

A. mangium is sensitive to soil conditions. It is therefore essential to study the soil requirements of this species. The success of modern silvicultural practices, especially in plantation forestry aimed at maximum productivity, is inextricably linked to an understanding of soil and nutrient relationships. The species prefers fertile soils that have good drainage but are not excessively drained. Soils derived from ultrabasic rocks in Bengkoka, Sabah have proven to be unsuitable for *A. mangium* due to their very high Mg and pH levels. The species tolerates low pH (<4.0) and indeed natural stands in Papua New Guinea grow on such acid sites

(Skelton 1987). Observations in Malaysia and Papua New Guinea indicate that leaves become chlorotic both under prolonged drought and water-logged conditions after heavy rains in poorly drained soils. Yellowing of foliage is associated with sub-optimal foliage nitrogen levels (<2.0% dry weight) due to interference with symbiotic nitrogen fixation. In fact, foresters in PNG have observed high mortality of newly planted seedlings in water-logged, swampy conditions.

In Peninsular Malaysia, analysis of soil chemicals showed that the basal area of trees in fully stocked stands at 27 months was closely related to the level of Bray-2 extractable P (phosphorus). The regression analysis suggested that 2 years after planting, available P of about 10 ppm produces optimum growth. If Bray-2 P is only 4 ppm, basal area is reduced by 30-40% (Mead and Speechly 1989; Mead and Miller 1991).

Simpson (1992) investigated the relationship between productivity of *A. mangium* and soil nutrient levels in Kalimantan. He found that productivity is related to the 'total' soil K (potassium) levels (Table 7.2, Figure 7.1). This parameter was responsible for 50% of the variation in data, the more productive stands showing higher K levels. The relationship was less evident for exchangeable K.

In an excellent paper, Thomas and Kent (1986) describe the effect of soil characters on the growth of *A. mangium* in Sabah on sites with different soil

Table 7.2. Soil chemical properties for a range of soils in the Riam Kiwa plantations, South Kalimantan.

Sample No.	Stand Health	pH	Ntot (%)	Ptot (ppm)	Pav (ppm)	Ktot (ppm)	Exchangeable K	Ca	Mg	Na	CEC	Mn (ppm)	OC (%)
							meq/100g						
1	Good	4.8	0.135	174	3.1	2634	0.16	0.24	1.09	0.06	28.1	85	1.98
2	Good	5.2	0.128	201	3.5	4519	0.51	3.07	2.08	0.05	29.4	90	1.58
3	Poor	5.3	0.122	402	4.2	536	0.20	1.25	1.48	0.05	19.3	64	1.65
4	V. poor	5.4	0.142	555	9.0	692	0.26	2.70	2.57	0.04	22.4	107	2.07
5	Good	5.1	0.127	81	5.9	1630	0.46	2.29	2.05	0.05	23.3	77	1.85
6	V. good	5.1	0.121	151	3.6	1165	0.33	1.33	1.37	0.04	21.4	102	1.72
7	Poor	5.3	0.144	159	2.2	261	0.25	1.32	1.39	0.05	23.3	98	2.21
8	Poor	5.1	0.104	91	2.3	284	0.23	0.72	0.65	0.04	20.8	72	1.53
9	Variable	5.3	0.134	205	3.5	341	0.18	1.09	1.18	0.02	18.6	78	2.01
10	Mediocre	5.3	0.105	86	3.5	3603	0.23	1.14	1.46	0.06	18.2	66	1.47
Mean		5.2	0.126	167	4.1	1566	0.28	1.52	1.53	0.05	22.5	84	1.81

Particle size analysis	Sample 2	Sample 4
Sand (%)	43	55
Silt (%)	21	25
Clay (%)	36	20

Source: Simpson (1992)

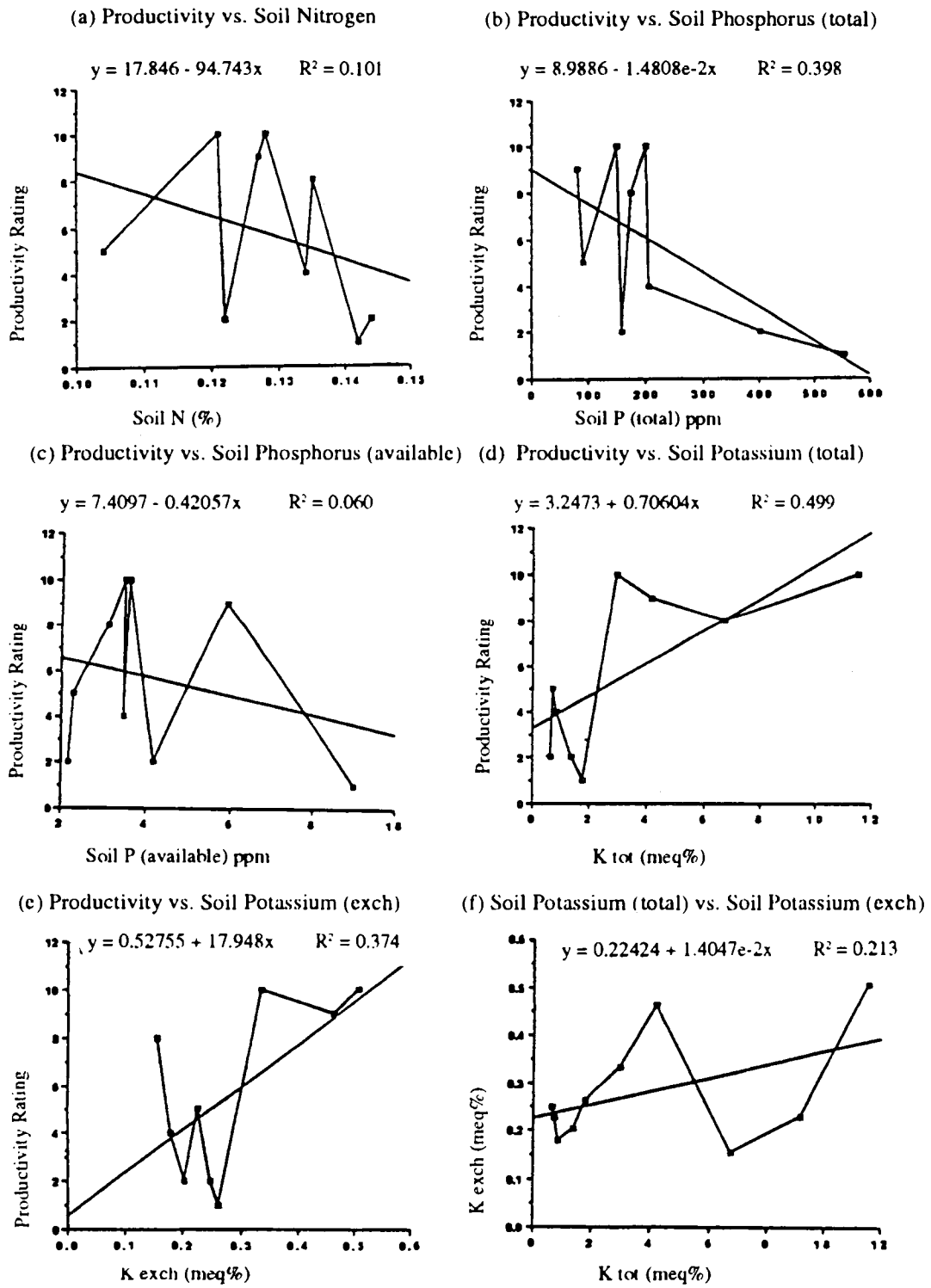

Figure 7.1. Plantation productivity related to soil chemical parameters: (a) productivity vs. soil nitrogen; (b) productivity vs. soil phosphorus (total); (c) productivity vs. soil phosphorus (available); (d) productivity vs. soil potassium (total); (e) productivity vs. soil potassium (exchangeable); (f) soil potassium (total) vs. soil potassium (exchangeable). *Source*: Simpson (1992)

types and previous vegetation. As Figure 7.2 indicates, growth is invariably better on the moderately drained and relatively fertile soils under logged-over forests than on the imperfectly drained sites dominated by *Imperata* grass. In fact, Hepburn and Udarbe (1986) indicate that height growth is reduced by almost 50% on *Imperata*-dominated sites. Topography, however, does not appear to have a pronounced effect on growth and yield of *A. mangium* (Tan 1989).

Hamsawi and Jugah (1989) compared the growth of *A. mangium* on different soil types in several countries (Table 7.3). The average height 18 months after planting ranged from 3.8 to 5.0 m, and average dbh of 5.25-7.45 cm in Peninsular Malaysia; this was comparable to growth on better sites in other countries.

Relationship Between Foliage Nutrient Content and Tree Growth

Foliar analysis has proven to be a powerful tool in tree nutrition and fertilizer research. In this, foliage nutrient levels are used as an index of the nutritional condition of the tree or stand. Given the relationship between tree growth and foliar nutrient levels, one can diagnose nutrient deficiencies, better interpret responses to fertilizer trials, and even predict fertilizer responses (Bevege 1978). In interpreting foliage nutrient contents, the concept of critical concentration has been used to define predictable functional relationships between nutrient concen-

Table 7.3. Mean height and diameter of *A. mangium* on different soils.

Location	Age (years)	Height (m)	Diameter (cm)	Remark
Costa Rica	2	8.0	9.0	good site
Mindanao, Philippines	2	5.8	7.1	good site
	3	8.3	9.4	good site
Bangladesh	2	8.0	15.0	good site
	2	4.0	7.0	poor site
Hawaii, U.S.A.	2	6.0	6.8	good site
Sook, Sabah, Malaysia	6	5.2	13.4	compacted soil
Sibu, Sarawak, Malaysia	2	2.3	n.a.	nyalau
	2	0.7	n.a.	upland semado soil
Niah, Sarawak	2	5.0	n.a.	heavy, red-podzolic soil
Kemasul, P. Malaysia	3.5	3.7	n.a.	severely disturbed soil
	3.6	13.8	17.8	old durian soil

Source: Hamsawi and Jugah (1989)

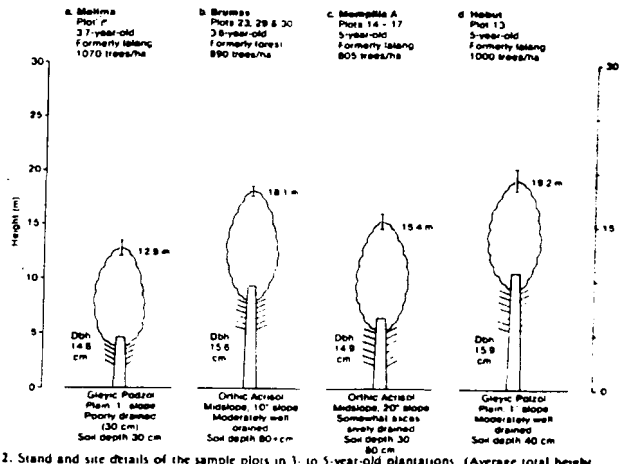

Fig. 2. Stand and site details of the sample plots in 3- to 5-year-old plantations. (Average total height and diameter at breast height over bark are given. Vertical line bars represent 95% confidence intervals of total height.)

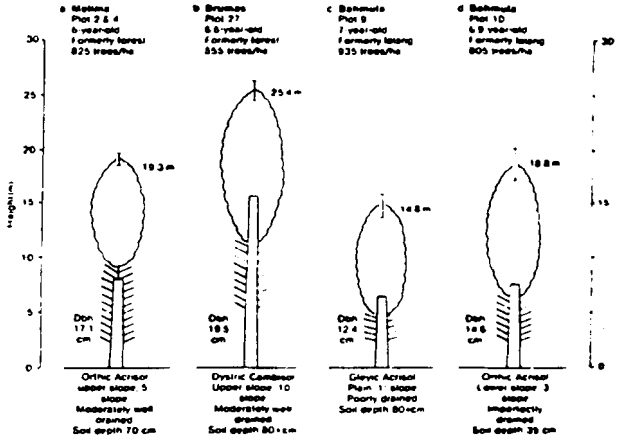

Fig. 3. Stand and site details of the sample plots in 6- to 7-year-old plantations. (Average total height and diameter at breast height over bark are given. Vertical line bars represent 95% confidence intervals of total height.)

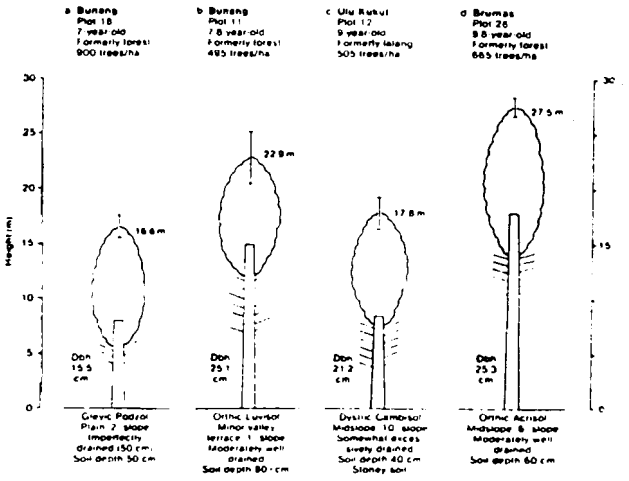

Figure 7.2. Stand and site details of sample plots in (a) 3- to 5-year-old plantations; (b) 6- to 7-year-old plantations; (c) 7- to 9-year-old plantations. Values for dbh and total height are averages. Vertical axes represent 95% confidence intervals of total height. *Source*: Thomas and Kent (1986)

tration and yield. This approach has proven successful for many tree species (*Pinus* spp. in Australia and New Zealand, rubber and *Pinus caribaea* in Malaysia). Many excellent reviews are available on the topic (see Qureshi and Srivastava 1966; Richards and Bevege 1969; Lambert 1984).

Mead and Speechly (1989) studied the relationship between the nutrient concentration of foliage and *A. mangium* growth. The freshly matured leaves taken from the upper part of the crown were analyzed for N, P, K, Ca, and Mg. There was no relationship between Bray-2 P and foliar P. However, foliar N level was related to foliar P, indicating that low P limits N fixation. The equations indicated that for *A. mangium*, foliar P levels of 0.12-0.15% is required to ensure 3.0% N in the foliage. The criteria for satisfactory foliage P levels was found to be 0.13-0.15% dry weight; this and other tentative criteria for interpreting foliage levels are given in Table 7.4.

Mead and Speechly (1989) also suggested that if foliage P is less than 0.12-0.13%, a broadcast application of 40 kg/ha P should immediately follow thinning, particularly if high-quality logs are desired.

Simpson (1992) studied these relationships in Kalimantan. Following standard sampling procedure, four representative trees were selected at each site and branches collected from the top third of the crown. Ten of the most recently formed, fully expanded leaves from the distal portions of the branches were collected from each tree and composited to give one sample of 40 leaves per sampling site. These were analyzed for chemical content (Table 7.5).

The results indicated that plantation productivity is related to foliar K levels (r = 0.48) but not to foliar N or P levels. Thus both soil and plant chemical data indicated that K deficiences could be limiting *A. mangium* growth in this locality. No relationship existed between soil and foliar N concentrations but a strong correlation between soil and foliar P was visible. Foliar P was also strongly related to available soil P (Figure 7.3).

Table 7.4. Proposed diagnostic levels of *Acacia mangium* foliage.*

Nutrient	Critical	Satisfactory
N (%)	not known	>3.0
P (%)	<0.13	0.13-0.15
K (%)	<0.6	>1.0
Mg (%)	<0.11	0.15-0.20
Ca (%)	<0.2	
S (%)	<0.10	
B (ppm)	<10	
Zn (ppm)	(10)	
Cu (ppm)	(3)	

*The fifth and sixth leaf from the bud of lateral, upper-crown branches should be sampled. Figures in brackets are tentative. *Source*: Unpublished information based on Mead's studies for CFPP and SAFODA

Table 7.5. Nutrient levels in foliar samples from Riam Kiwa, South Kalimantan.

Sample Number	Stand Health	N	P	K	Na	Ca	Mg	Mn	B	Cu	Zn
		mg/g						ug/g			
1	Good	25.5	0.93	8.76	1.68	3.73	2.22	470	16.4	14.1	22.8
2	Good	25.4	1.06	9.35	0.88	8.44	2.51	360	18.3	11.0	25.2
3	Mediocre	22.4	1.16	6.44	0.78	9.86	2.14	300	9.8	13.7	23.8
4	Very poor	21.5	2.36	4.75	0.59	14.54	3.35	270	11.2	21.8	35.5
5	Good	21.7	0.80	7.24	0.45	11.82	2.17	460	19.4	19.6	18.6
6	Very good	20.0	0.80	7.21	0.60	4.69	2.06	320	11.1	9.6	17.6
7	Poor	19.0	0.84	5.29	1.02	15.45	2.45	430	16.5	17.6	26.2
8F	Poor	20.8	0.72	5.61	0.66	15.86	2.45	930	18.9	23.0	16.7
8UF	Poor	18.3	0.69	5.66	0.55	17.91	2.52	870	21.7	21.9	19.8
9	Variable	24.0	0.80	8.59	1.19	8.37	1.99	390	15.4	8.4	13.4
Mean	*A. mangium*	21.8	1.02	6.89	0.84	11.07	2.39	480	15.8	16.05	22.0
10	*Pinus oocarpa*	13.7	0.66	4.23	1.25	2.97	1.49	620	4.2	2.8	11.5

F = fertilized with 20 kg/ha P at planting; UF = unfertilized plot. *Source:* Simpson (1992)

The study of foliar nutrient ratios indicates that relatively low K and high Ca and Mg proportions are probably responsible for poor health (Table 7.6). More studies are needed to confirm these results.

Simpson (1992) also compared the nutrient concentrations of *A. mangium* foliage from Kalimantan (Indonesia), Sabah (Malaysia), and Dongmen (China) (Table 7.7). The results indicated that:

- the foliar N levels were comparable, levels below 20 mg/g of N being unacceptably low
- regarding foliar P, the data was not enough to a suggest a critical concen tration but levels below 1.0 mg/g may be taken with caution
- in Dongmen, 4 mg/g of foliar K was regarded as the critical level; however in Kalimantan, 6 mg /g should be regarded as the minimum acceptable level.

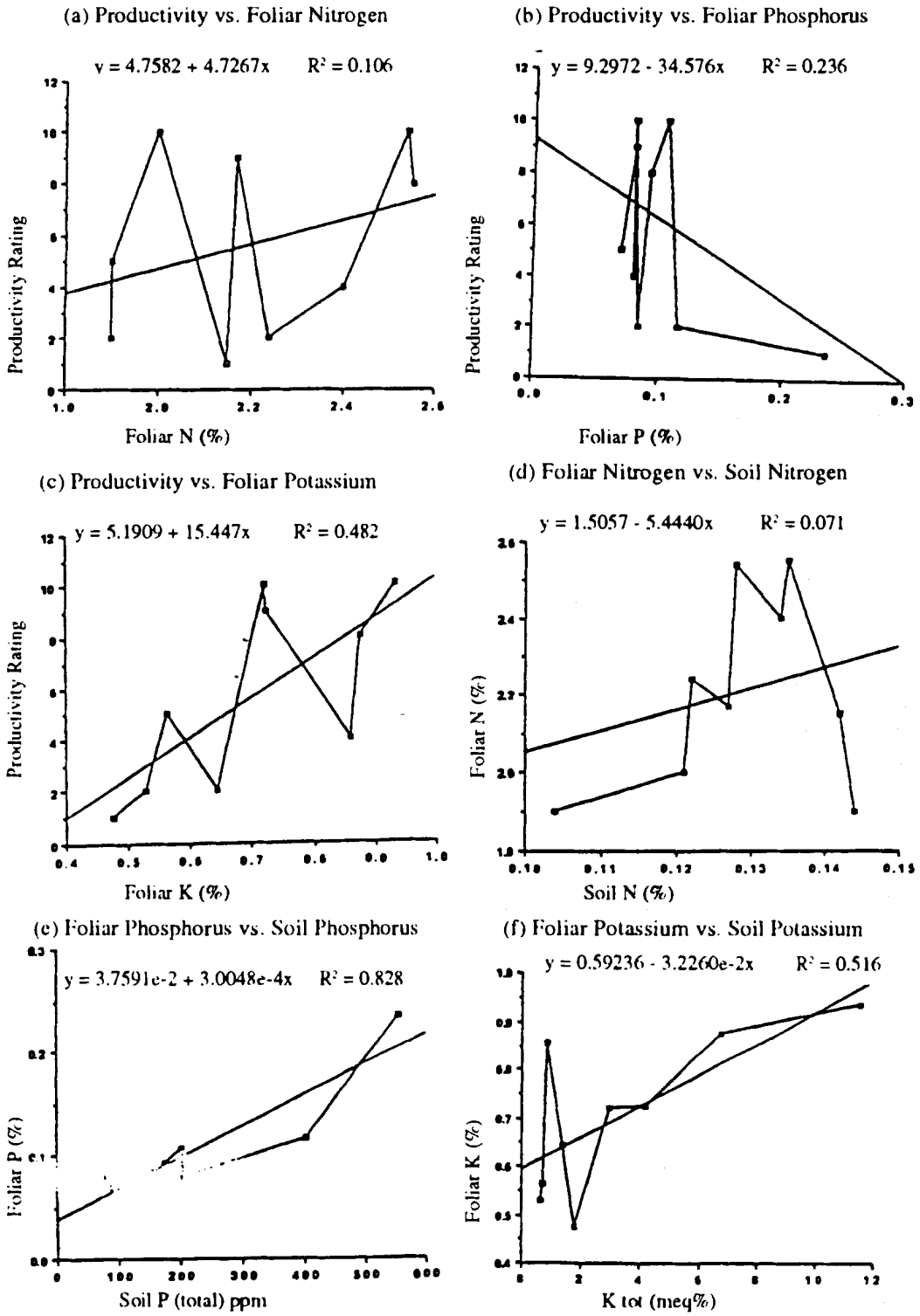

Figure 7.3. Plantation productivity related to foliar nutrient parameters (a-c) and relationships between soils and foliar nutrients (d-f): (a) productivity vs. foliar nitrogen; (b) productivity vs. foliar phosphorus; (c) productivity vs. foliar potassium; (d) foliar nitrogen vs. soil nitrogen; (e) foliar phosphorus vs. soil phosphorus; (f) foliar potassium vs. soil potassium. *Source*: Simpson (1992)

Table 7.6. Nutrient proportions, adjusted to Nitrogen 100, for foliar samples from Riam Kiwa plantations, South Kalimantan.

Sample Number	Stand Health	P	K	Na	Ca	Mg	Mn	B	Cu	Zn
1	Good	3.6	34.3	6.6	14.6	8.7	1.8	0.06	0.06	0.09
2	Good	4.2	36.8	3.5	33.2	9.9	1.4	0.07	0.04	0.10
3	Mediocre	5.2	28.7	3.5	44.0	9.5	0.9	0.04	0.06	0.11
4	Very poor	11.0	22.1	2.7	67.6	15.6	1.2	0.05	0.10	0.16
5	Good	3.7	33.4	2.1	54.5	10.0	2.1	0.09	0.09	0.08
6	Very good	4.0	36.0	3.0	23.4	10.3	1.6	0.05	0.05	0.09
7	Poor	4.4	27.8	5.4	81.3	12.9	2.3	0.08	0.09	0.14
8F	Poor	3.5	27.0	3.2	76.2	11.8	4.5	0.09	0.11	0.08
8UF	Poor	3.8	30.9	3.0	97.8	13.8	4.7	0.12	0.12	0.11
9	Variable	3.3	35.8	5.0	34.9	8.3	1.6	0.06	0.04	0.06
Mean	*A. mangium*	4.7	31.3	3.8	52.8	11.1	2.2	0.07	0.07	0.10
10	*Pinus oocarpa*	4.8	30.9	9.1	21.7	10.9	4.5	0.03	0.03	0.08

Source: Simpson (1992)

Table 7.7. Comparative mean foliar nutrient data for four *Acacia mangium* plantations.

Location/ Condition (no. samples)	N	P	K	Ca	Mg	Na	Mn	Cu	Zn	B
	mg/g							ug/g		
Riam Kiwa, Indonesia (10)	21.8	1.02	6.89	11.07	2.39	0.84	0.48	16	22	16
Dongmen, China (16)										
unfertilized	19.5	0.74	3.67	5.91	1.24	1.48		9	18	13
fertilized	21.2	0.88	4.14	6.73	1.27	1.44		10	18	15
Vinh Phu, Vietnam (9)										
mean	23.1	1.27	7.81	5.43	1.30	1.65	0.52	35	39	19
range										
low	13.8	0.61	3.48	2.45	1.09	0.33	0.21	16	28	8
high	27.0	3.23	20.51	9.89	1.71	3.04	0.86	57	52	30
Sabah, Malaysia (4)										
unhealthy	30.6	1.45	15.1	4.98	1.55		0.23	11	21	16
healthy	28.9	1.12	14.0	5.51	1.65		0.34	12	28	27

Source: Simpson (1992)

Fertilizer Trials

Application of fertilizers is a standard practice in the countries where *A. mangium* is a major plantation species. In most cases, however, the nature of fertilizers and their quantity are not based on systematic research. Fertilization levels and time of application have been decided tentatively, probably based on a few studies or on experience with other species in the area.

The main aim of fertilizer application is to produce uniform, fast-growing plantations. Uniformity makes it easier to prescribe operations (thinning, pruning) on time; fast growth ensures that the site is quickly captured.

A few examples of fertilizer trials are given below.

1. SAFODA adopted the following fertilizer regime for *A. mangium* plantations:

   - Apply 113 g of a Christmas Island Rock Phosphate (CIRP) in each planting hole at the time of planting.

   - Apply 57 g of NPK-BC 12:12:17:2 + TE to each plant 3 months after planting, placed equally in two holes opposite each other at about 15-23 cm from the stem.

   - At 8 months, broadcast 113 g of NPK-Blue around each plant at least 15 cm from the stem.

   - Finally, at 18 months increase the dose per tree to 170 g of NPK - Blue on sites showing poor growth (Raymond Tan 1992).

2. Wan Rasidah et al. (1989) concluded in Malaysia that the soils are low in nutrients, especially in phosphorus. A number of fertilizer trials have been carried out to determine the best schedule for fertilizers. Table 7.8 summarizes diameter and height growth responses for three fertilizer trials. Best response was recorded where compound fertilizers (such as NPK-Blue 12-12-17-2+TE) were applied, although responses tend to be short lived and exhibit the gain in about 6 months. This helps in terms of faster canopy closure, reduced fire risk, and shorter rotation (Miller and Hepburn 1989; Mead and Speechly 1989).

   In Bengkoka (Sabah), 90-100 g of CIRP is applied at the time of planting, followed by 45 g of NPK mixture 2 months later at the time of first weeding. Further application of fertilizer may be needed, according to Udarbe and Hepburn (1987).

Table 7.8. Growth comparison of fertilizer treatments at different ages (months).

Site/Treatment	DBH (cm)							Height (m)							
	6	12	16	19	25	31	36	5	6	9	12	20	25	31	36
Tanjung Piring															
Phosphate trial															
• Control (no fert.)	1.16	1.37		3.28	7.15	10.12			1.02		2.05		5.38	8.39	
• 469 g Rock P applied to planting hole	1.46	1.85		4.15	8.12	10.77			1.15		2.41		5.72	8.68	
• 110 g RP at planting + 340 g NPK blue over 3 yrs	1.58	2.37		5.20	9.22	11.57			1.21		2.61		6.44	9.06	
Kupang															
Phosphate trial															
• Control (no fert.)								1.46		2.65					
• 200 l g P_2O_5/ha broadcast at planting								1.54		2.38					
• 50 g/tree NPK blue applied at 2 months								1.76		2.47					
Tanjung Piring															
Extra NPK blue trial															
• Standard (50 g NPK blue)			1.97			9.32				1.6	3.23				
• Extra (150 g NPK blue)			4.57			10.57				2.5	4.66				
PSP Averages for comparison	1.5		3.0	3.5	5.5	7.5	9.5		1.5			4.5	6.0	7.5	9.0

Source: Miller and Hepburn (1989)

3. For the CFPP in Peninsular Malaysia's ex-jungle sites, Mead and Speechly (1989) recommend the following fertilizer schedule for *A. mangium* on the basis of preliminary studies:

   - Broadcast-burnt sites require no fertilizer.

   - For semi-mechanically prepared sites, apply a total of 100 g triple superphosphate (TSP)/tree between ash beds at planting in two slits 15-20 cm from the seedling. Apply a second dressing of 150 g TSP in a ring about 0.3-1.0m from the tree at 5-6 months. On erodible sites, this dressing should be applied at 3-5 months and covered with soil.

   - For log-landings, increase the second dressing to 250 g/tree, and also rip the site to a depth of 60 cm.

   On less fertile *Imperata* sites, such as at Bengkoka, they found it useful to add N and a general trace element mix to the P applied at planting. For example, the results of a trial on a Tanjung Lipat soil at Bengkoka showed that the best treatment resulted in a 4-month gain in diameter growth (Figure 7.4). They suggested replacing the initial fertilizer dressing with 120 g of a 1:1 mixture of TSP and NPK blue (12:5:14+TE). There was no recommendation whether the second dressing should contain nutrients other than P.

In Kalimantan, the following fertilizer trials have been conducted:

- *A. mangium* planted December 1987, fertilized January 1988 with triple superphosphate to supply 0, 5, 10, 15, or 30 kg/ha P, 12 kg/ha N + 10 kg/ha P and 10 kg/ha each of N, P, and K (Adjers and Luukkanen 1988). After three months, fertilizer treatments had no effect on survival in this short-term trial. Although triple superphosphate significantly improved height growth over no fertilizer, the major response was to the mixed fertilizers. The NPK mix improved height development by 260% and mean diameter by 184%.

- *A. mangium* planted December 1987, fertilized February 1988, testing mechanical soil preparation vs. herbicide treatments with and without fertilizer (20 kg/ha P as triple superphosphate). Fertilizer clearly improved growth of the trees.

- *A. mangium* planted June 1991 in a short-term trial (1 x 1 m spacing) adjacent to the Banjarbaru nursery to test 5, 10, 20, and 40 g P per plant

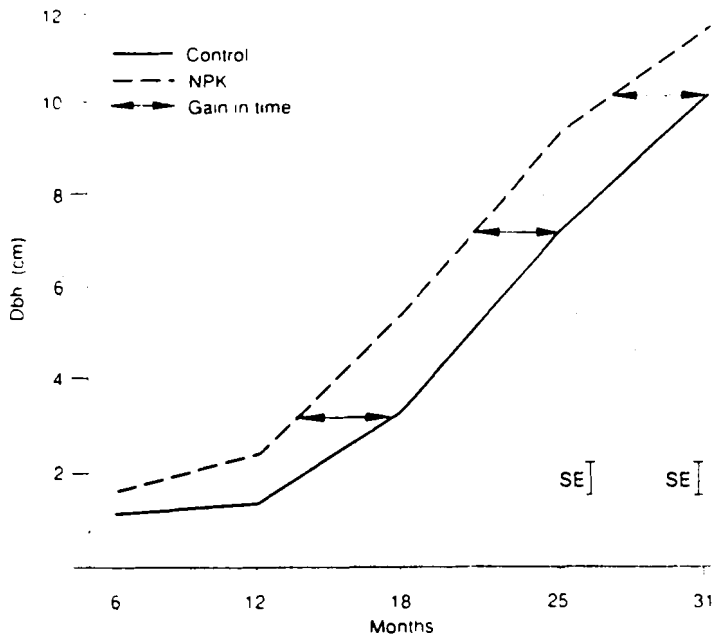

Figure 7.4. Response in diameter growth to fertilizer (113 g Christmas rock phosphateapplied in planting hole, followed by 57, 113, and 170 g NPK plus trace elements applied at 2, 8, and 20 months, respectively) at Bengkoka, Sabah. *Source*: Mead and Miller (1991)

as triple superphosphate, and as rock phosphate Lime at 210, 420, 840, and 1,680 kg/ha were applied, respectively, in addition to P5, 10, 20, and 40 treatments (triple superphosphate). A control (no fertilizer) was also included. By December 1991, satisfactory establishment had been achieved.

In Dongmen, China, a regime of 100 kg/ha N, 50 kg/ha P, and 50 kg/ha K was applied to an *A. mangium* plantation resulting in 179% increased volume production at age 2.6 years (Simpson 1992).

It is apparent that application of suitable fertilizers in adequate amounts at the proper intervals has great potential to increase early growth of *A. mangium*. Certainly, more intensive research is needed, as both the type and amount of fertilizer will vary with soil and other site conditions. For example, in Malaysia, P appears to be the most important nutrient, while in Kalimantan, K appears to be the limiting factor to growth. The first step in any comprehensive research on species fertilizer requirements is to identify the nutrient(s) likely to limit growth on a particular site. Such a research program needs to use foliar analysis combined with soil properties.

Fertilizer application inevitably adds to the cost of raising plantations. It is therefore essential to prove that the cost incurred by fertilizers is commensurate with gains in terms of survival, growth, and yield.

Pruning and Thinning Schedules

Plate 7.5. Four-year-old stand at Sabah Softwoods ready for thinning. *Photo*: K. Awang

A. mangium stands need regular pruning and thinning only if the plantation objective is to produce quality saw logs on a 15- to 20-year rotation (Plate 7.5). These operations, in general, are not required for pulpwood production on a 6- to 8-year rotation. It is possible to combine the two objectives, however, when adequate data are available on species growth requirements, initial planting spacing, thinning schedules, and market demands. In agroforestry, *A. mangium* trees should be lopped frequently to reduce the amount of shade and competition on nearby agricultural crops.

Singling

Although *A. mangium* shows strong apical dominance, on many sites trees show a strong tendency (probably controlled by genotype and, to some extent, by site conditions) to develop multiple leaders from the base (Plate 7.6). In South Kalimantan, trees of

Plate 7.6. Multi-stemmed seedling.

Plate 7.7. One-year-old seedling after singling and weeding. *Photos*: K. Awang

the same provenance planted on the same date show very low frequency of multiple leaders, especially when planted on a site with no mechanical soil preparation. In Peninsular Malaysia the standard practice is to remove all shoots besides the leader at about 4-6 months after planting, before they form heartwood but late enough to ensure that there will be no further sprouts (Plate 7.7). Pathological studies suggest that if this exercise is delayed, there is a danger of rot fungus entering through large-diameter scars (Mead and Speechly 1989; Thang and Zulkifli 1992).

Pruning

In pruning, branches are removed in one or more steps along the bottom trunk up to a certain height. Generally, *A. mangium* produces many persistent branches, typically about 50 in the lower 6 m. This is a strongly inherited characteristic and varies with genotype, although site conditions and proper silvicultural practices may reduce this tendency to some extent. Observations in Peninsular Malaysia also indicate that rapid height growth during the early years is accompanied by increased height growth of the green crown of up to 7 m in unthinned stands in a stocking of 900 stems/ha. This necessitates early pruning and thinning for the stands to maintain their growth potential (Mead and Speechly 1989). Pruning is also important to limit the size of the defect core. The diameter at the bottom of the pruned crown is equivalent to the minimum diameter of the core for that pruning lift. Knowledge about stem taper is important to predict this, which permits estimates of the length of the green crown. Mead and Speechly (1989) came up with harmonized curves of dbh (OB) against tree height on the basis of sectional measurements of 12-26 months old trees to see the effect of pruning (Figure 7.5).

The taper curves were used to examine the effects of pruning to different heights and to different top diameter limits. Diameter limit pruning has the advantage that it can better handle variability in the stand, as it ensures that the same crown height is left on all the trees. On this basis, Mead and Speechly (1989) recommend pruning up to a diameter limit of 6 cm. Assuming this is done when one can see the bottom log of potential crop trees (that is, 6 m), then the upper height for pruning would average about 2 m, leaving about 4 m crown length which could grow out from the ground. The diameter at the bottom of the pruned section would average about 10 cm, which represents the maximum diameter over branch stubs (DOS). If a two-lift pruning schedule is desired, either the pruning height would have to be reduced to 5.5 m to maintain a DOS of 20 cm and a pruning limit of 6 cm, or the diameter limit should be reduced to 5 cm to achieve a 6-m pruned log. Reducing the diameter limit to 5 cm would reduce the residual crown to 3 m; maintaining a 6-cm limit and pruning to 6 m would increase the DOS to about 11.5 cm.

Trees selected for pruning must have a single leader and be free of very large branches in the lower 6 m. They should be straight (stem deviation <10 cm) and

preferably dominant.

On the basis of the observations above, Mead and Speechly (1989) recommend a two-pruning option to 5.5 m until more information and experience is gained. A two-pruning option reduces the number of entries into the stands, and also ties in well with the thinning, so that the first thinning can coincide with the second pruning lift.

However, Weinland and Zuhaidi (1992) studied the size of pruning wounds and related fungal infections in 16 trees (Kemasul, Peninsular Malaysia) pruned two years earlier. They found that wounds of more than 2 cm in diameter, both in dry and green pruning, were infected. According to them, with trees at the wide initial spacings currently followed in Peninsular Malaysia (3 x 3.7 m), most branches in the pruning zone of 6 m are likely to have diameters greater than 2 cm at the base. Counting in a pruning trial revealed that almost all trees ready for pruning had at least one branch (and often more) with a base diameter greater than 2 cm. Although the maximum branch size for safe pruning has yet to be determined, even one big branch in the pruning zone may prove dangerous. Therefore, the authors recommend strong lateral competition in young plantations, for:

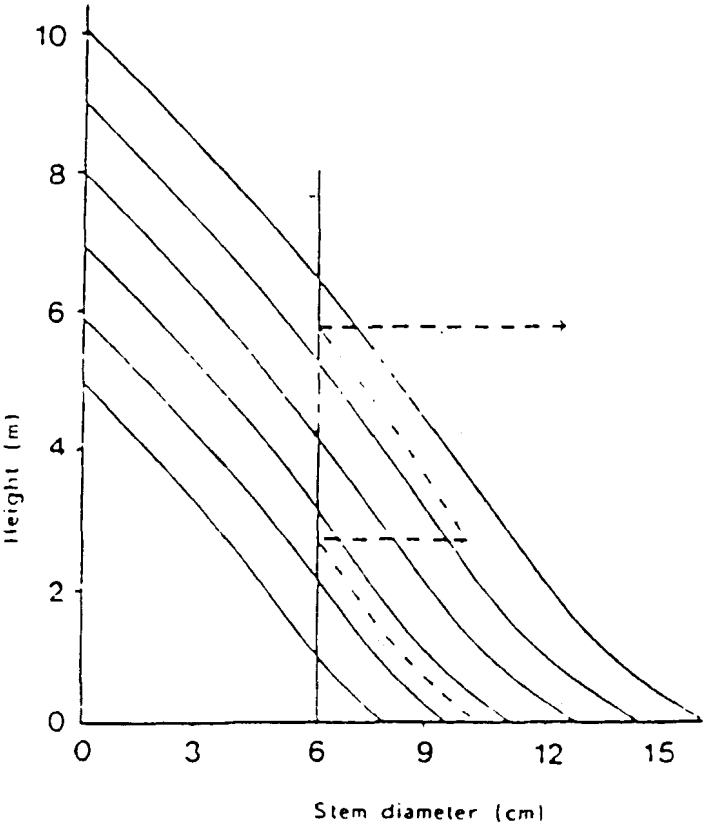

Figure 7.5. Stem taper lines showing how pruning to a diameter of 6 cm can be used to predict diameter over stubs. *Source*: Mead and Speechly (1989)

- formation of small branches of less than 2-cm diameter along the bottom trunk
- reduced number or complete absence of multiple shoots
- prevention of of large piths in trunk and branches, thus reducing the risk of fungal infections

According to them, lateral competition can be achieved by:

- using a high planting density
- interplanting with other species
- encouraging natural regeneration
- non-blanket weeding, thus retaining harmless secondary vegetation

Nik and Paudyal (1992) report the results of a pruning trial in Peninsular Malaysia in some stands of 3 x 3 m spacing (1,110 trees/ha). Treatments were pruning at and up to:

- 0, 3, 4, and 6 m in a 3-year-old-stand
- 0, 2.5, 3.5, and 5 m in a 1.5 year-old-stand
- 0, 4, 5, and 6 m in a 4-year-old-stand

All pruning treatments resulted in reduced diameter growth, especially significant when crown removal was more than 40%. The pruning treatments also affected taper, with a decrease of 1 cm in diameter for each 1 m in height.

For more definitive conclusions, systematic trials are needed on these aspects.

Thinning

Thinning is a manipulation of stocking density that can be carried out at any time between onset of between-tree competition and the final cut, either as thinning to waste or as production thinning. The thinning schedule and its intensity are dictated by many factors, including growth rate (both in terms of height and diameter), basal area, relationship between diameter and crown growth, onset of competition, stem form, end-use, and operational cost. Three excellent articles (Miller and Hepburn 1989; Mead and Speechly 1989; Mead and Miller 1991), all from Malaysia, summarize the available information on these aspects for *A. mangium* and recommend a tentative thinning (and pruning) schedule for saw-log production.

Pulpwood Schedule

Most *A. mangium* plantations grown for chipwood are not thinned. Rotation length is normally set at about culmination of the MAI. Both at SSSB (in Sabah) and JANT (in Papua New Guinea), stands are clear-felled at 6 or 7 years.

However, according to Mead and Miller (1991) selection thinning of such stands offers some advantages. The economics of a pulpwood crop are sensitive to tree size, straightness, and degree of branching, as well as yield. Since *A. mangium* stands show considerable variability in malformation and straightness, incorporating an early thinning to waste can yield considerable advantages.

On low fertility sites—like at Bengkoka in Sabah, where basal area capacity is only 20-25 m^2/ha—management trials have shown that final crop stocking should be around 600-700 stems/ha. At Bengkoka, trees are normally planted at 1,250 stems/ha, with a stand improvement thinning carried out at 18 months (4-5m). This removes 50% of the stems, but only 25-30% of the basal area. Thinning (using bush knives) is cheap, taking about 4 working days/ha. Growth modeling indicates that yields from thinned stands at age 8 years should be within 5% of unthinned stands. Average piece size, however, increases from 0.18 to around 0.25 m^3/tree with thinning; this should reduce logging costs by 23-37%, depending on the logging method. Final yields and piece sizes still have to be proven in practice.

In JANT plantations, however, the increase in piece size as a result of thinning does not apply unless the company reduces initial spacing, which is at present set at 4 x 4 m or 4 x 3 m.

The disadvantage of thinning to waste is the increased risk of fire in areas with a pronounced dry period.

Sawlog Schedule

Developing thinning regimes for producing high-quality saw logs of *A. mangium* is more complicated due to growth variation in terms of height, diameter, volume, taper, stem form, branching, and crown development, which are controlled by genotype as well as by site conditions. In addition, as emphasized by Mead and Speechly (1989), growers have also to study:

- physical properties of the wood and conversion limitations
- other biological and abiotic limitations
- economics
- practicality of prescriptions

Furthermore, growers need to integrate various inputs from tree breeding, nursery practices, establishment, tending, fertilization, etc. to clear-felling. This can be achieved using computer models, given sufficent data.

Mead and Speechly (1989) therefore suggest a radical pruning and thinning policy for growing sawlogs in Peninsular Malaysia. Pruning to 5.5 m was to take place in two lifts at a very early age, and at the time of the second pruning the trees were to be given their first pre-commercial, selection thinning (Table 7.9). This part of the silviculture was to be completed by the time the trees reach about 9 m tall, which in Peninsular Malaysia is before 2 years. They do not recommend thinning earlier than this, due to the necessity of selecting the most vigorous trees with good boles; also, competition has barely set in by this age. Later thinnings, which might be commercial, eventually reduce the stands to a final crop stocking of about 100 stems/ha. The objective is to keep the trees in a free-growing condition with large, deep crowns, thus maximizing diameter growth. They suggest a rotation of about 15 years.

Table 7.9. Thinning and pruning schedules for high-quality *A. mangium* logs.

	Fertile sites			Infertile sites		
Operation	Ht (m)	Age (mo)	Stems/ha (residual)	Ht (m)	Age (mo)	Stems/ha (residual)
First pruning	6.0	~12	900	5	18	500
Waste thin	9.0	24	(450)	5	18	(500)
Second pruning				8	30	250
High prune	9.0	24	450	11	38	250
Thin	13	36	(250)	11	38	(250)
Thin	22	72	(150)			
Thin	27	120	(100)			
Clearfell	28	180		23	240	-

Source: Mead and Speechly (1989)

SAFODA attempted a similar schedule on its less fertile sites at Bengkoka (Table 7.9). The major difference here was that no commercial thinning was envisaged and the proposed rotation is longer.

At the time these schedules were proposed, very little evidence existed to show that it was possible to grow large saw or veneer logs. A thinning trial at Bengkoka, however, offers some encouraging evidence, showing that diameter growth of *A. mangium* is very responsive to extra growing space (Table 7.10).

It has yet to be shown whether 50-cm-diameter trees at age 15, which Mead and Speechly (1989) suggest are desirable, can be obtained routinely. However, even if such diameters are not always obtained, it was thought that, with advances in utilization technology, smaller-sized pruned logs will be sought after and put to high-quality uses. This has happened in Australia, where new technology is allowing relatively small eucalypt logs to be utilized for products such as

Table 7.10. Growth of *Acacia mangium* after thinning[1] to different stocking densities at age 6 years; trial data from Bengkoka, Sabah.

		23-months increment	
Treatment	Stocking (stems/ha)	Diameter[2] (mm)	Height[3] (m)
Control	900	18	4.1
50% thinning	550	31	4.4
75% thinning	275	43	3.4
90% thinning	110	78	3.1

[1]Thinning as a percentage of trees planted (1,150 stems/ha)*Source*: Udarbe and Hepburn (1989)
[2]Average increment of the diameter at breast height
[3]Average height increment of the 100 largest-diameter trees

furniture (Mead and Miller 1991), and in Malaysia and Thailand, where the same technological breakthroughs are permitting the use of logs of *Hevea brasiliensis*.

Table 7.11 shows these recommendations in a simpler form.

On the other hand, Weinland and Zuhaidi (1991, 1992) recommend an early, heavy thinning before between-tree competition fully sets in, and two further thinnings to maintain a low level of competition.

The main changes from the regime proposed by Mead and Miller (1991) that are currently being practiced by the Forestry Department of Peninsular Malaysia relate to the initial stand density and timing of pruning and thinning. Instead of age, timing of operations is based on stand height. High pruning is recommended at a stand height of 10 m when the live crown ratio is temporarily reduced to 40%. Weinland and Zuhaidi (1992) expect that crowns will recover in less than a year, accompanied by increased rate of diameter growth. At the same time, the

Table 7.11. Silvicultural and management schedule for *A. mangium*.

Treatment Number	Age	Activity	Remarks
1	4 months after planting	General slashing and form	Uproot all climbers within 45 cm of each plant.
			Remove branches less than 30 cm from the ground
	6 months after planting	General slashing	
2	12 months after planting	General slashing and First pruning	As in Treatment 1
			Remove all branches up to 2-1.5 m in height (up to 50% of total height)
3	2 years after planting	General slashing	
		First thinning and high pruning	Remove 300 stems/ha, retaining 600 trees/ha, pruning up to 6 m of the 200 selected final crop trees
4	4-5 years after planting	Second thinning	Remove another 200 trees/ha, retaining 400 trees/ha
5	8-9 years after planting	Final thinning	Remove another 200 trees/ha

Source: Thang and Zulkifli (1992)

stand is thinned to 500 stems/ha. Since the final cut would still be 12 to 13 years later, excess 200 stems should be enough to compensate for possible mortality, damage and disease and unexpected deterioration in growth and quality. The number of trees in the final crop is not yet certain; 300 final crop trees/ha implies a between-tree spacing of about 5.5 m; 200 final crop trees, about 7 m between trees. However, the authors recommend a third thinning at a stand height of 20 m. The operations are summarized in Table 7.12.

Table 7.12. Tending regimes for *A. mangium*.

Activity	Timing
Planting (1,400 stems/ha)	
Refilling	1/2 months after planting, only if mortality exceeds 10%.
Weeding	Circle weeding 2 months after planting; further weeding operations 4 and 6 months after planting
Pruning - Low (6 m)	4 months after planting, removal of multiple stems and big side branches; at 5 m stand height pruning (green pruning) to 2.5 m (900 stem/ha); at stand height of 10 or 12 m pruning (500 stems/ha).
Thinning	At stand height of 5 m to 900 stems/ha (to waste); at stand height of 10 m to 12 m to 500 stems/ha (to waste); at stand height of about 20 m thinning to 300 stems/ha (productive).

Source: Weinland and Zuhaidi (1991)

Second Rotation

A. mangium stumps coppice profusely if a high stump of >50 cm is left. But unlike *Gmelina arborea*, *Paraserianthes falcataria*, some species of *Eucalyptus*, *Tectona grandis*, and *Shorea robusta*, its coppice shoots do not develop to tree size. It is therefore not possible to obtain a second rotation by coppicing. However, profuse natural regeneration in clear-felled *A. mangium* areas has been observed in Sabah, Kalimantan, and Papua New Guinea (Sim 1987; Srivastava and Yelu 1992; Weinland and Zuhaidi 1992). This regeneration is further encouraged by light fires after clear-felling, which probably destroys or softens the hard seed coat and stimulates germination if moisture is available (Plate 7.8). Various aspects of natural regeneration thus merit study, and research should develop techniques and schedules for tending, pruning, and thinning to make productive use of naturally produced crops. Studies will also be needed to determine the form, rate of growth, and quality of a crop raised from natural regeneration.

Plate 7.8. Natural regeneration on a burn site at Kota Belud, Sabah. *Photo*: K. Awang

Fire Protection

Plantations of any species are open to great risk of fire (Plate 7.9). Although damage varies depending on species, all monocultures have suffered heavy losses due to fires. This is true even in tropical areas where a drought or dry period may be as short as 2-3 weeks. Thousands of hectares of plantations of various age classes and species have been lost in the tropics due to fires. Therefore every large plantation project has prepared guidelines and proper equipment, and watch towers have been installed to control fires. Although the exercise is expensive, it is worth the cost.

In the tropics—especially where communities still follow cultivation and subsistence farming in and around forest plantations, and in areas dominated by grasses (such as *Imperata cylindrica*)—most fires are man-made for slash-and-burn agriculture or to foster young grass for new pasture grounds. In fact, the initial objective of introducing *A. mangium* in Sabah was to use it as firebreaks in such areas, because of its ability to suppress grasses with its rapid growth and crown closure, and its ability to grow on acid soils. Now, however, it is among the most important plantation species there.

Seibret (1988) reported the effect of groundfire damage to an 18-month old *A. mangium* plantation in East Kalimantan. The plantation was attacked by an *Imperata* ground fire in 1986. Trees with diameter <4 cm died, while those

Plate 7.9. Three-year-old *A. mangium* killed by fire. *Photo*: Enso Forest Development

having a diameter >7 cm survived. Survival of trees in the critical diameter range of 4-7 cm depended on the value of damage index, with higher index values resulting in higher mortality.

Further research is needed on the susceptibility of *A. mangium* to fire.

Fire protection has two main components: fire prevention and fire control (also called fire-fighting or suppression) (Romijn 1986).

Fire Prevention

The following measures help to minimize the incidence of fire in monocultures.

- Design plantations with a well-planned layout, especially in terms of accessibility to each part of the plantation.
- Provide a network of greenbreaks and fire access roads, and maintain these regularly.
- Apply silvicultural practices on schedule.
- Reduce fuel levels in the plantation by (1) clean-tending around trees, (2) controlled burning, and (3) introducing grazing cattle.

- Create awareness of the dangers and losses due to fires among communities near the plantation.

- Formulate and enforce fire regulations.

Fire Control

To minimize damage in the event of fire, the following measures are suggested:

1. Set up and maintain an effective detection system, such as fire towers, mobile patrols, and/or radio communication system.

2. Maintain a well organized and equipped fire-fighting team with

   - a fire plan,
   - equipment for firebreak construction and maintenance,
   - fire tanks and pumps, knapsack spray pumps, fire rakes, and fire beaters,
   - access to well maintained ponds and other reservoirs,
   - adequate trained manpower, and
   - if necessary, incentives for motivation (for example, firefighting bonuses, overtime, or free housing near the plantation).

Research Priorities

In Asia, large-scale plantation programs using *A. mangium* have been planned in Malaysia, Indonesia, Papua New Guinea, and Thailand on the basis of available information on its adaptability, site requirements, growth, and utilization. This review, however, indicates that serious gaps on many aspects of this species remain and require the attention of researchers in order for *A. mangium* plantations to meet their objectives. In particular, optimum silviculture schedules have yet to be worked out. In fact, the current information on pruning and thinning is sketchy and controversial. Table 7.13 shows the latest information on research priorities in the region. Many of these aspects were earlier mentioned in ACIAR proceedings 16 and 35.

Table 7.13. Priorities for silviculture research on *A. mangium*.

Planting Objective	Priority: Low	Medium	High
Site rehabilitation	Site suitability Pruning Pollarding Thinning Rhizobium inoculation	Spacing Tending Pests and diseases	Growth and yield Direct seeding
Industrial Plantation			
Pulp and fuelwood	Spacing Tending Rhizobium inoculation	Fertilizer use Pests and diseases	Growth and yield Direct seeding
Saw logs	Pests and diseases	Rhizobium inoculation	Growth and yield Direct seeding Spacing Tending Pruning Thinning Fertilizer use
Agro- and Community Forestry	Growth and yield Rhizobium inoculation	Pruning Pests and diseases	Spacing Pollarding

Source: Awang and Taylor (1992)

Summary

Site preparation for *A. mangium* plantations should consider:

- past and present vegetation
- climate
- topography
- soil type
- soil fertility
- equipment
- availability of labor

Depending on these factors, either mechanical (including semi-mechanical) or manual methods may be used. Controlled burning plays an important part in

the survival and early growth of *A. mangium*.

Depending on the objective of raising *A. mangium* plantations, initial spacing can vary from 2 x 2 m to 4 x 4 m. More research is needed on optimum spacing.

Where weeds abound, as in PNG, a weeding schedule of 4-3-2 should be strictly followed in the first 3 years, with the first weeding taking place 2 months after planting. Both chemical and manual (and mechanical) control methods have been successfully used.

A. mangium attains its growth potential in logged-over forest areas with fertile soils. Application of suitable fertilizers in adequate amounts at the right times has yielded better growth; fertilizer mix, amounts, and timing vary with site. More site-specific research is needed on this aspect.

Singling is an important silvicultural operation on many sites and with many genotypes. It should be carried out at 4-6 months after planting.

Pruning and thinning schedules have yet to be conclusively determined. For the present, the schedules recommended in Peninsular Malaysia (Mead and Miller 1991) can be followed.

Standard fire prevention and control measures are needed in every large plantation project using this species.

A. mangium regenerates profusely in clear-felled areas where it is grown. Research is needed on tending, pruning, and thinning techniques to develop naturally produced crops into productive plantations.

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References

Adjers, G. and O. Luukkanen. 1988. Fertilization trial of recently planted *Acacia mangium* seedlings. Res. Paper 3, University of Helsinki, Dept. of Silviculture. 77 pp.

Arif, A., T. Sutomo, and C. Matseri. 1990. The establishment of *Acacia mangium* forests by Roundup techniques in South Kalimantan reforestation project. BIOTROP Special Publication No. 38:143-148.

Awang, Kanis and D.A. Taylor, eds. 1992. *Tropical Acacias in East Asia and the Pacific*. Proc. of a first meeting of the Consultative Group for Research and Development of Acacias (COGREDA), June 1-3, 1992, Phuket, Thailand; 1-7. Bangkok, Thailand: Winrock International.

Bevege, D.I. 1978. Foliar analysis as a guide to the nutrient status of tropical pines. In Proc. of the Eighth International Colloquium on Plant Analysis and Fertilizer Problems, Auckland, New Zealand, August 1978; eds. A.R. Ferguson, R.L. Busliske, and I.B. Ferguson. N.Z. DSIR Information Series No. 134. Wellington, New Zealand: Government Printer.

Chai, J.T. 1984. Compensatory plantations in Peninsular Malaysia. In Proc. Seminar on Forest Plantation Development in Malaysia, July 9-14, 1984, Sabah, Malaysia; eds. T.C. Lew, M.P. Udarbe, and H.T. Tang; 35-44. Kota Kinabalu, Malaysia: Forest Department, Sabah.

Gessusse, B. 1992. Agroforestry training needs for coordinated extension. Paper presented at the National MPTS Committee Meeting, May 25-26, 1992, PNG Forest Research Institute, Lae.

Hamsawi Sani and Jugah Kadir. 1989. An early growth assessment of *Acacia mangium* Willd. and *Gmelina arborea* Roshb. on sub-soil of Nyalau Soil series in Bantulu. In *Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 337-342. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

Kanua, M.B. and E.C. Sitipai. 1992. Agroforestry - sustainable agriculture research programme. Paper presented at the National MPTS Committee Meeting, May 25-26, 1992, PNG Forest Research Institute, Lae.

Khamis Selamat. 1991. Trials of *Acacia mangium* at the Sabah Forestry Development Authority. In *Advances in Tropical Acacias*, ed. J.W. Turnbull; 224-226. ACIAR Proceedings No. 35. Canberra, Australia: ACIAR.

Lambert, M.J. 1984. The use of foliar analysis in fertilizer research. In *Proc. IUFRO Symposium on Site Productivity of Fast Growing Plantations*, held Pretoria and Petermaritzburg, South Africa, Vol 2: 669-678.

Mead, D.J. and R.R. Miller. 1991. The establishment and tending of *Acacia mangium*. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 116-122. ACIAR Proceedings No. 35. Canberra, Australia: ACIAR.

Mead, D.J. and H.T. Speechly. 1989. Growing *Acacia mangium* for high quality saw logs in Peninsular Malaysia. In *Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 54-71. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

Miller, R.R. and A.J. Hepburn. 1989. A review of the growth of *Acacia mangium* at the Bengkoka afforestation and settlement project North Sabah. In *Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 93-110. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

Nik, M.M. and B.K. Paudyal. 1992. Pruning trial for *Acacia mangium* Willd. plantation in Peninsular Malaysia. *For. Ecol. and Management* 47(1-4):285-293.

Qureshi, I.M. and P.B.L. Srivastava. 1966. Foliar diagnosis and mineral nutrition of forest trees. *Indian Forester* 9(7):447-460.

Rahim, S. 1987. Survival rates of direct seedling and containerized planting of *Acacia mangium*. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 173-175. ACIAR Proceedings No. 16. Canberra, Australia: ACIAR.

Raymond Tan, G.S. 1992. Economics of planting and marketing of *Acacia mangium*. In *Tropical Acacias in East Asia and The Pacific*, eds. K. Awang and D.A. Taylor; 96-103. Proc. of first meeting of the Consultative Group for Research and Development of Acacias (COGREDA), June 1-3, 1992. Bangkok, Thailand: Winrock International.

Richards, B.N. and D.I. Bevege. 1969. Critical foliage concentration of nitrogen and phosphous as a guide to the nutrient status of *Araucaria* underplanted to *Pinus*. *Plant and Soil* 31(2):328-337.

Romijn, K. 1986. *Plantation Silviculture*. Training Manual No. 18. Bulolo, Papua New Guinea: PNG Department of Forests, Forestry College.

Seibert, B. 1988. Groundfire damage to young *Acacia mangium* Willd. stand. *NFT Res. Rpts.* 6:38-39.

Sim, B.L. 1987. Research on *Acacia mangium* in Sabah. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 164-166. ACIAR Proceedings No. 16. Canberra, Australia: ACIAR.

Simpson, J.A. 1992. An assessment of the soils and nutrient status of trial plantations in the Indonesia-Finland project at Riam Kiwa, South Kalimantan, Indonesia. Report prepared for Enso Forest Development, Ltd., Helsinki, Finland.

Skelton, D.J. 1987. Distribution and ecology of Papua New Guinea Acacias. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 38-44. ACIAR Proceedings No. 16. Canberra, Australia: ACIAR.

Srivastava, P.B.L. and W. Yelu. 1992. Acacias in Papua New Guinea: current and future research. In *Tropical Acacias in East Asia and the Pacific*, eds. Kamis Awang and D.A. Taylor; 44-49. Proc. of a first meeting of the Consultative Group for Research and Development of Acacias (COGREDA) held in Phuket, Thailand, June 1-3, 1992. Bangkok, Thailand: Winrock International-F/FRED.

Tan, K.C. 1989. The effect of topographic positions on the growth of *Gmelina arborea* and *Acacia mangium*. In *Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et

al. Proc.of a regional symposium held June 5-9, 1989 in Serdang, Malaysia; 390-400. Serdang: Universiti Pertanian Malaysia.

Tan, K.C. and R. Dougles. 1989. Harvesting and plantation management in the tropics: a case study. Paper presented at the Thirteenth Commonwealth Forestry Conf., held Rotorua, New Zealand, September 1989.

Thang, H.C. and M. Zulkifli. 1992. Management practices of *Acacia mangium* plantations in Peninsular Malaysia. Paper presented at the International Symposium on Harvesting and Silviculture for Sustainable Forestry in the Tropics, October 5-9, 1992, Kuala Lumpur, Malaysia.

Thomas, K.I. and G.A. Kent. 1987. Growth of *Acacia mangium* throughout Sabah. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 160-166. ACIAR Proceedings No. 16. Canberra, Australia: ACIAR.

Udarbe, M.P. 1984. Forest plantation development economic considerations: a case study of the activities of Sabah Forestry Development Authority (SAFODA). In *Proc. seminar on Forest Plantation Development in Malaysia, July 9-14, 1984, Sabah, Malaysia*; eds. T.C. Liew, M.P. Udarbe, and H.T. Tang; 28-34. Kota Kinabalu, Malaysia: Forest Department, Sabah.

Udarbe, M.P. and A.J. Hepburn. 1987. Development of *Acacia mangium* as a plantation species in Sabah. In *Australian Acacias in Developing Countries*, ed. J.W. Turnbull; 157-159. ACIAR Proceedings No. 16. Canberra: ACIAR.

Wan Rasidah bt A.K., Aminah bt. H., and P. Sundralingam. 1989. Effect of nitrogen and phosphorus on the early growth of three exotic plantation species in Peninsular Malaysia. *J. Trop. For. Sci.* 1(2):178-186..

Weinland G. and A.Y. Zuhaidi. 1991. Management of *Acacia mangium* stands: tending issues. In Proc. of Malaysian Forestry and Forest Products Research Conference, October 3-4, 1990, Kuala Lumpur, Malaysia; eds. S. Appanah, F.S.P. Ng, and Roslan Ismail; 41-53. Kuala Lumpur, Malaysia: FRIM.

_____. 1992. Stand management of *Acacia mangium* for sawlog production. Paper presented at the Int. Symp. on Harvesting and Silviculture for Sustainable Forestry in the Tropics, October 5-9, 1992, Kuala Lumpur, Malaysia.

Werren, M. 1991. Plantation development of *Acacia mangium* in Sumatra. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull; 107-109. ACIAR Proceedings No. 35. Canberra, Australia: ACIAR.

Chapter 8

Growth and Yield

Lim Meng Tsai

Introduction

The terms *growth* and *yield* refer to the change in certain tree or stand parameters of interest to the manager of a stand of trees for wood and/or other products. Conventional foresters record growth parameters like tree diameter (usually diameter at breast height, or dbh) and height (usually height to a specified minimum diameter or clear bole height) in order to derive other parameters such as basal area and volume. Other useful parameters include the density or stocking and in regenerating forests, measures of regeneration like ingrowth and mortality. *Yield* usually refers to the quantities of the desired product(s). Here again, foresters have in the past used measures like commercial volume (volume of the stem down to a specified minimum diameter—often 10 cm) and/or the number of bolts or lengths of stems of certain dimensions.

Growth and yield information is important for planning and managing a forest resource. It is also important to the agroforester in deciding what species to plant and what components can be harvested. The information required for agroforestry will be different from that required for conventional forestry as the products and uses of the trees in agroforestry are different.

Knowing the growth and yield of a species (together with a clear planting objective, end use, and understanding of site suitability) is therefore critical for informed decisions concerning species selection. The end use (or uses) is also important in determining which parameters to measure. For instance, stocking may be irrelevant where trees are planted individually; in that case, parameters such as crown diameter and number of branches may be more useful. In agroforestry situations such as alley cropping, where there is regular pruning for harvest, dbh and height cannot be used and biomass estimates must be based on other parameters, such as the number and size of stems.

In many growth and yield studies on *Acacia mangium*, the parameters of dbh and height are measured, as the species has primarily been planted for timber products. In view of its other uses, other parameters of growth and yield need to

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be included. For instance, where *A. mangium* is used for fuelwood production through regular harvesting and regeneration through coppicing, information on coppice regrowth rates should be studied; if phyllodes were regularly harvested for green manure, the rate of regrowth of phyllodes would also need to be investigated.

Since much of the information available is from research based on this conventional forestry approach, this review of growth and yield of *A. mangium* concentrates on these parameters. Wherever available, other information has been incorporated.

Growth Phenology and Pattern

To understand growth and yield, it is important to understand the species' basic biology and behavior. This is often approached through phenological observations. *A. mangium* is a fast-growing pioneer species with self-pruning branches (NRC 1983), but there is no published information on the pattern of leaf and shoot growth.

The growth of *A. mangium* can be described as continuous. Studies at Universiti Pertanian Malaysia (UPM) show that when conditions are favorable, new shoots and new phyllodes are found throughout the year, and leaf shedding occurs continuously.

Shoot Elongation

Acacia mangium forms branches and forks easily, and the forks and branches grow very rapidly. Some lower lateral branches may become dormant and even stop growing, dying quite rapidly. Approximately 25-35% of these lateral branches may stop growing within a six-month period. The growing shoots will produce phyllodes continuously. Some shoots grow continuously while others grow for a while and then become dormant and stop producing new phyllodes. Dormant shoots normally do not resume growing along the same axis except through development of a new lateral shoot. This can produce a branch with several die-back branches/shoots (Plate 8.1). Shoots have been observed to elongate between 3-5 cm per month.

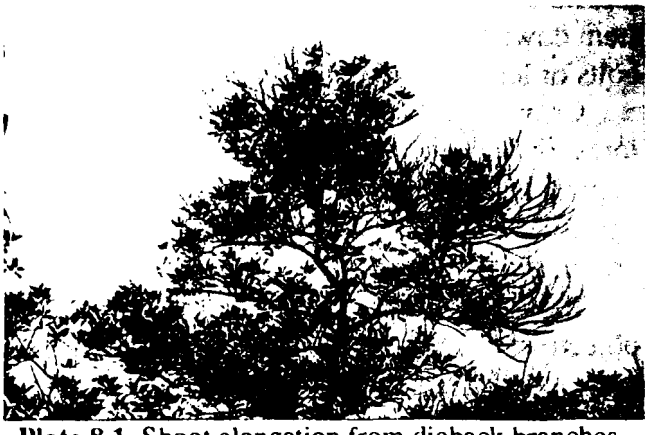

Plate 8.1. Shoot elongation from dieback branches. *Photo*: Lim Meng Tsai

Phyllode Expansion

Phyllode (or leaf) growth is related to shoot growth. In an actively growing shoot, phyllodes are produced continuously. Between 2 and 4 phyllodes are produced each month. Phyllodes take about 6 weeks to expand from about 1 cm to full size, which can be up to 25 cm long and 10 cm wide. UPM studies show that phyllodes expand rapidly and achieve 50% of their mature size in about 1.5-3 weeks and 90% of their full size within another 1-2 weeks. Phyllode weight follows the same pattern and reaches its maximum at about 4-5 weeks. The phyllode also begins to lose weight after about 10 weeks and can drop off after about 6-11 months.

Growth Form

NRC (1983) describes *A. mangium* as able to grow to 30 m with a straight bole, which may be unbranched for over 15 m. *Acacia mangium* seedlings grown in fairly open conditions often develop a bushy appearance with multiple leaders. In plantations, this necessitates pruning and removal of lateral stems in the first year or so.

Trees planted in the open have deep and globular and/or columnar canopies that begin almost at ground level, while trees in plantations after canopy closure have crowns that are restricted to the top 3-4 m from the top. The lower branches of closely planted trees usually die rapidly and are sometimes shed. Studies on distribution of biomass in plantation- and open-grown *A. mangium* show that over 57% of the total biomass of open-grown trees can be in the canopy—branches and phyllodes—while the corresponding figure for plantation-grown trees is below 28%. The percentage of leaf biomass to total biomass of open-grown trees (16.9%) is also considerably higher than that of plantation-grown trees (5.5%)(Lim 1985, 1986).

Siregar and Djaingsastro (1988) investigated the growth of *A. mangium* at different spacings and developed the following simple relationship between height and dbh:

$$\text{Height(cm)} = -8.4052 + 120.0915 * \text{dbh(mm)}$$

Crown development is an aspect of tree growth that needs to be studied further (Lim 1991; Mead 1991). Crown development is important because it is related to spatial requirements and thus involves competition between plants. In plantations, it can be related to density or stocking. In agroforestry, overshading of other food crops may reduce the yield of food crops intercropped between the trees (Adjers and Hadi, in press). *A. mangium* is a pioneer species and requires much light to grow well. Given sufficient light (for example, when grown

individually), it will develop a wide and deep crown. Dawkins (1963) and Wong (1966) used the crown diameter (CD) - stem diameter (dbh) relationship to determine the crown space requirements of a number of forest tree species. Lim (1991) and Mead and Speechly (1991) found the CD-dbh relationship of open-grown *A. mangium* trees to be highly significant.

CD(m) = 1.373 +0.252*dbh(cm)	Lim (1991)
CD(m) = 1.704 +0.251*dbh(cm)	Mead and Speechly (1991)
CD(m) = 1.89425 + 0.17822*dbh (cm)	Paudyal and Nik Muhamad (1990)

Paudyal and Nik Muhamad (1990) applied this technique to plantation-grown trees up to about 8 years old and also found a significant relationship between dbh and crown diameter. They recommended thinning regimes using information from these relationships.

Growth Rates

Table 8.1 summarizes information on growth rates from various sources and under different conditions. Dbh increases fairly rapidly, up to 15-20 cm in trees less than four years old. The growth rate slows down noticeably after the fifth year, and dbh begins to level off around 30 cm by the eighth year. Height growth shows the same trend as dbh: there is a sharp increase in the first 3-4 years, after which the height levels off around 25-30 m.

These dbh and height data vary considerably with age and site. Comparisons can be made on the basis of the mean annual increment (MAI) values (Table 8.1). The MAI for dbh ranges from 1.8 to 7.4 (cm/yr). High MAI values (over 4) are recorded for trees 2-4 years old, after which the MAI values generally decline towards 2-2.5. The MAI for height ranges about 1.2-7.2, and high values (over 4) are recorded for trees less than 5 years old. Like MAI-dbh, MAI for height drops rapidly towards 2.5-3.

The information in Table 8.1 can be summarized by analyzing the change in dbh and height with age. Lim (1991) attempted to determine *A. mangium*'s maximum performance capacity using data from various sources, including those cited in Table 8.1, to generate growth functions. The following Chapman-Richards Functions provide good enveloping (maximum) curves for dbh and height.

$$\text{Dbh} = 30*(1-e^{(-0.30*\text{Age})})$$
$$\text{Height} = 35*(1-e^{(-0.21*\text{Age})})$$

From this analysis, the maximum values (asymptotes) were estimated at 30 cm for dbh, and 35 m for height. In Indonesia, Harbagung (1991) studied 3-11

year-old stands in South Sumatra, West Java, and East Kalimantan and developed an Upper height (top height) - age equation of the following form:

$$\text{Ln Ho} = 4.11011 + (\text{bsi} - 4.14291)/(1/A)^{(0.57645)}$$

where bsi = regression coefficient of each site-index value
A = age of stand
Ho = upper height of stand

Table 8.1. Dbh, height, and mean annual increments (MAI) of dbh and height values for *Acacia mangium* of different ages.

Age (years)	DBH (cm)	MAI DBH (cm/yr)	Height (m)	MAI Height (m/yr)	Reference
0.5	-	-	0.55	1.18	Daryono (1988)
0.5	-	-	1.03	2.06	Pettersson and Havmoller (1984)
1	1.8	1.8	2.7	2.7	Yanthasath et al. (1986)
1	-	4.98	-	4.20	Kamis and Mohd. Amran (1984)
1.5	8.8	5.87	6.1	4.07	Paudyal and Nik Muhamad (1990)
1.6	-	-	1.9	1.19	Glover and Heuveldop (1985)
1.6	-	-	7.4	4.65	Sim, and Gan (1988)
2	4.2	2.1	6.0	3.0	Yanthasath et al. (1986)
2	9.9	4.95	8.6	4.3	Sim (1984)
2	14.8	7.4	14.4	7.2	Racz and Zakaria (1986)
2	10.3	5.15	6.7	3.35	Pan Zhigang and Yang (1986)
2	5.2	2.6	5.1	2.55	Boontawee and Kuwalairat (1986)
2.1	-	-	2.8	1.33	Glover and Heuveldop (1985)
2.25	13.6	6.04	12.3	5.47	Mead and Speechly (1991)
2.33	11.39	4.89	8.36	3.59	Bhumibhamon and Atipanumpai (1992)
3	-	4.99	-	4.33	Kamis and Mohd. Amran (1984)
3.5	18.1	5.17	10.6	3.03	Lim (1985)
3.5	15.8	4.5	8.0	2.3	Lim (1985)
3.5	12.5	3.6	15.5	4.4	Lim and Mohd Basri (1985)
3.9	15.1	3.87	15.4	3.95	Paudyal and Nik Muhamad (1990)
4	12.6	3.15	16	4.0	Lim (1988)
4	7.2	1.8	9.4	2.35	Yanthasath et al. (1986)
4.5	14.3	3.18	20.5	4.56	Lim (1986)
5	15.9	3.18	19.2	3.84	Thomas and Kent (1986)
5	18.7	3.74	20.0	4.0	Wan Razali et al. (1989)
5.1	17.3	3.39	16.97	3.33	Paudyal and Nik Muhamad (1990)
6.6	19.5	2.95	25.4	3.85	Thomas and Kent (1986)
6.8	25.8	3.79	25	3.68	Halenda (1988)
7.8	25.1	3.22	22.8	2.92	Thomas and Kent (1986)
8.25	20.25	2.45	25.0	3.03	Paudyal and Nik Muhamad (1990)
8.8	25.3	2.88	27.5	3.12	Thomas and Kent (1986)
9	23	2.55	23	2.55	Tham (1976)
13	28.6	5.98	21	1.61	Chai (1980)

Ten-year-old stands would have upper heights of about 20-26 m, depending on the site index.

Yield

Yield refers to the quantity of product that can be obtained from a stand of trees and is usually measured as wood volume or biomass per unit area. On a stand basis, this information on volume and biomass integrates the effects of density (and mortality), thinning, commercial/marketable yield, growth rates, and even genetic differences.

Volume

Volume is perhaps the most commonly measured or estimated parameter in both natural and plantation forestry, as it is a routine requirement for estimating stand output. Volume can be estimated from dbh alone or in combination with total height (Watts 1989), or from the length of bole measured to a specified minimum top diameter, such as 4 cm (Soemarna and Bustomi 1986), 7 cm (Bustomi 1988) or even 10 cm (Wan Razali et al. 1989). Volume yields are often presented as volume tables, which may be either one-way tables in which volumes are given for a particular dbh, or two-way tables that provide estimates for a dbh against a range of height measurements.

In Malaysia, Wan Razali et al. (1989) estimated merchantable volume (down to a minimum diameter of 10 cm) for a 5-year-old stand using a variety of regression equations developed from felled and standing trees. They used the Furnival index to determine the equation with the best fit. The best equation was one that required the log transformation of volume and dbh. They also recommended the use of another factor to correct for transformation bias. From these equations they established two-way stand volume tables for *A. mangium* stands based on diameter and total log length.

Watts (1989) sampled over 200 trees from a plantation in Sabah and developed volume equations based on dbh alone and dbh and total height. He also presented both one- and two-way tables. The method of using diameter alone is considered more practical, as measurements of height require additional time and costs, and the improvement in accuracy is not significant enough to warrant the extra costs.

Setyarso (1992) reviewed growth and yield studies of *A. mangium* in Indonesia and found no comprehensive studies, even though the species is planted on very large scales in Sumatra and Kalimantan. Soemarna and Bustomi (1986) sampled over 100 trees in 3-, 5-, and 7-year-old plantations and developed the

following equations to estimate the clear bole volume as well as volume to 4 cm diameter:

$$\text{Vol (clear bole)} = .1217*\text{dbh}^{(2.4697)}$$
$$\text{Vol (4 cm)} = 0.1537*\text{dbh}^{(2.4247)}$$

In another study involving over 130 trees, Bustomi (1988) developed other equations for volume down to 7 cm diameter.

$$\text{Vol(7cm)} = 0.7932*\text{dbh}^{(1.8873)}$$
$$\text{Vol(7cm)} = 0.0396*\text{dbh}^{(1.6536)}*\text{Height}^{(1.2432)}$$

These studies on growth and yield have proposed and used numerous forms of regressions. The ultimate factors in the decision of which form to use are practicality, ease of use, and accuracy. In forestry, complex equations can be developed using a number of variables to account for the variability of site, but for agroforestry purposes it may be necessary to develop simple equations, as end users may not have sophisticated equipment with which to measure many parameters. Table 8.2 lists volumes estimated for a tree with dbh of 20 cm, derived using different methods of estimation by different authors. Given the similarity of these estimates and the multipurpose use of the species, it may be appropriate to suggest that the most simple and direct method is sufficient.

Table 8.2. Volume estimates of a sample tree 20 cm dbh, from different volume tables.

Dbh (cm)	Height (m)	Volume (m^3)	Reference
20	--	0.221	Watts (1989)
20	--	0.229	Bustomi (1988)
20	16	0.190	Watts (1989)
20	16	0.178	Bustomi (1988)
20	10 (4cm)	0.206	Soemarna and Bustomi (1986)
20	10 (log)	0.209	Wan Razali et al. (1989)
20	10 (bole)	0.185	Soemarna and Bustomi (1986)

Biomass

Biomass as a unit of yield has only become fairly widely used since the 1970s. It is in many ways a more useful measure than volume, as it allows comparisons to be made between different crops, as well as among different tree components (for example, leaves, fruits, and stems). Furthermore, it can be used to estimate

energy and nutrient contents rapidly. In agroforestry, the amount of leaf or litter that can be used for fodder is more appropriately measured in terms of biomass rather than volume. However, estimation of tree biomass involves much time and effort and few results are available. Those that are available are often limited to smaller trees.

Lim and Mohd. Basri Hamzah (1985), using a modified Smalian formula and an assumed wood density of 0.5, estimated the total biomass of a stand of 3.5-year-old *A. mangium* to be 54.4 t/ha (Table 8.3). Lim (1986) followed on the same study by developing regression equations from destructive sampling of trees and relating biomass (kg) of different aboveground components, such as stem, branch, and leaf, to dbh (cm). A 4.5-year-old stand of mean dbh of 14.3 cm and density of 1,084 stems/ha was found to contain 84 t/ha total biomass, consisting of 54 t of stems, 16 t branches, and 6 t phyllodes. Lim (1985) also studied open-grown trees and estimated that if planted under plantation conditions, a 3.5-year-old stand could yield a total above-ground biomass of 102.6 t/ha.

log(total) = -1.629 +3.024*log(dbh) Lim (1985)
log(total) = -1.074 +2.5201*log(dbh) Lim (1986)
log(total) = -1.420 +2.8320*log(dbh) Lim (1988)

Halenda (1989), working in Sarawak, Malaysia developed regression equations for estimating total height and biomass of different components of 6.8-year-

Table 8.3. Biomass estimates (oven dry basis) of stands at different ages.

Age (yrs)	Density (no/ha)	Leaf (t/ha)	Branch (t/ha)	Stem (t/ha)	Total (t/ha)	Reference
3.5	1,089				54.4	Lim and Mohd. Basri Hamzah (1985)
3.5	625				64.1[1]	Lim (1985)
4	2,500				48.[2]	Yantasath (1992)
4	10,000				128.[2]	Yantasath (1992)
4	1,566	5.4	14.1	57.6	90.4	Lim (1988)
4.5	1,084	4.2	24.1	82.7	86.9	Lim (1986)
6.8	730	4.7	15.3	97.4	123.2	Halenda (1989)
Sample	20 cm dbh				202.0	Lim (1985) (open grown)
tree[3]	20 cm dbh				160.2	Lim (1986)
	20 cm dbh				183.9	Lim (1988)
	20 cm dbh				178.9	Halenda (1989)

[1] projected for plantation condition
[2] converted from fresh weight data by multipling by 0.4
[3] estimated from regression equations

old *A. mangium* stands using dbh (cm) and height (m) as parameters. The equations were:

$$\text{Height} = -3.821 + 1.796*\text{dbh} - 0.025*(\text{dbh})^2$$
$$\text{Ln(Stem Weight)} = -3.212 + 0.905*\text{Ln}((\text{dbh})^2*\text{H})$$
$$\text{Ln(Branch Weight)} = -2.073 + 1.030*\text{Ln(Stem Weight)}$$
$$\text{Ln(Branch Weight)} = -5.464 + 0.942*\text{Ln}((\text{dbh})^2*\text{H})$$
$$\text{Ln(Leaf Weight)} = -2.026 + 0.792*\text{Ln(Stem Weight)}$$

These regressions are somewhat difficult to use as some components require other parameters to be calculated before they can be estimated. The relative errors based on the difference between estimated with the actual tree sample are, however, low (generally below 5%). Using these equations, Halenda (1989) obtained a total biomass of 123.2 t/ha (Table 8.3).

Yantasath et al. (1986, 1992) conducted trials on species and spacing in Thailand to determine the effects of spacing on growth and biomass yield. They obtained an allometric regression of the form,

$$\log(\text{weight}) = -0.9892 + 0.2781*\text{Log}(\text{dbh}^2*\text{H})$$

At very high densities (20,000 stems/ha), high biomass accumulations of up to 80 ha/year (fresh weight) were recorded. This high figure may be partly due to the use of small plots.

Another aspect of biomass yield that has been relatively neglected is the below-ground biomass. Daryono (1988) investigated 6-month-old *A. mangium* and found that root lengths vary from 30-51.8 cm. Lim (1992) reported preliminary results of fine root biomass of about 4 t/ha in stands 2-6 years of age.

Other Forms

Apart from being an important aspect of yield, biomass is also an important component of an ecosystem's bioproductivity. Another important component of productivity is litter production. Litter serves ecologically important functions and has been included in many ecological studies on forests and plantations. Litter production is also important in the process of nutrient cycling. In agroforestry systems, litter can be viewed as another tree product that is useful for the agricultural component of the system; tree litter can be harvested for brown manure, mulch, and sometimes as fuel. Studies have shown that fine litter (leaf and twigs < 2 cm diameter) production of *A. mangium* stands can amount to 8-11 t/ha/yr; 75% of this is leaf litter (Lim 1988).

Another measure of yield that can be derived from biomass is the energy content of the wood and branches. The calorific value of *A. mangium* wood has been estimated at about 5,000 kcal/kg (Yantasath et al. 1986). Together with

biomass information on wood yield, the potential energy yield can be estimated. This information is also important in agroforestry uses of *A. mangium*, as woody parts of the tree may be harvested as fuelwood. This is important in modern forestry as well, since plantations are viewed as potential sources of biomass energy.

Another derivative of biomass information is the trees' carbon yield. With the current concern over the global environment and the increase in the carbon dioxide content of the atmosphere, plantations of fast-growing species can be important carbon sinks. As a rough estimate, the carbon content is approximately half of the biomass (Brown and Lugo 1984).

Nutrient Cycling

The importance of nutrient cycling in the maintenance of natural ecosystems is well known. The patterns of cycling in temperate plantations are also fairly well researched and understood (Miller 1984). The processes of nutrient cycling in *A. mangium* stands are not likely to be very different, but the rates and quantities involved are less well understood, especially in relation to the stages of growth. This requires quantitative assessment of the nutrient content of the standing tree, the nutrient requirements for growth, and the quantities being recycled.

Table 8.4 shows data on nutrients in *A. mangium* stands. The high N content is attributable to the tree's nitrogen-fixing ability. The contents of the other nutrients, such as P, K, Ca, and Mg, can be considered average and are comparable to those in natural forest stands.

Future Research

Table 8.4. Nutrient contents of *A. mangium* stands and leaf litter.

Nutrient	1 yr (%)	4.5 yrs (kg/ha)	6.8 yrs (kg/ha)	Leaf litter (kg/ha/yr)
N	2.5	352	616	153
P	0.3	69.5	33.2	8.5
K	0.6	223.9	297.7	40.6
Ca		158.4	404	63.2
Mg		21.4	48.4	12.0
Reference	Yantasath et al. (1986)	Lim (1989)	Halenda (1989)	Lim (1989)

For more efficient harvest of *A. mangium* for various uses, growth and yield studies need to be pursued more intensively. The species will likely be planted under a wide range of conditions, from agroforestry systems to industrial plantations. The planting objectives also vary: in addition to the conventional tree products of wood, pulp, and cellulose, the species will be planted for fuel and chemicals. In view of this diversity, measures of yield must be broadened. An important aspect of growth and yield studies for such diverse uses is the ability to synthesize information rapidly and effectively, through development of computer models for forecasting growth and yield. MPTGro, a growth simulation model for fast-growing trees, represents a step in this direction. Efforts are now underway to model the growth of *A. mangium* using MPTGro.

Summary

The considerable amount of information published on the growth of *A. mangium* confirms that the species can achieve an MAI in dbh of up to 5 cm and MAI height of up to 5 m in the first four or five years. However, growth declines rapidly after seven or eight years and except under very ideal conditions or over long (>20 years) periods, the tree probably will not grow beyond 35 cm in dbh and 35 m in height.

Application of volume yield tables on a sample tree with dbh 20 cm showed that various estimates using height and dbh are quite similar, with values ranging from 0.185 m^3 to 0.220 m^3. Biomass estimates for this sample tree, using biomass equations for plantation conditions, range between 160 and 183 kg, suggesting that these equations may be generally applicable.

Dbh, height, and even site index have been used as variables in modelling yield. Using the minimum number of variables can reduce time, expense, and errors in recording parameters that are difficult to measure. In predictions of volume and biomass yield, dbh alone appears to provide sufficiently accurate and reliable estimates.

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References

Adjers, G. and T.S. Hadi. In press. Acacias in agroforestry. In *Acacias in Rural, Industrial, and Environmental Development*, eds. Kamis Awang and D.A. Taylor. Proc. of a workshop held in Udon Thani, Thailand, February 15-18, 1993. Bangkok, Thailand: Winrock International and FAO.

Bhumibhamon S. and L. Atipanumpai. 1992. Family variation in growth and some morphological characteristics of *Acacia mangium* grown in Thailand. In *Biotechnology for Forest Tree Improvement*; 155-162. BIOTROP Special Publication No. 49. Bogor, Indonesia: BIOTROP.

Boontawee, B. and P. Kuwalairat. 1986. Introduction of *Acacia mangium* to Thailand. In *Australian Acacias in Developing Countries*, ed. J. Turnbull; 149-150. ACIAR Proceedings No. 16. Canberra, Australia: ACIAR.

Brown, S. and A.E. Lugo. 1984. Biomass of tropical forests: a new estimate based on forest volumes. *Science* 223:1290-1293.

Bustomi, S. 1988. Tabel isi pohon lokal *Acacia mangium* untuk daerah Balikpapan, Kalimantan Timur (Local tree volume table of *Acacia mangium* Willd. for the Balikpapan Forest District, East Kalimantan). *Bul. Pen. Hutan* 495:31-38.

Chai, D.N.P., ed. 1980. *Sabah Forest Research Report 1979-1980*. Sandakan, Sabah: Forest Research Centre.

Daryono, H. 1988. Pengaruh jenis tanah dan perawatan benih dengan panas terhadap perkecambahan benih dan pertumbuhan Bibit *Acacia mangium* Willd. (Effects of soil type and seed treatment with hot water to the seed germination and growth of *Acacia mangium* Willd.). *Bul. Pen Hutan* 496:17-30.

Dawkins, H.C. 1963. Crown diameters: their relation to bole diameter in tropical forest trees. *Comm. For. Rev.* 43:318-333.

Glover, N. and J. Heuveldop. 1985. Multipurpose trial in Acosta- Puriscal Costa Rica. *NFT Res. Rpts.* 3:4-6.

Halenda, C.J. 1988. Performance of *Acacia mangium* Willd. and Leucaena leucocephala (Lam) De Wit at Niah Forest Reserve, Sarawak. *NFT Res. Rpts.* 6:15-17.

Halenda, C.J. 1989. Biomass estimation of *Acacia mangium* plantations using allometric regression. *NFT Res. Rpts.* 7:49-51.

Harbagung. 1991. Grafik bonita sementara hutan tanaman *Acacia mangium* Willd. (Preliminary site-class curves of *Acacia mangium* Willd. plantations). *Bul. Pen. Hutan* 537:13-25.

Kamis Awang and Mohd. Amran Mohd. Ghazali. 1984. Initial performance of *Gmelina arborea* Roxb. and *Acacia mangium* Willd. under plantation conditions. *Malaysian Forester* 47(4):255-262

Lim, M.T. 1985. Biomass and biomass relationship of 3.5 year-old open-grown *Acacia mangium*. Faculty of Forestry Occasional Paper No. 2. Serdang: Universiti Pertanian Malaysia. 13 pp.

_____. 1986. Biomass and productivity of 4.5 year-old *Acacia mangium* in Sarawak. *Pertanika* 9:81-87.

_____. 1988. Studies on *Acacia mangium* in Kemasul Forest, Malaysia. I. Biomass and productivity. *J. Trop. Ecology* 4:293-302.

_____. 1988. Nutrient content in a young *A. mangium* stand. Paper presented at the Australian Bicentennial International Forestry Conference held in Albury-Wodonga.

_____. 1991. Modelling the growth of *Acacia mangium* Willd. In *Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 459-467. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

_____. 1992. Research on growth and yield, litter production and nutrient cycling in acacias. In *Tropical Acacias in East Asia and the Pacific*, eds. Kamis Awang and D.A. Taylor; 72-75. Bangkok, Thailand: Winrock International.

Lim, M.T. and Mohd. Basri Hamzah. 1985. Biomass accumulation in a naturally regenerating lowland secondary forest and an *Acacia mangium* stand in Sarawak. *Pertanika* 8(2):237-242.

Mead, D.J. and H.T. Speechly. 1991. Growing *Acacia mangium* for high quality sawlogs in Peninsula Malaysia. In *Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 54-71. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

Miller, H.G. 1984. Dynamics of nutrient cycling in plantation ecosystems. In *Nutrition of Plantation Forests*, eds. G.D. Bowen and E.K.S. Nambiar; 53-78. London: Academic Press.

National Research Council. 1983. *Mangium and Other Fast-growing Acacias for the Humid Tropics*. Washington, D.C.: National Academy Press.

Pan Zhigang and Yang Minquan. 1986. Australian acacias in the People's Republic of China. In *Australian Acacia s in Developing Countries*, ed J. Turnbull; 136-138. ACIAR Proceedings No. 16. Canberra, Australia: ACIAR.

Paudyal B.K. and Nik Muhamad Majid. 1990. Preliminary thinning guideline for *Acacia mangium* Willd. plantations in Kemasul Forest Reserve, Peninsular Malaysia. *J. Trop. For. Sci.* 3(1):25-34.

Pettersson, H. and P. Havmoller. 1984. Provenance tests and breeding strategies for *Acacia mangium* and *Eucalyptus* spp. in Philippines and India. In *Provenance and Genetic Improvement Strategies in Tropical Forest Trees*, eds. R.D. Barnes and G.L. Gibson; 432-435. Oxford: Commonwealth Forestry Institute,Oxford and Forest Research Institute, Harare, Zimbabwe.

Racz, J. and Zakaria Ibrahim. 1986. Growth of *Acacia mangium* in Peninsular Malaysia. In *Australian Acacias in Developing Countries*, ed. J. Turnbull; 154-156. ACIAR Proceedings No. 16. Canberra, Australia: ACIAR.

Setyarso, A. 1992. The state of growth and yield study of *Acacia mangium* in Indonesia. In *Tropical Acacias in East Asia and the Pacific*, eds. Kamis Awang and D.A. Taylor; 76-80. Bangkok, Thailand: Winrock International.

Sim Boon Liang. 1984. The genetic base of *Acacia mangium* Willd. in Sabah. In *Provenance and Genetic Improvement Strategies in Tropical Forest Trees*, eds. R.D. Barnes and G.L. Gibson. Oxford: Commonwealth Forestry Institute,Oxford and Forest Research Institute, Harare, Zimbabwe.

Siregar, C.A. and N. Djaingsastro. 1988. Pertumbuhan awal *Acacia mangium* Willd. di petak percobaan Tanjung Bintang, Lampung (Preliminary growth of *Acacia mangium* Willd. in a plantation trial at Tanjung Bintang, Lampung Province). *Buletin Penelitian Hutan Pusat Penelitian dan Pengembangan Hutan Indonesia* 504:1-9.

Soemarna, K. and S. Bustomi. 1986. Tabel isi pohon lokal *Acacia mangium* Willd. untuk daerah Subanjeriji, Sumatra Selatan (Local tree volume table for *Acacia mangium*). *Bul. Pen. Hutan* 487:41-49.

Tham, C.K. 1976. Introduction of plantation species *Acacia mangium* Willd. Paper presented at the Sixth Malaysian Forestry Conference, Kuching. 6pp.

Thomas, K.I. and G.A. Kent. 1986. Growth of *Acacia mangium* throughout Sabah. In *Australian Acacias in Developing Countries*, ed. J. Turnbull; 160-163. ACIAR Proceedings No. 16. Canberra, Australia: ACIAR.

Watts, M. 1989. Individual Tree Volume Equations for *Acacia mangium*. AIFM Technical Report. Kuala Lumpur, Malaysia: ASEAN Institute of Forest Management.

Wan Razali, Khali Aziz Hamzah, and T.K. Chew. 1989. A volume table for planted *Acacia mangium* in Peninsular Malaysia. *J. Trop. For. Sci.* 2(2):110-121.

Wong, Y.K. 1966. Crown diameter/bole diameter relationship of *Dyera costulata* and its planting distance and crop density. *Malayan Forester* 29:163-169.

Yantasath, K., Siriphong Patanayibul, Winai Supatanakul, Ittirit Ungyichian, and Suthijed Chantrasiri. 1992. Field trials and multipurpose testings of selected fast-growing, nitrogen-fixing trees in Thailand. *Thai J. Ag. Sci.* 25:141-169.

Yantasath, K., Winai Supatanakul, Ittirit Ungyichian, Supun Chamsawad, Siriphong Patanayibul, Chamnong Hyakitkosol, Samorn Prompetchara, Nara Pithakarnop, and Piya Chalermkin. 1986. Country Report for Thailand. *NFT Res. Rpts.* 3:48-56.

Chapter 9

Insect Pests

Chaweewan Hutacharern

Introduction

The rapid increase in forest plantation establishment in South and Southeast Asia with fast-growing, exotic tree species, often in monocultures or with a few high-yielding varieties, tends to narrow the genetic base. Particularly for an exotic species, this reduction in diversity of species, tree age, and genetic variation produces conditions favorable to the spread of pests. This chapter describes insects that attack living *Acacia mangium* trees. Insects that attack timber and wood products are not included here.

Very few insects cause significant problems to *A. mangium*. The countries covered in the survey for this chapter were Indonesia (Selander 1990), Malaysia (Hamid 1987), the Philippines (Braza 1990b, 1991a, 1991b), and Thailand (Hutacharern and Choldumrongkul 1989; Hutacharern et al. 1988). Many articles in the literature mention insects only by name, with no further details. In some cases, insects' host plants are identified only to genus level as they were reported in the surveyed articles. For example, Nobushi and Hariyono (1987) list insects damaging *Acacia* without specifying the tree species, thus it is not certain whether they are pests of *A. mangium*. They are: *Coccus elongatus* Signoret, *Desmeocraera varia* Janse, *Ericeia inangulata* Guénee, *Metanastria hyrtaca* Cramer, *Ophiusa janata* Linne, and *Rhadinosomus lacordairei* Pascoe.

The reader can use Table 9.1 to identify insect species from type of damage and symptoms before looking up the species descriptions in the text. Insects for which sufficient details were available are presented below, arranged alphabetically by genus, with their family, known host trees, distribution, description, biology and habits, economic importance, and control measures.

Some insects were reported generally as pests of *A. mangium* because they were unintentionally intercepted in their feeding in the course of a pest survey; these do not cause any significant damage. Others were reported as potential pests, but were not identified to the species level. In these cases, the insects are

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Table 9.1. Summary of insect damage and associated pest(s), by symptoms.

Symptom(s)	Insect(s)
Leaf damage	
Curling leaf, stunted shoot	*Acizzia* sp.
Leaves rolled, young shoots consumed	*Archips micacaena*
Defoliation	*Charaxes solon sulphureus, Colasposoma igneicolle, Hypomeces squamosus, Orgyia turbata, Thosea asigna, T. bipartita, Valanga nigricornis*
Defoliation, presence of larval cases	*Cryptothelea variegata, Pteroma plagiophleps*
Defoliation of young leaves	*Eurema hecabe*
Discoloration and necrotic spots on leaves, malformed shoots	*Helopeltis* spp.
Necrotic spots on leaves	*Piezoderus rubrofasciatus*
Seedling damage	
Part or whole seedling consumed	*Nisitrus vittatus*
Branch and stem damage	
Branch and stem near the shoot are girdled and broken	*Callimetopus gloriosus*
Bark consumed, larval protective web cover present on stem	*Indarbela quadrinotata*
Loose bark, dead branches	*Xystrocera globosa*
Galls on branch, branch broken at girdling point	*Sagra femorata*
Branches or small stems broken at girdling point	*Sinoxylon anale*
Branches or small stems broken at girdling point, frass pellets present at base of tree	*Zeuzera coffeae*
Root damage	
Wilting, mud cover on bark	*Coptotermea curvignathus, Microtermes distans*
Wilting	*Leucopholis irrorata, Sternocera aequisignata, S. ruficornis*
Premature fruit drop	*Dysdercus cingulatus*

listed in the appendix along with the source references where they were mentioned.

The text specifies "host trees," not "host plants"; many insects are polyphagous, meaning they feed on an almost endless list of agricultural crops. For brevity and relevance, only forest trees are listed here.

The information under "type of damage" describes the insect's general habit; although some details may not occur on *A. mangium*; they are still more or less applicable.

Control measures suggested result from a review of available literature. Where control of certain insects could not be found in the literature, the author has used her judgment and experience to suggest what can be done. However, no experiments or trials were performed to support this opinion; readers with entomological experience are therefore encouraged to amend the information with their own experience. The reader should remember, also, that trees can tolerate a surprisingly high level of insect damage with little or no effect on growth and survival. The damage described in this text does not always imply the need for insect suppression or control. Where insect damage becomes intolerable, remedial action is then indeed required.

Regular surveys of insect population and insect damage should take place even when the pest population is at an endemic level. Perceptions gained from such regular visits provide the grower with the basis for an educated guess as to when an insect becomes a pest requiring pest management. An insect becomes a pest only when its interference adversely and significantly affects the production system. In general, a pest management program is introduced only when the population reaches an economic threshold. An economic threshold is the population level that produces damage equal to the cost of preventing that damage. Thus, cost-benefit must be considered before undertaking pest control management. Forest insect control cannot be based on a nonrational assessment of damage, for insect damage is not restricted to economic value of the crop, but also the costs to the area's recreational value. Economic importance is included for each species to help the forester diagnose this level of damage.

Pest Descriptions

Acizzia sp. (Jumping plant louse)

Family: Psyllidae
Host trees: *Acacia mangium*, *A. auriculiformis*, and *Paraserianthes falcataria*
Distribution: Philippines

Description

Adult: Yellowish-brown head and thorax, bluish-green abdomen; in some

individuals, abdomen is yellowish-brown. It measures 1.8-2.1 mm long from head to wing tip. The front wings are brownish and densely covered with prominent, dark brown spots on the apical half. Very active insect. Nymph: Light-orange, blue-green, shiny, oval to nearly circular.

Biology and Habits

The nymphs infest acacia shoots, usually colonizing and feeding at the base of the internodes, or near the axil between the leaves and the stem of the apical part of the shoots. Their concealed feeding site makes the nymphs less noticeable. Some nymphs feed at the buds. Adults suck up on either sides of the leaves and on leaf margins.

Economic Importance

Psyllid infestation results in curling leaves, stunted growth of the terminals, and an unusual number of branches on the shoots. A chocolate-brown honey secretion covers the infested shoots. Severely and repeatedly infested shoots become completely defoliated, stunted, and bushy.

Control

Although attacks by *Acizzia* on *A. mangium* are not as serious as those of the leucaena psyllid (*Heteropsylla cubana*) on *Leucaena leucocephala*, some control strategies developed for the leucaena psyllid can also be useful for *A. mangium* growers. Many introduced coccinellids have greatly helped to reduce leucaena psyllid populations. *Curinus coeruleus* has been introduced into several Southeast Asian countries with good results. Growers should also select for psyllid-tolerant varieties and hybrids of *A. mangium*.

Archips (Cacoecia) micacaena (Leaf roller)

Family: Tortricidae
Host trees: *Acacia arabica, A. mangium, A. nilotica, Albizia procera, Azadirachta indica, Bombax malabaricum, Bucklandia populnea, Cassia fistula, Cedrela toona, Dalbergia sissoo, Dillenia indica, Eucalyptus camaldulensis, Gmelina arborea, Lantana aculeata, Mangifera indica, Michelia champaca, Morus indica, Santalum album, Syzygium cuminii, Tectona grandis, Terminalia tomentosa, Toona ciliata*
Distribution: Throughout Asia and Africa

Description

Adult: Brownish front wings, expanding to 2-2.5 cm, mottled with light brown and silver, usually forming two large patches on the front margin in the female; the male does not have the patches. Hind wings are orange-yellow in both sexes, without marking. Egg: Yellowish, laid in mass as yellow patches on young leaf

(Plate 9.1). Larva: Body is pale green with black head and brown sclerotized pronotal shield.

Biology and Habits

Polyphagous on dicotyledons and has occurred on citrus, soya, strawberries, and many other agricultural crops. From shortly after the buds open, the larva webs leaves together and feeds on their epidermis and mesophyll within the shelter thus formed. When about 2 cm in length, the larva pupates within the folded or rolled leaves. From this pupa the moth emerges. Within a few days they mate and lay eggs in mass. The egg masses which contain 50-200 eggs are flattened. Egg stage lasts 3-5 days. The larva has 4 instars; larval stage is 14-18 days. Pupation occurs in a thin cocoon in the rolled leaf. After 5-7 days, the active moth emerges. During the day, the moth hides itself in cool places or shaded areas. The adult lives 7-10 days.

Economic Importance

Seedlings are most affected. Young shoots are consumed, causing lateral shoots to develop. This insect is an important pest on agricultural crops.

Control

When control is needed, spray monocrotophos, methamidophos, or methomyl on young shoots.

Callimetopus gloriosus

Family: Cerambycidae
Host trees: *Acacia mangium, Paraserianthes falcataria*
Distribution: Philippines

Description

Adult: Medium-sized beetle, 1.5-2.0 cm long and 5-8 mm wide; metallic purplish-black with white markings. Larva: Legless, elongate, and cylindrical with a slightly broader and flat anterior. The body is yellowish white, the head black. Full grown larva measures on average 4 cm long and 8 mm wide (Braza 1991b).

Biology and Habits

Adults girdle-prune succulent shoots, while larvae bore inside the stem and branches.

Economic Importance

Both adult and larva are destructive to young mangium trees. The adults girdle and usually cut branches near the shoots, causing some to die starting from the tip downward. Surviving branches sprout and become bushy. In severe infesta-

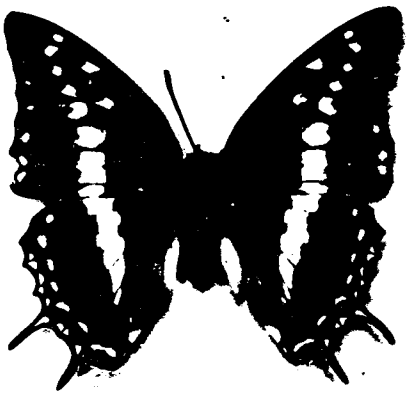


Plate 9.1. Egg mass of *Archips micacaena.* **Plate 9.2.** *Charaxes solon sulphureus* adult.

tions, beetles may cut most or all of the branches of a single tree. Braza (1991b) reported up to 5% of all trees in plantations in the Philippines may become infested. The damage does not result in death, but suppresses tree growth and makes the trees bushy.

Control

Spray chlorpyrifos or fenvalerate on branches when needed.

Charaxes solon sulphureus Rothschild and Jordan

Family: Nymphalidae
Host trees: *Acacia mangium, Xylia xylocarpa*
Distribution: Northeast India, Myanmar (Burma), and Thailand

Description

Adult: Dark brown with pointed tails at the end of the vein 2, 4 of the hind wing. Both wings are crossed by yellow bands, which in the forewing is made up of separate discal spots. Wings span 7.5-8.0 cm. (Plate 9.2). Egg: Spherical and white with brown streaks. Larva: The caterpillar is characterized by long, paired filaments, a branching spine or a horned head. There are two pairs of filaments on its head: the center pair is longer than the adjacent ones. Between the center pair there is another short pair showing as horns. The tips of these filaments are reddish brown. The posterior end has one pair of appendages which are brown at the tip (Plate 9.3). These appendages disappear in the last larval stage. The body is dark green with a yellow line that runs laterally across the body. A fully grown larva is 5.5-6 cm, and has 3 pairs of legs and 5 pairs of prolegs. Pupa: Green color, 2-2.5 cm, oval shape pointed at one end.

Biology and Habits

The female lays eggs singly on a leaf. The hatched larva feeds on the upper side of the fully developed leaf. The full-grown larva moves to the underside of the leaf or leaf petiole and pupates. Pupal stage lasts 5-7 days. Development from egg to adult takes at most 3 weeks.

Plate 9.3. Larva of *Charaxes solon sulphureus.*

Economic Importance

Larvae defoliate some forest trees, but they are not major pests.

Control

Use *Bacillus thuringiensis* as a biocide to control larval stages.

Colasposoma igneicolle Baly

Family: Chrysomelidae
Host trees: *Acacia auriculiformis, A. mangium, Cassia garettiana, Combretum quadrangularis, Croton longissima, Dipterocarpus tuberculatus, Eucalyptus camaldulensis, E. torelliana, Lagerstroemia speciosa, Pterocarpus macrocarpus, Xylia xylocarpa*
Distribution: Thailand

Description

Adult: Bright green sometimes with blue metallic reflection; body is oblong and clothed with very short pubescences, 5-6 mm long.

Biology and Habits

Adult feeds on leaves and young shoots.

Economic Importance

It has not occurred as a major forest pest, but is to some extent injurious in the adult stage. In 1987, heavy defoliation was noticed in young *Eucalyptus camaldulensis* plantations in Thailand.

Control

Spray monocrotophos or azinphos-ethyl on young plants when the beetles' population is high.

Coptotermes curvignathus Holmgr. (Termite)

Family: Rhinotermitidae
Host trees: Young plantations of *Acacia mangium* and many other tropical tree species appear to very susceptible to attack. In Malaysia, Hamid (1987) also reported *Coptotermes sepangensis* destroying *A. mangium*. Nobushi and Hariyono (1987) identified the host tree genera as *Albizia, Araucaria, Eucalyptus, Fagratae, Ficus, Gmelina, Hevea, Hymenaea, Mangifera, Pinus, Salix, Shorea, Tectona.*
Distribution: Sumatra (Indonesia), Malaysia, and Thailand

Description

Soldier: Head and antennae yellowish; mandibles dark reddish brown, yellowish brown at bases; pronotum pale yellow. A distinct opening of the frontal gland on the head capsule from which, when alarmed, it produces a white fluid. These soldiers may compose up to 12% of the colony. Reproductive: Small, black-brown with silvery wings and fast moving. More taxonomic details are described by Ahmad (1965). They are remarkably efficient at penetrating living trees as well as dead material. This termite can easily be noticed, as it builds runways of soil and faeces on a tree's bark. In defense, the tree exudes a thick clear fluid.

Plate 9.4. Mud covering made by *Coptotermes curvignathus* on tree trunk.

Biology and Habits

This is a damp-wood termite, living partly above and partly below ground. Nests can be found in dead stems above or below the ground and are connected by 6-mm high tunnels up to 90 m long at a depth of 30-60 cm (Kalshoven 1981). The termites make mud covers on the bark of tree trunks, sometimes to a height of 4 m (Plate 9.4), intended to protect the colony from other insects, birds, and heat (Harris 1964).

Economic Importance

This termite is of major economic importance, as it feeds on young seedlings' roots or stems near the ground and penetrates to the heartwood. Attack on trees is primary, regardless of wounds or decay; the termites may enter through the root or above ground. During drought periods young trees can be attacked, causing wilting. In mature trees, termites may eat through the inner bark and occasionally cause death (Plate 9.5).

Damage is greatest in dry plantation sites after the clearing of old forests, and on low-lying, moist sites.

Plate 9.5. Large section of bark damaged by *C. curvignathus*.

Control

Damage prevention is the best form of control. After clearing the ground, destroy all wood before replanting the land. Sajap and Jan (1990) tested two entomopathogenic fungi—*Beauveria bassiana* and *Metarhizium anisopliae*—to control *Coptotermes curvignathus*, and found that both fungi could cause mycoses to the termites. *M. anisopliae* is evidently more pathogenic than *B. bassiana*. If control is needed in a high-risk area, apply a water solution of chlordane 1.0% or dieldrin 0.5% around the affected area and nearby; best results are obtained when the solution soaks at least 15 cm into the soil.

Cryptothelea (=Clania)variegata (Snellen) (Bagworm)

Family: Psychidae
Host trees: *Acacia mangium*, *Albizia* sp., *Ceiba pentandra*, *Deguelia* sp., *Hevea brasiliensis*, *Casuarina* sp, *Cinnamomum camphora*, *Pinus merkusii*, *Shorea robusta*
Distribution: India, Indonesia, Malaysia, Philippines, and Thailand

Description

Adult: A large bagworm moth, the female is wingless. Larva: The larval case is 4-7 cm and covered with all sorts of dry material. Hatching larvae are less than 1 mm in size.

Biology and Habits

Newly hatched larvae spread rapidly, hanging on their silken threads. Within 24 hours they make a small case of brown-grey, shiny webbing. The larvae grow rapidly and after 2 months the cases are about 4 cm long. The total development takes 3.5-5 months. Females produce 450 eggs each, never leaving the case in which both pupation and oviposition occur.

Economic Importance

Due to their large size and the fact that they feed actively for two months, outbreaks can occur suddenly given conducive environmental conditions. En-

demic outbreaks have occurred in Java, Indonesia. It is more often a pest of agricultural crops, including cassava, coffee, and cocoa. Outbreaks on agricultural crops are believed to have begun with the defoliation of forest trees. Kalshoven (1981) reports that defoliation in Sumatra occurred in part on *Casuarina* and *Pinus merkusii* plantations.

Control

The best control is to handpick the cases and destroy them. Pesticidal spray can also be applied to foliage during the larval stage: use monocrotophos or endosulfan at a rate of 20-30 cc in 20 l of water and mix with wetting agent.

Dasychira mendosa Huebner (syn. *D. fusiform* Walker)

Family: Lymantriidae
Host trees: *Acacia mangium, A. catechu, Aleurites fordii, A. montana, Butea monosperma, Cassia fistula, Ceiba pentandra, Cinnmomum zeylanicum, Dalbergia sissoo, Ficus* spp.. *Lagerstroemia speciosa, Mangifera indica, Palaquium gutta, Santalum album, Schleichera trijuga, Shorea robusta, Tectona grandis, Terminalia bellerica, T. catappa, T. tomentosa, Zizyphus mauritiana* (Browne 1968).
Distribution: Throughout Southeast Asia, also in Australia, India, Sri Lanka, and Pakistan

Description

Adult wings span 1.3 cm; markings on fore wing vary, with shades of brown, hind wing is pale, creamy yellow. Egg: Masses of yellow. Larva: Red head, body greyish or yellowish, spotted with stripes and having long tufts of whitish hair; full grown larva is 2-3.5 cm. Pupa: Pupates in cocoon spun from larval hair and attached to a partially rolled leaf.

Biology and Habits

Larval stage lasts 3 weeks, pupal stage about 1 week (Chey 1987).

Economic Importance

Larva feeds on foliage of many plants, sometimes causing severe defoliation. This species is mainly a pest of agricultural crops (castor, coffee, maize, and tea).

Control

Use *Bacillus thuringiensis* as a biocide to control larval stage. A botanical insecticide made from neem (*Azadirachta indica*) seed kernels crushed and soaked in water is also recommended for direct spray on the caterpillars.

Dysdercus cingulatus Fabricius (Red seed bug)

Family: Pyrrhocoridae
Host trees: *Acacia auriculiformis, A. mangium, Albizia procera, Bombax malabaricum, Dalbergia donnaiensis*
Distribution: Australia, India, Malaysia, Pakistan, Solomon Islands, Sri Lanka, and Thailand

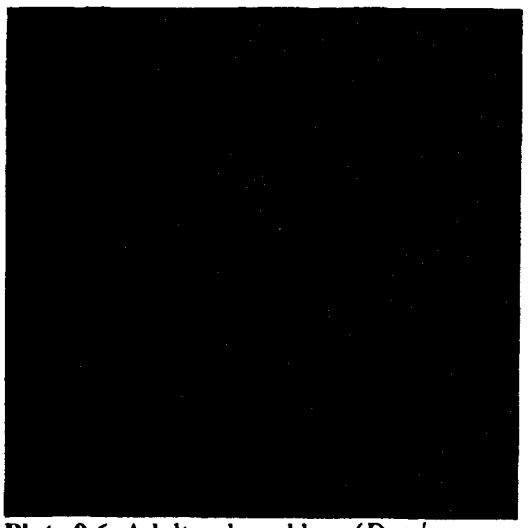


Plate 9.6. Adult red seed bug (*Dysdercus cingulatus*).

Description

Adult: Bright red bug with the apical membranous part of the wings black, the red portion of the front wing having one black spot (Plate 9.6). The body is 1.2-1.6 cm long and is easily recognized by the white band behind the head and on each segment of the abdomen. Egg: Eggs are laid in loose mass, oval, 1.5 mm long and 0.9 mm wide. Newly laid eggs are white and turn orange when ready to hatch. Nymph: Resembles the adult, except that wings are not maturely developed.

Biology and Habits

One of the most common insects in cultivated land. Both nymph and adult feed on the sap of the more tender parts of host trees. Adults do not fly readily. A female lays 100 or more eggs in the soil and after oviposition the bug camouflages the site with soil particles or other debris. Egg stage lasts 4-8 days. The nymph period varies from 26-39 days according to the season and local climate. The adult lives 28-43 days. The nymph and adult feed gregariously and are often numerous on *Bombax malabaricum* in India during March and April, when trees are flowering and the pods are ripening. They feed also on the sap of seeds fallen on the ground. The bugs multiply considerably on ripening pods of *Ceiba pentandra* and cotton bolls (Kalshoven 1981).

Economic Importance

This insect's feeding results in premature fruit drop and reduced seed germination. Damage to forest trees is negligible.

Control

Spray with Monocrotophos, methamidophos, or triazophos.

Eurema (Terias) blanda Boisduval (Yellow butterfly)

Family: Pieridae
Host trees: *Acacia mangium, Artocarpus fraxinifolius, Albizia chinensis, A. lebbek, A. odoratissima, Cassia fistula, C. donosa, Paraserianthes falcataria, Xylia xylocarpa* (Beeson 1961)
Distribution: India, Malaysia, Myanmar (Burma), Sri Lanka

Description

Adult: Bright yellow butterfly, black-bordered wings that span 3.5-5 cm. Larva: Full grown, 2.5 cm, green with pale lateral stripes and a black head. Pupa: Black, somewhat flattened and attached to the plant by its caudal extremity, often forming a conspicuous cluster (Browne 1968).

Biology and Habits

Life cycle ranges from 40-50 days, depending on the weather; there are several generations per year. It is found at altitudes up to 1,500 m. Adults habitually fly low, often migrating in large swarms. Eggs, which are laid in clusters on the under sides of leaves, are rarely placed higher than 5 m. Larvae feed gregariously on the leaves, devouring all tissues except the midribs.

Economic Importance

Frequently a destructive pest of nurseries and young plantations of forest and shade trees.

Control

Same as for *Eurema hecabe*, below.

Eurema (Terias) hecabe Linnaeus (Common grass yellow butterfly)

Family: Pieridae
Host trees: *Acacia* spp., *Albizia procera, Cassia fistula, C. siamea, Paraserianthes falcataria, Pithecellobium dulce, Sesbania* spp., *Tectona grandis*
Distribution: Widely distributed in the tropics from Africa eastward through southern Asia and Australia to the Pacific islands

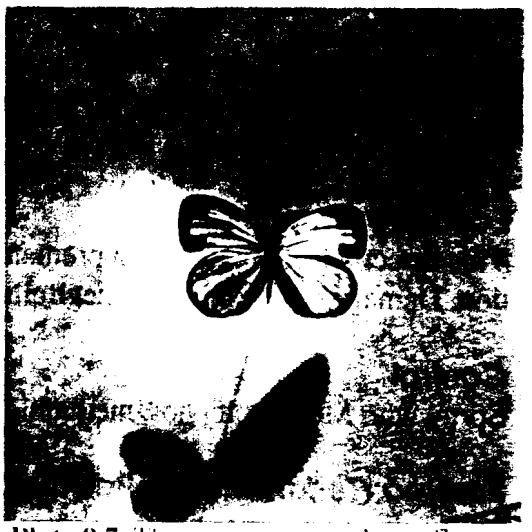


Plate 9.7. The common grass butterfly (*Eurema hecabe*).

Description

Adult: Wings are lemon yellow with a black border and two large excavations on the upper side of the forewings (Plate 9.7); the underside is yellow without

black border. The forewing is lemon yellow. Usually the female is paler and more broadly black-bordered than the male, but the species exhibits such wide variation in size, color, and markings that no two specimens are alike. Larva: Yellowish-green with a pale lateral line, black head (Plate 9.8), attaining a length of about 2.5 cm; feeds principally on foliage of Leguminosae, sometimes injuring various agricultural crops. Pupa: Leafy-green color, hangs head downwards from twigs and the veins of leaves.

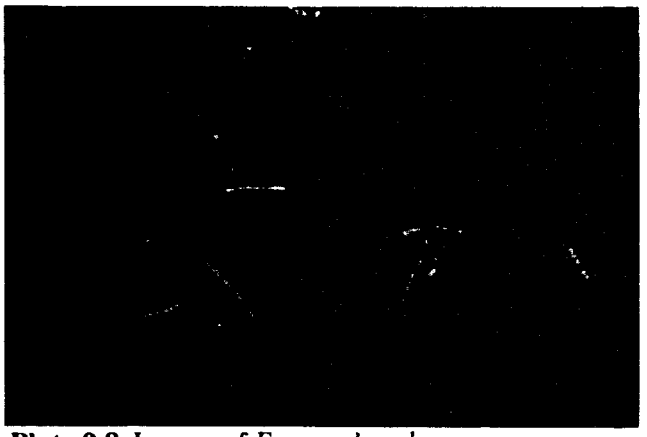


Plate 9.8. Larvae of *Eurema hecabe*.

Biology and Habits

The egg stage is 3-4 days, larval stage 10-12 days. Chey (1987) reports a pupal stage of 6 days and butterfly life span of 2-3 days. Adults swarm on damp patches of road. The insect occurs year-round, with population highest during the rainy season when new flushes of leaves are abundant.

Economic Importance

In Fiji, larvae have heavily defoliated isolated *Cassia siamea* trees, showing a preference for young leaves. In Peninsular Malaysia, severe but brief outbreaks of the subspecies *E. hecabe contubernalis* Moore have occurred during dry weather in plantations of *Paraserianthes falcataria* (Menon 1958, cited by Browne 1968; Morimoto and Raros 1979) and in nurseries and young plantations of *Tectona grandis* (Menon 1963).

Control

Bacillus thuringiensis Berliner is an effective biocide to spray (10 g in 20 l of water) while larvae are in an early stage or actively feeding.

Helopeltis spp. (Mosquito bug)

Family: Miridae
Host trees: *Acacia mangium*, *Anacardium occidentale*, *Bixa orellana*, Cacao, Cinchona, *Cinnamomum camphora*, *Erythrina* spp., *Melia azedarach*, *Swietenia* spp.
Distribution: *Helopeltis* species are found in many countries: *H. cinchonae* and *H. bradyi* in Malaysia; *H. antonii* Signoret in India, Malaysia, and Thailand; *H. anacardii* Miller and *H. schoutedni* Reuter in Africa; and *H. theivora* in India.

Species have also been collected in Brazil, Indonesia, Papua New Guinea, Philippines, Sri Lanka, the United States, and Europe.

Description

Adult: The elongate body measures 6-8 mm long, depending on the species, with antennae about 11 mm; white abdomen and greenish-brown wings. The male adult's head is black with white markings. The female is white to light yellow ventrally and yellow to orange dorsally. These insects can be distinguished by a fine pin that projects upwards from the scutellum of nymphs and adults. Mirid are commonly called 'mosquito bugs,' as they resemble mosquitoes in flight. (Hamid 1987). Egg: Tabular in shape with a cap bearing two fine, white filaments which are externally visible under a stereomicroscope. Nymph: Resembles adult, wings are in the developing stage, orange in color.

Biology and Habits

Lays eggs 2-3 days after mating, singly or in groups of 2-6 and inserts them into soft plant tissues. *Helopeltis* is capable of producing 1-20 eggs per day until death. Egg stage lasts 1-4 weeks, depending on the temperature. Nymphs go through 5 instars within 3-4 weeks. The adult stage is 2-3 weeks. Both nymphs and adults feed at night, sucking plant sap primarily at the underside of the leaf edge.

Economic Importance

Can cause dark discoloration and necrotic spots due to toxic saliva injected into feeding punctures (Lamb 1974 cited by Hamid 1987). The growing points become malformed or dead. The infestation in Sibu, in Sarawak, Malaysia, cited by Hamid (1987) was mild and no congregation of nymphs was found on any single tree.

The insect is polyphagous, with a host range that includes crop plants, fruit trees and various wild and cultivated legumes. It is a pest on cocoa, tea, gambier, and many other plants. It can reduce tea yields by up to 80%, while on cocoa a heavy attack has been recorded to cause abnormal tree growth (Kalshoven 1981). Effects are distorted growing tips and buds and necrotic spots and burning effects from phytotoxic reactions attributed to the insect's salivary juices. *Helopeltis* also causes oviposition injury to the plant stem.

Control

To prevent damage, eliminate weeds that serve as secondary or alternate hosts of *Helopeltis* spp. Mixed species plantations also help to prevent epidemics. Use particular vigilance from July to December, or infestation can easily be overlooked until it is too late for effective action. Chemical control is quite controversial, but is effective when promptly and properly applied. Suggested insecticides are malathion, fenitrothion, carbaryl, and trichlorfon.

Hypomeces squamosus Fabricius (Green weevil)

Family: Curculionidae
Host trees: *Acacia auriculiformis, A.mangium, Achras zapota, Aleurites montana, Artocarpus integra, Bombax malabaricum, Cassia fistula, Casuarina equisetifolia, Ceiba pentandra, Eucalyptus torelliana, Flindersia brayleyana, Hevea brasiliensis, Lagerstroemia speciosa, Mangifera indica, Palaquium gutta, Paraserianthes falcataria, Pterocarpus indicus, Tectona grandis*
Distribution: The Orient

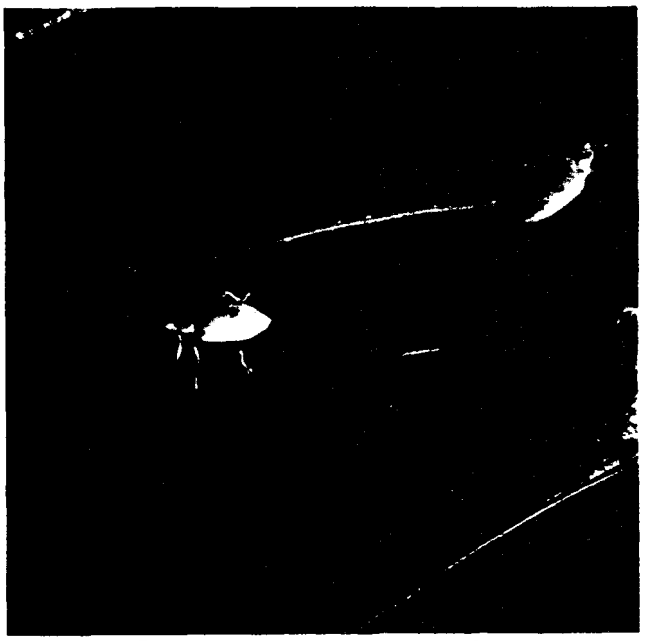


Plate 9.9. Color variation of the adult *Hypomeces squamosus.*

Description

Adult: A short snout weevil, 1.3-1.5 cm long, covered with two layers of shining, powdery colored dust (Plate 9.9): outer layer is golden-yellow, inner layer is greenish yellow. Underneath these layers is black. Larva: Grub-like, greenish white, fully grown larva is 1.5-2.0 cm; stout and tapered abdomen. It is less curved than the melolonthine larva with which it is frequently confused (Kalshoven 1981).

Biology and Habits

The female lays eggs in the soil and they hatch after 10-15 days. The larva lives and pupates in dry soil, pupation taking 10-15 days. The larva feeds on roots or root collars of grasses and shrubs, sometimes injuring hill rice, maize, sugarcane, tobacco, and other crops. Beetles occur throughout the year but are most abundant from May to July. The male lives only 8 months, the female for 12 months (Choonhawongse et al. 1982). The adults, which often occur in large numbers, are polyphagous on foliage of dicotyledons, devouring young, tender leaves from the edge inward, but on older leaves eating only the softer tissue between veins. When disturbed on host trees, weevils drop to the ground without taking flight.

Economic Importance

The species is very common in Southeast Asia, where it often causes damage in forest nurseries. The foliage of heavily infested trees becomes soiled with characteristic pellets of excrement. *Hypomeces* is also a frequent minor pest of cover crops in *Hevea* plantations, although *Hevea* itself is rarely heavily infested.

Control

Drop weevils onto the ground by shaking the host trees, then sweep them up and drown them in soapy water. Chemical sprays using carbaryl (50% WP 40 g), methamidophos (60% SL 30 cc), or monocrotophos (60% WSC 25 cc) in 20 l of water are also effective.

Indarbela quadrinotata Walker and *I. phaga* (Bark caterpillar)

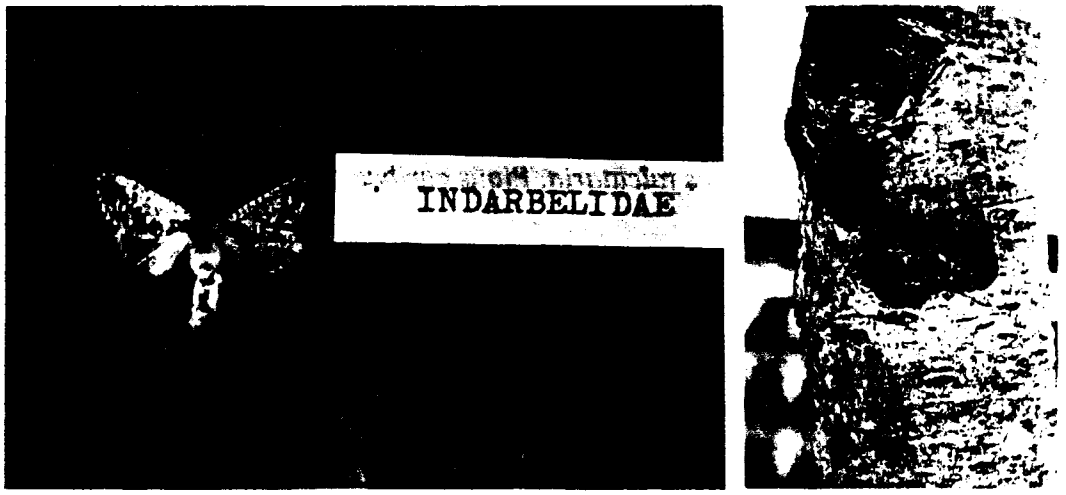
Family: Indarbelidae
Host trees: *Acacia auriculiformis, A. catechu, A. mangium, Albizia chinensis, A. procera, Artocarpus integra, Casuarina equisetifolia, Eucalyptus camaldulensis, E. deglupta, Gmelina arborea, Lagerstroemia speciosa, Mangifera indica, Paraserianthes falcataria, Peltophorum pterocarpum, Samanea saman, Syzygium ciminii, Tectona grandis, Terminalia myriocarpa, T. superba, Xylia xylocarpa*
Distribution: The Orient

Description

Adult: Wings spread to 4.0-5.0 cm (*I. phaga* wingspan is 3.0-4.0 cm); white with dark grey spots throughout the wings, more dense at the base (*I. phaga* has grey spots lined across the middle of the front wing). Forewings are longer than hindwings. When wings are spread, half of the abdomen extends longer than the base line of the hindwings (Plate 9.10). Larva: Active, dark grey, 4-5 cm long (*I. phaga* 3.0-3.5 cm), strong mandible, body smooth with dark corneous patches on the body segment. Pupa: 2.5 cm, brown and slender (pupa of *I. phaga* is smaller).

Biology and Habits

Larval feeding of *I. quadrinotata* begins early in the rainy season when bark is soft; it feeds only at night. The larval period lasts 10-11 months, from June until the following April. The larva bores a short burrow down into the wood and, using this as a day shelter, forages on the surface of the bark at night under the protection of a tunnel made of silk mixed with excrement and bark fragments (Plate 9.11). These tunnels may extend for some distance from the shelter burrow, and a considerable area of bark may be damaged by a single larva. A heavy infestation may destroy most of the outer bark of the stem. Pupation occurs in the shelter burrow, which measures 10-15 cm long. This is easily observed, as it is the beginning of the feeding tunnel. Pupation lasts for 2 weeks, occurring from March until April, with a pupal period of 20-31 days. Adults emerge from late April until June, leaving pupal cases visible at the dwelling tunnels, as occurs also in the family Cossidae. The adult lays eggs in groups on the bark of the stem or branches. Each female may lay nearly 2,000 eggs. The generation is annual, but in Myanmar (Burma) there are apparently 2 generations each year (Nobushi and Hariyono 1987).



Plates 9.10-11. *Indarbela phaga* (left) with pupal case at thewound; (right)tunnel on *Cassia fistula.*

Economic Importance

The caterpillar feeds on the outer bark of trees more than 2 years old, leaving visible wound patches around the stem. The larva makes a dwelling tunnel at the joint between branch and trunk, causing the trunk to break at that point, as with *Eucalyptus deglupta* in Thailand. Feeding on small branches and thin bark causes death to the upper part of the wound. The insect attacks trees of fairly small to large size; trees are not killed directly but injury results in reduced vigor, exposure to infection by wound parasites, and degradation of the wood. Probably some damage attributed to this species is actually the work of *Indarbela tetraonis*, but *Indarbela* is known to be an important pest of casuarina plantations in parts of India (Browne 1968).

Control

The following methods have been employed:

1. Using stiff wire 10 cm long, push into shelter burrows to kill larvae.

2. Spray the stem surface with nematode *Neoaplectana carpocapsae* during the rainy season.

3. Inject the trunk with mathamidophos (60% SL) while larval feeding is still active. The rate is 5 cc in 15 cc of water; 20 cc of the solution can be injected at each point. The number of injection points depends on the size of the tree; they are usually spaced 20 cm apart and should be located spirally. Trunk injection is recommended only for very fast-growing species like *A. mangium*, and only for high-value trees, such as those in seed orchards. Slower-growing trees can be sprayed on the stem surface with the same insecticide at 25 cc/20 l of water.

Leucopholis irrorata (Chevrolat) (White grub)

Family: Scarabaeidae
Host trees: *Acacia mangium, Antocephalus cadamba, Eucalyptus deglupta, E. urophylla, Paraserianthes falcataria, Pinus caribaea, P. merkusii*
Distribution: Philippines

Description

Adult: Large beetle, 3.5-4.0 cm, reddish brown; tip of abdomen extends beyond elytra. Larva: Curved, milky white, robust bodies with three pairs of prominent legs and a brown head. The hind part of the body is smooth and shiny, the body contents showing through the skin. Two rows of minute hairs on the underside of the last segment distinguish the true white grubs from similar-looking larvae. Mature larvae measure 5-6 cm long and 1-1.5 cm wide.

Biology and Habits

Larvae live in the soil and are known as white grubs. The larvae hatch from eggs laid in wood tissues at or near the cut ends of branches. The larva cuts 1-mm diameter holes at irregular intervals along the sides of branches through which frass extrudes. Adults fly about during the night, and feed on tree foliage. They leave the soil at dusk and remain on the trees during the night, mating and feeding. At the first sign of dawn, they return to the soil, where the females lay their pearly white eggs. The eggs are generally laid in grasslands or patches of grassy weeds in cultivated fields. The eggs hatch in 2-3 weeks, and the young grubs feed on the roots and underground parts of plants until they change to the pupal stage in cells or cocoons.

Economic Importance

A common major pest of agricultural crops and fruit trees in the Philippines (Baltazar and Salazar 1979), the larvae damage mangium seedlings by feeding on roots up to the root collar (Braza 1987). The leaves of an infested seedling turn yellow. The whole plant becomes severely stunted and ultimately dies. The white grubs attack seedlings ranging from a few days to about six months in age. In a severely infested plantation, white grub damage may affect 5% of all seedlings (Braza 1991b).

Control

Treat seedbeds immediately after planting with carbofuran (3% G at a rate of 10 kg per acre, or 25kg/ha) to prevent grub damage. One or two applications is sufficient to destroy a grub infestation during the growing season. In high-risk areas, add carbofuran (3% at 3 g in each planting hole) at time of planting in the field. Braza (1990b) found that application as conidia of entomogenous fungus *Metarhizium anisopliae*, a strain from *L. irrorata* larvae, on infected palay, mixed with sawdust at 5 g of mixture/larva, effected 73% mortality in *L. irrorata*.

Microcerotermes distans Hav.

Family: Termitidae
Host trees: *Acacia mangium, Intsia palembanica,* and other dicotyledon trees
Distribution: Malaysia

Description
Soldier: The head is yellow, rectangular, mandibles are slightly curved with irregularly serrate inner margins.

Biology and Habits
This is a wood-eating species (not the species in the same genus that cultivates a fungus), living chiefly in timber logs and stumps in the forest. Nests are made of brown cartons built on tree trunks at about waist level. It is a subterranean termite, reported to injure living trees in Sarawak (Hamid 1987).

Economic Importance
See *Coptotermes curvignathus.*

Control
Infestation can be controlled by destroying the nests and spraying with chlorinated hydrocarbon insecticides or chlorpyrifos. Existing nests in nearby plantation must be destroyed in the same way.

Nisitrus vittatus (de Haan) (Cricket)

Family: Gryllidae
Host trees: *Acacia mangium*
Distribution: Indonesia, Malaysia

Description
Adult: 2 cm long; dark-brown with yellow stripes along the sides and antennae as long as the body. Wings are brownish, hind legs are adapted for jumping.
Nymph: Resembles the adult except that wings are not maturely developed.

Biology and Habits
Crickets are nocturnal, living in debris and on rubbish heaps. They move very rapidly, are also active during the daytime, and are difficult to catch. They are often found in moist layers of plant debris. Cover plantings (such as *Mimosa*) and harvested paddy fields are favored sites. Females lay eggs in masses, about 100 eggs per mass. Nymphs molt 5 times on a 6- to 8-week cycle. The egg stage lasts 8-12 days.

Economic Importance

Crickets consume a wide range of food, but particularly young plants in nursery beds, biting through stems and consuming the plants completely. One cricket can consume hundreds of seedlings in one night.

Control

Poison baits provide satisfactory control. Spread a dry bait (composed of 1 part carbaryl, 8 parts flour, and 1 part molasses) as a dry mixture in a shallow trench along the edges of the nursery or sown patches. Wan (1972, cited by Hamid 1987) recommends a 0.2% trichlorfon spray on young plants in nurseries.

Orgyia postica Walker (Tussock moth)

Family: Lymantriidae
Host trees: *Acacia mangium*, *Albizia lebbek*, *Anogeissus latifolia*, *Casuarina* spp., *Eucalyptus leucoxylon*, *E. multiflora*, *Hevea brasiliensis*, *Lagerstroemia marsupium*, *Santalum album*, *Shorea robusta*, *Tectona grandis*, *Terminalia bellerica*, *Tristania conferta*, *Xylia xylocarpa*, *Zizyphus mauritiana* (Browne 1968)
Distribution: The Orient

Description

Adult: The male is a brown moth mottled with black; the female is stout and has no wings. Larva: Reddish head, body covered with tufts of yellow hairs.

Biology and Habits

Development from egg to adult takes about 3-5 weeks. There are 5-6 generations per year. The wingless female moth usually never strays far from the site of her pupation. The winged male is an active flier and is attracted by the female's pheromone (Kalshoven 1981). After mating, the female lays many eggs on the cocoon and dies. The larvae feed gregariously at first, principally on young leaves, but later tend to disperse. Pupation occurs in cocoon between leaves or twigs. In Malaysia, the caterpillars are parasitized by a braconid, *Apanteles cloemani* Vier, nematodes, fungi and other diseases, and by the tachinid *Exorista sorbillans* (Wied.).

Economic Importance

Heavy defoliation has occurred occasionally on young rubber trees in Indonesia and on *Anogeissus latifolia* in India. It is known as a minor pest of various perennial crops, including cinchona, citrus, coffee, and tea.

Control

See *Orgyia turbata* below.

Orgyia turbata Butler (Tussock moth)

Family: Lymantriidae
Host trees: *Acacia auriculiformis, A. mangium, Delonix regia, Erythrina fusca, Hevea brasiliensis, Peltophorum pterocarpum, Tectona grandis, Terminalia catappa*
Distribution: Malaysia, Myanmar (Burma), and Thailand

Description

Adult: The male is a rusty-brown moth with a wingspan of about 2 cm. The front wing has dark brown marking and orange spots; the hindwing is chocolate brown without marking. The female has only vestigial wings (Plate 9.12). When at rest, wings are folded as flatted roof-like, with the first pair of legs extending anteriorly beyond the head. Female is wingless and worm-like. Egg: Round, white color laid in masses on host trees. Larva: Black with long brushes of hair along the sides of the body. The longest pair of hair is black and located behind the head. There are four bunches of yellow hair on the dorsal part of abdomen, one on each segment (Plate 9.13). The first two bunches are black at the tip. Prolegs are reddish. A fully grown larva is 2.5-3 cm long. Pupa: Pupates in a thin-walled, cylindrical cocoon 1 cm long, covered with white web. The pupa is easily seen through the cocoon (Plate 9.14).

Biology and Habits

Larvae feed on leaves of many forest trees as well as Leguminosae. In bright sunshine they hide in shaded undersides of leaves, but continue feeding. The larval stage is 14-16 days. The life cycle can be completed in about 1 month. The female never strays far from the site of her pupation and lays masses of white, round eggs. The pupa is formed in a cocoon, usually on the lower surface of a leaf (Browne 1968).

Plates 9.12-14. *Orgyia turbata.* Left: winged male and wingless female. Center: larva. Right: cocoon covered with white web.

Economic Importance
Although they are frequently observed to defoliate a single tree completely, serious damage to plantations has not been reported. Sporadic defoliation of ornamental trees has also been observed.

Control
Spray leaves with the bacteria *Bacillus thuringiensis* (10 g in 20 l of water) while larvae are in early stages.

Piezoderus rubrofasciatus F. (Stink bug)

Family: Pentatomidae
Host trees: *Acacia auriculiformis, A. mangium*
Distribution: Thailand

Description
Adult: 1 cm long with reddish orange cross stripe on neck. The rest of the body is yellowish brown. Egg: Characterized by a whorl of small dents on the upper side. Nymph: Resembles an adult; wings are not maturely developed.

Biology and Habits
The female lays eggs in groups on leaves. The development of egg to adult takes 18-34 days. Nymph and adult feed on plant sap.

Economic Importance
Damage to forest trees is negligible; it is a common pest of beans.

Control
Same as for *Dysdercus cingulatus.*

Pteroma plagiophleps Hampson (Bagworm)

Family: Psychidae
Host trees: *Acacia mangium, Anacardium occidentale, Cassia biflora, Cinnamomum malabratum, Delonix regia, Emblica officinalis, Eucalyptus tereticornis, Paraserianthes falcataria, Populus deltoides, Syzygium aqueum, Tamarindus indica, Tectona grandis* (Nair and Mathew 1988 contains a complete list of hosts)
Distribution: India, Indonesia, Malaysia, Sri Lanka, and Thailand

Description
Adult: Males are small, with well-developed wings, wingspan of 1.3-1.4 cm, and light brown color. Females are wingless, legless, and larviform. Egg: Creamy white, ellipsoidal, 0.8 x 0.75 mm. Larva: Creamy white with brown marking on

head and thorax. Fully grown measures 1 cm long, wide anteriorly and tapering posteriorly. It lives in a case made of leaf particles, which enlarges as the larva grows. Pupa: Dimorphism, male pupa is exarate, 2 x 4 mm in size, brown with a paler abdomen. The mesothorax is prominent and humped. Female pupa resemble larva in shape, 2 x 10 mm. The abdomen retains its musculature and is capable of effecting pulsating movements. Ovipositor is dark brown and scoop-shaped (Nair and Mathew 1988).

Plate 9.15. Pupal cases of *Pteroma plagiophleps* hanging from a *Delonix regia* branch.

Biology and Habits

The insects in this family are so named for all their larval stages, and because the female lives inside the bag or case formed by plant materials. It is a small conical case, no more than 16 mm high and covered by a mosaic of leaf particles. Larvae feed from the underside of the leaf, consuming the epidermal layer and mesophyll tissues, leaving the single layer of epidermis on the upper side. Larvae usually then migrate to branch stems and often to the main trunk to feed on the live surface layer of bark, leaving feeding scars on the stem. When pupation approaches, the case is modified into an ellipsoidal form and hangs on threads from the under sides of branches (Plate 9.15). In heavy infestations, thousands of these cases can be seen hanging from branches.

The egg stage lasts not more than 10 days, the larval stage 49-62 days, pupal stage 14 days. The adult lives about 4 days. Total development for the male is 2 months, 2.5 months for the female (Nair and Mathew 1988).

Economic Importance

Total defoliation in large patches leads to die-back of trees. Damage to *A. mangium* is minor, but in India it is known as serious pest of *Paraserianthes falcataria* (Mathew and Nair 1985).

Control

Normally infestation is not severe enough to warrant control. When control is needed, apply trichlorfon (95% WP 15 g) or carbaryl (85% WP 60 g in 20 l of water) as a foliage spray. Nair and Mathew (1988) recommend 0.5-1.0% methyl parathion applied as a foliar spray.

Sagra femorata purpurea Lichtenstein

Family: Chrysomelidae
Host trees: *Acacia mangium, Centrocema pubescens, Dolichos lablab, Fabia vulgaris, Lagerstroemia speciosa, Mucuna* spp., *Tectona grandis*
Distribution: Southern Asia

Description

Adult: Metallic blue or green color, very shiny; size varies from 1.3-2.0 cm; hind femur is enlarged (Plate 9.16). Larva: Legless, curved like a 'C' shape, milky white.

Biology and Habits

This insect is a serious pest of the common bean *(Dolichos lablab)* in India. Both larvae and adults feed on the stems. Larval feeding causes the formation of galls in which larval and pupal development occur (Plate 9.17). The pest has one generation per year. In young plants, the adults girdle the stems, causing swelling of the tissue above and below the girdle and drying up of young plants above the girdle, sometimes breaking at the site of gall formation. Larval density varies from 1-42 individuals per gall, with up to 7 galls on a single plant. Tayade (1979) found that the egg, larval, and pupal stages last a mean of 15.5, 143.4, and 31.5 days, respectively. Adult life span averages 39.9 for males and 35.2 days for females. The adult is not active and pretends to be dead when disturbed. *Sagra* does not make galls on forest trees. In Thailand, the larva was found to be attacked by the fungus *Beauveria bassiana* (Bals.) Vulemin (Pholwicha 1991). Attacks on forest trees occur only when the primary host, a climber, is attached to the trees. Larvae are then moved from the climber and bore into the trees' bark, leaving a visible gum exudation on the bark surface.

Plates 9.16-17. *Sagra femorata purpurea.* Left: adult. Right: Feeding of larvae causes swelling of branch.

Economic Importance
Small branches are broken at the point of larval feeding. Poor maintenance of young plantations exacerbates damage.

Control
Remove climbers from trees.

Sinoxylon anale Lesne (Branch and twig borer)

Family: Bostrychidae
Host plants: *Acacia arabica, A. auriculiformis, A. catechu, A. gageana, A. mangium, A. modesta, Acrocarpus fraxini, Adina cordifolia, Albizia amara, A. lebbek, A. odoratissima, A. procera, A. stipulata, Anigeissua acuminata, A. latifolia, Bombax malabaricum, Casuarina junghuhniana, Pithecellobium dulce, Samanea saman, Terminalia alata, Thyrsostachys* spp.
Distribution: India, Myanmar (Burma), and Thailand

Description
Adult: The beetle is elongate, somewhat cylindrical, and the head is bent down and scarcely visible from above; body length is 4-5 mm; the posterior end is cut sharply with a pair of spines at the center of the cut surface (Plate 9.18). The newly emerged adult is light brown and turns dark brown when aged. Posterior and anterior ends are darker than the middle part of the body. Posterior end of elytra cut sharply and bear one tooth on each elytra at the center of the cut surface, forming a pair of teeth easily visible at the posterior end. Larva: Legless and grub-like, milky white, and C-shaped. Pupa: Looks much like a pale, mummified adult, and is not covered by a cocoon.

Biology and Habits
The beetle usually bores into cut logs, but sometimes bores into green shoots and twigs for the purposes of feeding or hibernation. The axial tunnels made as a result may girdle or kill leaders of seedlings or saplings. Beetles bore into the stems of sickly or dying poles with varying success. Horizontal tunnels are made just within the circumference of the cambium layer and (in resistant species) these become filled with a black gum that exudes from the entrance hole and runs down the bark. Due to the exudation of gum, the borers do not remain to lay eggs. Eggs are laid only in clean tunnels. Larval galleries run upwards and downwards in the stems broken as a result of adults' girdling. They are tightly packed with find wood dust. Pupation takes place in a cell at the extreme end of the larval tunnel; the beetle bores out by a direct route to the surface.

The development period is quite variable, from 3 months to several years. *S. anale* emerges as an adult beetle throughout the year; there is no regular sequence of generations and no regular correlation between the length of the life

Plates 9.18-19. *Sinoxylon anale*, the branch and twig borer. At right, adult girdles and breaks the stem.

Plate 9.20. Red-leg flat-headed borer adult (top) and green leg (bottom).

cycle and the season of the year. The species is active at all times in all its stages (Browne 1968).

Economic Importance

It is primarily a borer of the sapwood of logs, particularly of Leguminosae, but its range of food plants is wide and varied. The species breeds in dead and dying sapwood, which is eventually reduced to a very fine dust, giving them the name "powder post beetles." Adults tunnel to feed in shoots and young stems of trees, killing them or rendering them liable to breakage (Plate 9.19).

Control

Remove and burn broken branches in which breeding has taken place.

Sternocera aequisignata (Green-leg flat-headed borer)

Family: Buprestidae
Host trees: *Acacia auriculiformis*, *A. mangium*, *Albizia odoratissima* *Pithecellobium dulce*

Description

Adult: Elytra is a beautiful, shiny, metallic blue or green, lustrous (Plate 9.20) and conspicuously dented with minute white spots; head blunt. All the body regions are very closely fitted together. Prothorax is swollen, the head short, sunken in the thorax; the wing covers taper and are slightly elongated behind. Antennae and legs are small. Legs are blue or green. Body length is 3-3.8 cm.
Larva: The newly hatched larva is yellowish and hairy. Fully grown larva is yellowish white with numerous minute, brownish hairs. The head is enlarged and

Plates 9.21-23. *Sternocera aequisignata* (left) feeds on the collar of *A. auriculiformis*; (center) feeding at the root collar causes death of young tree. Right: irregular burrows in a young tree's root caused by feeding of the flat-headed borer.

flattened; legless grub, fully grown larva is 5-7 cm long (Plate 9.21). Egg: Hard-shelled, yellow, and spherical.

Biology and Habits

Adults are rather sluggish and fly only short distances, but they are very active under sunshine. In Thailand, beetles have been seen congregating and feeding on leaves of *A. auriculiformis* and other Mimosaceae, and on leaves of *Pithecellobium dulce* (Roxb.) Benth. They lay their eggs in the soil just below the surface. Sharma (1966) found eggs hatching from late February to early March. Larvae feed on root collars and pupate in cocoons made of soil, in the ground near the infested trees. In Thailand adults emerge from May until November, peaking in November. The life cycle is one year.

Economic Importance

Adults feed on leaves of many trees, while larvae bore at root collars. The borer can kill many trees and shrubs in the nursery and many more after outplanting (Plate 9.22). They are especially destructive during the first 1-2 years after the trees are planted. Their presence is indicated by irregular burrows in the root collar (Plate 9.23).

Control

Sharma (1966) recommended preventive control treatment in the nursery consisting of isobenzan (Telodrin) at 1.3 gallon toxicant per acre (3.25 gallon per ha) applied to the soil or the beds; or, where polythene sleeves are used, mix the filling soil with one part isobenzan in 500 parts water before or after filling. Further application of the chemical around the collar of each plant for two consecutive years after planting in early March is required in areas with dense *Sternocera* populations.

Where isobenzan is not available, diazinon, carbofuran, and chlorpyrifos can be used.

Sternocera ruficornis (Red-leg flat-headed borer)

All details are the same as for *S. aequisignata* with the exception of the description of the adult: the elytra of *S. ruficornis* lacks the minute white spots, and the legs are red (see Plate 9.20).

Striglina scitaria Walker

Family: Thyrididae
Host trees: *A. mangium, Albizia procera, Anogeissus latifolia, Dalbergia latifolia, Mangifera indica, Terminalia bellerica, Xylia xylocarpa*; also on *Prunus persica* in Japan (Issiki et al. 1969, cited by Chey 1987)
Distribution: from India east to the Pacific islands

Description
Adult: Wing span 1.2 cm. A dark line present on the margin of both wings; black line found descending from the subapical and crossing toward the dorsal part of hindwing. Larva: yellowish green, 1.5 cm.

Biology and Habits
The eggs are laid on leaves. Egg stage is 2-3 days, larval stage 12-14 days, pupal stage 6-8 days. Larva are polyphagous, feeding on foliage of dicotyledons by rolling the leaf with silk and feeding within.

Economic Importance
Heavy defoliations have not been reported.

Control
When control is needed, spray monocrotophos, methamidophos, or methomyl on foliage.

Thosea asigna van Eecke (Nettle or slug caterpillar)

Family: Limacodicae
Host trees: *Acacia mangium*
Distribution: Sumatra (Indonesia), Malaysia, and Thailand

Description
Adult: The moth is medium size and brown, having a relatively stout body with a dense pile of scales. The brown color of this species distinguishes it from the *T. sinensis* group, which has identical markings but is grey. Wingspan is about 5 cm. Egg: Scale-like, somewhat flattened, often laid in an irregular mass. Larva: Characterized by absence of prolegs and presence of an adhesive, sucker-like zone on the abdomen which sometimes deposits a viscous, slug-like trail on host

plant foliage. The body is rectangular and bright green, and has characteristic dorsal markings, lateral stinging spines, and four pairs of groups of large spines (3.5 cm long) dorsally. Pupa: Pupation is in a hard, spherical, almost nut-like cocoon, which measures 1.8 x 1.4 cm.

Biology and Habits

The eggs are laid in straight rows, with a total of 350-400 eggs per female. The cocoons are found at the base of *A. mangium* trees. During the day, the moths rest on the underside of leaves. The reduviid bugs, including *Sycanus* spp., *Astynus* spp., and *Velinus* spp., are reported as predators. Some larvae are parasitized by phorid flies (Hamid 1987).

Economic Importance

Defoliation by *T. asigna* is reportedly very light. Such a low level of infestation would not impair tree growth. Infestations on cocoa are more severe.

Control

The main limiting factor of its population is a microbial disease which brings outbreaks to a sudden end. Emulsions of diseased caterpillars have sometimes been sprayed on the palms by growers as a means of biological control. Defoliated trees fail to yield for a year (Kalshoven 1981).

Thosea (Phorma) bipartita (sinensis) Walker (Nettle or slug caterpillar)

Family: Limacodidae
Host trees: *Acacia mangium, Azadirachta indica, Punica granatum*
Distribution: India, Indonesia, Hongkong, Malaysia, Philippines, Republic of China (Taiwan), and Thailand

Description

Adult: Wings spread 3-3.5 cm; body stout and greyish color. Larva: The newly hatched larva is yellow, changing to greenish when fully grown. Body is broad and oval with a white or yellow dorsal stripe and two dorsolateral rows of colored spots. There are 11 pairs of spinal tubercle along the side of the body. A full-grown larva measures up to 1.3 x 2.5 cm. Pupa: Pupates in a hard shell, brown cocoon. Egg: Oval shape, 2 x 3.5 mm; yellowish shiny; it attaches flat on a leaf surface.

Biology and Habits

Young larvae feed on leaf epidermis on the ventral side. After the third instar, they feed on the whole leaf except for the midrib. Development from egg to adult takes 2.5-3 months on *Musa textilis* in the Philippines; each female produces 150-500 eggs. Eggs are laid singly or in a straight line, each line consisting of 2-

50 eggs. The larva molts 8 times and pupates in a cocoon on the underside of a leaf. Larvae have been seen congregated on a panel of mature trees, but without causing any apparent injury to the bark. Baltazar (1965) reported two parasites of this species were *Brachymeria obscurata* (Walker) and *Paraphylax sorionoi.*

Economic Importance

Larvae are polyphagous on leaves, and are most commonly found on coconut, oil palm, and other low plants, but also on trees. Outbreaks have been reported in Java, Indonesia and the Philippines.

Control

In the Philippines, *T. sinensis* on coconut was parasitized by the chalcidid *Brachymeria obscurata* (Walker) and the ichneumonid *Paraphylax soriansi* Balt. Both parasites could give 70-90% parasitism. Madamba (1975) recommended bacterial spray of *Bacillus thuringiensis* on leaves at a rate of 10 g in 20 l of water, applied every 7-10 days. This method is currently used in Thailand.

Valanga nigricornis (Burmeister) (Spur-throated grasshopper)

Family: Acrididae
Host trees: *Acacia mangium, Hevea brasiliensis, Swietenia macrophylla, Tectona grandis*
Distribution: India, Indonesia, Malaysia, Thailand, and other parts of the Orient

Description

Adult: Large and robust body. Pronotum compressed laterally and more or less constricted in the metazona, surface very coarsely punctured anteriorly, posterior margin distinctly pointed. Tegmina and hind wings well developed, reaching beyond apex of hind femora. General coloration of the body is yellowish brown or greenish, with bluish-black markings. Head with small round bluish-black spots on the frons and along the keels of the frontal ridge, beyond the eyes, with a blackish band and blackish stripes on the cheeks. The pronotum has a blackish longitudinal band on both sides of the paler dorsal median carina; also lateral lobes with several dark spots. Hind wings slightly darkened, tinged with rose at base. Hind femur with two distinct blackish transverse bands (Plate 9.24). From above,

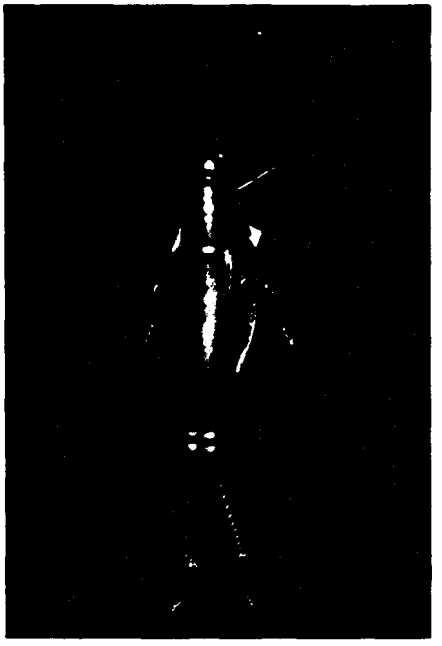


Plate 9.24. The spur-throated grasshopper, *Valanga nigricornis.*

knee is yellowish and hind tibiae appear black; from below hind tibiae are yellowish-brown, spines yellow with black tips (Roffey 1979). Nymph: Early stages are greenish-yellow with black spots. Egg: The egg pod is 4-5 cm long and about 1 cm in diameter, slightly curved, brown color. The egg pod is laid in a hole 5-8 cm deep filled with a hardening foam mass.

Biology and Habits

This species breeds in dense forest but often swarms to neighboring cultivated lands to feed. It is a common pest of banana and tobacco. Eggs are laid in brown pods at a depth of several centimeters in the soil. Shortly after oviposition, the hoppers emerge in the morning, first feeding on the ground and later ascending trees. They are greatly activated by the heat of the sun. They skeletonize the foliage of the undergrowth and reach the tops of *Tectona grandis* trees within 2 days. Later the nymphs are quite variable in color and design, mostly grey and yellow, often darkening to brownish-black. They then remain high in the trees, where they are relatively inconspicuous save for the dropping of baculiform excrement. Adults feed on flowers, leaves, buds, and green bark of forest trees. Copulation can occur in the tree canopy. When disturbed, they fly to nearby cultivated areas and return to the forests at night. These insects can become so abundant that all vegetation is destroyed and many proceed from the original breeding site to new areas. In some cases dispersal may be directional, apparently through the assistance of wind, with which they may fly over great distances. For egg-laying, the female seeks any open barren ground. Overgrown sites are not suitable. A few males follow them to these places.

The development from newly hatched nymph to winged adult takes about 80 days in the field, and between 50 days and 5 months in the laboratory. After the last moult, it takes 2-4 weeks before the adults can mate. Mating and oviposition occur repeatedly. The first pod (about 90 eggs) is laid 10-12 days after the first copulation. Further pods are produced intermittently over 2-3 weeks and gradually contain less eggs, the last containing only 10. The females live for 3-4 months, the male 4- 5 months. As a result, at the end of an outbreak the population may contain up to 95% males.

In central Java, nymphs hatch in the first months of the wet season. The adults appear in teak forests from December to February; oviposition starts in February and continues until April. Then follows the long resting period of the egg stage during the dry season. Thus only one generation of the Javanese subspecies *melanocornis* occurs annually.

Mortality factors are numerous: egg pods may be damaged by ants, larvae of Meloiddae (blister beetles, *Mylabris* and *Epicauta*), or wasps (*Scelio* spp). Hardening of the ground caused by alternating rain and drought kills the eggs or prevents nymphs from hatching. A period of rain and cloudy weather retards nymphal development, and heavy showers kill many nymphs. Adults are attacked by parasitic flies (Sarcophagidae). Sometimes adults and nymphs are attacked by the fungus *Metarrhizium*.

Breeding places are where suitable forest feeding sites for nymphs and adults occur together with suitable egg-laying sites with sparse ground cover. This combination exists where teak forests are adjacent to agricultural crops. Also, to obtain large numbers a particularly noticeable drought period is needed. In this case, only unfavorable climatic conditions will end the outbreak. There are further indications, however, that the species can develop to epidemic proportions regardless of the climate, particularly where extensive tracts of land are claimed for cultivation within a rather short time and much wild forest is removed. The cleared ground provides an excellent oviposition site for the adults, and ground cover of green manure subsequently promotes nymph development.

Economic Importance

This grasshopper can completely defoliate young plantations. Teak forests situated next to rubber plantations, oil palms, and maize are most vulnerable to defoliation.

Control

Poison baits provide satisfactory control. Mix carbaryl (125 g) with 20 l water, 2 l of molasses, 60 l rice hulls or coarsely ground corn cobs. Place bait during the day in a 1-m wide band, with bands 40 m apart, from February to April or at time of adult emergence. Carbaryl spray is recommended for nymphal control. Other controls have been used by Uvarov (1928), Metcalf and Flint (1962), and Mongkolkitti (1981).

Xystrocera globosa (Olivier) (Capricorn beetle)

Family: Cerambycidae
Host trees: *Acacia catechu, A. mangium, A. modesta, Acrocarpus fraxinifolius, Albizia lebbek, A. lucida, A. moluccana, A. odoratissima, A. procera, A. stipulata, Anacardium occidentale, Bauhinia acuminata, Bombax anceps, B. malabaricum, Grewia tiliaefolia, Xylia dolabriformis*
Distribution: Widespread from Asia (including India, Malaysia, and Sri Lanka) eastward to Hawaii, also in Puerto Rico and Mauritius

Description

Adult: 1.5-3.2 cm long; reddish-brown, parts of prothorax metallic blue or green, elytra are testaceous-yellow, each with a metallic blue or green longitudinal band (Plate 9.25). Prothorax densely and fine granulated on the disk in males, less densely so in females. Larva: Bright yellowish-white with a small brown head and black mandibles. Pupa: White and of ordinary longicorn shape.

Biology and Habits

Tunnels run mainly in the inner bark, but also groove the sapwood superficially. In trees with thick bark, a heavy infestation reduces more than half the thickness

of the bark to dust so that the bark readily separates from the wood. The prepupal tunnel is made at a right or obtuse angle to the surface of the sapwood, then turns downward to terminate in a pupal chamber parallel to the long axis of the log. This chamber is lined throughout with a fine deposit of calcium carbonate; the lining is white with some yellowish discoloration, especially at the lower end where the larval exuviae rest. The upper end is closed by a thin, smooth, ellipsoidal dome of calcium carbonate, produced in two of the four Malpighian tubules. The pupal period lasts about 3 weeks.

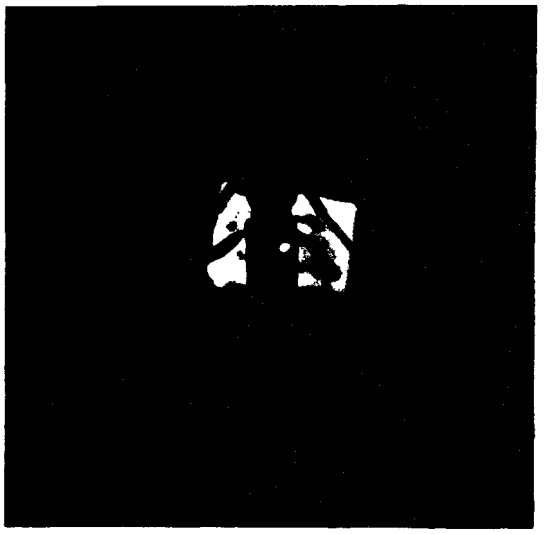


Plate 9.25. Beetle of *Xystrocera globosa.*

The digestive juice of *X. globosa* does not contain cellulase and consequently it does not digest cellulose. There are no mycetocytes in any parts of the body. The principal food supply is from other carbohydrates and soluble sugars in the sapwood. The heartwood of *Albizia lebbek* contains only small traces of starch and sugar; this explains why the larval tunnels do not penetrate the heartwood of that species.

In India, emergence occurs throughout the year but mainly in May, June, and September. In Thailand, adults are seen from January to May. The larval life is variable; in some individuals it may be prolonged for two years, while other individuals of the same brood may develop in less than a year. The larval gallery is described and figured by Stebbing (1914).

In Sabah, Malaysia, it is known as *Albizia* bark longicorn beetle, and the adult is attracted to light (Abe 1986).

Economic Importance

The species is notable in India and Sri Lanka as a pest of roadside trees and shade trees in tea plantations, particularly of *Albizia* spp., attacking those that are injured or sickly and hastening their death. Less resistant trees can be killed in one season by a heavy infestation; more resistant trees may produce callus that restricts attacked patches of bark. *X. globosa* is also a pest in Malaysia, and in Egypt was responsible for the disappearance of *Albizia lebbek* from several cities (Beeson 1961). In Thailand, it is one of the major pests of *Albizia saman*, causing the death of branches.

Control

Remove infested branches and trees, and dispose of them by burning. Due to the fact that the early larval stage feeds under the bark in the cambium layer, trunk

injection of insecticide is applicable for fast-growing trees (see trunk injection instructions for *Indarbela quadrinotata*).

Zeuzera coffeae (Nietn.) (The red coffee borer)

Family: Cossidae
Host trees: *Acacia auriculiformis, A. mangium, Anona squamosa, Amherstia nobilis, Bauhinia malabarica, Cassia auriculata, C. fistula, C. grandis, C. siamea, Casuarina equisetifolia, Cedrela frebifuga, C. sinensis, C. toona, Cestrum nocturnum, Chikrassia tabularis, Cinnamomum zeylanicum, Citrus* spp., *Clerodendron infortunatum, Coffea robusta, Eriobotrya japonica, Grevillea robusta, Hibiscus rosa-sinenis, Hydnocarpus wightiana, Lagerstroemia speciosa, Meliaazedarach, Nephelium litchi, Persia gratissima, Phyllantus emblica, Psidium guava, Santalum albu, Schleichera trijuga, Swietenia macrophylla, S. mahogani, Taraktogenus kurzii, Tectona grandis, Terminalia belerica, Thea sinensis, Theobroma cacao, Vitex pubescens, Xylia dolabriformis* (Beeson 1961)
Distribution: The Orient

Description

Adult: The moth is white with pairs of small black dots on the thorax and numerous small black spots and streaks on the forewing and a few black spots on the hind edge of the hindwing; expanse, 3.5-4.5 cm. (Plate 9.26). Larva: Full-grown larva is about 4.0 cm long, with a brown head and brown sclerotized pronotal shield, which is broader than it is long. The first seven abdominal segments are pinkish- to purplish-brown above and yellowish below (Plate 9.27); the eighth, ninth, and tenth segments are brownish, the two last with smooth glossy plates. Pupa: The pupa is about 2.5 cm. long, chestnut brown (Plate 9.28), with a short blunt process above the eyes, and with transverse rows of backwardly projecting asperities on the dorsal surface of the abdominal segments.

Biology and Habits

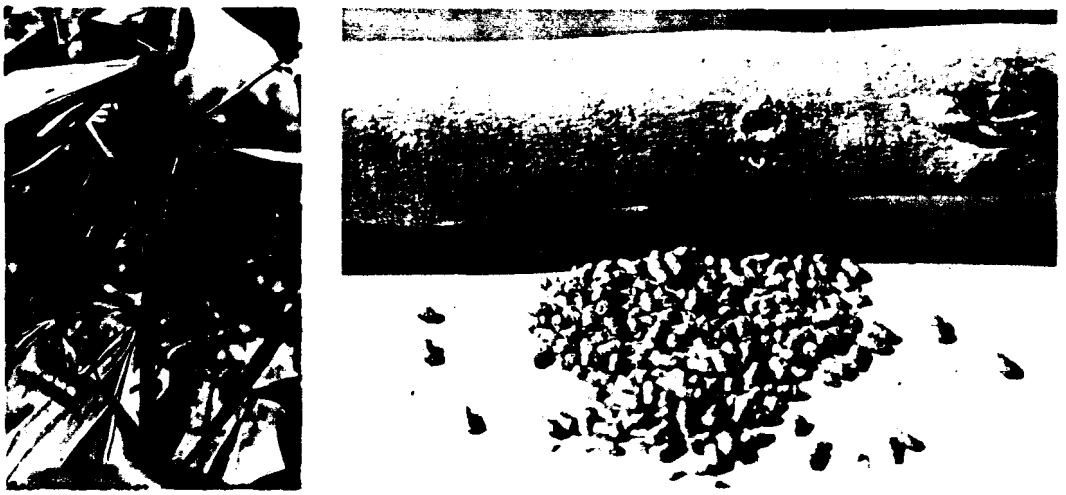
The reddish-yellow eggs are laid in strings on the bark of small stems or branches. Larvae hatch after about 10 days and spin a shelter network of silk. A few days later they launch themselves some distances. Eventually, some settle on suitable food plants and bore in, usually entering at the junction between a leafstalk or twig and the main stem (Plate 9.29). There is considerable mortality in the young larval stages. The tunnels of young larvae in small branches or stems are cylindrical and run more or less straight up and down the center, but those of older larvae are widened out into irregular cavities at intervals. The tunnel may eat away right into the cambium. Sometimes the cavities are ring-shaped and completely girdle the shoot, which dies back at once; the side branches of older trees break of at the girdle. A well-developed tunnel reaches an overall length of between 30-60 cm and may extend down to the root of a small

Plates 9.26-28. The red coffee borer (*Zeuzera coffeae*). Left: moth. Center: adult. Right: Pupa is slender; pupation takes place inside larva tunnel.

plant; exceptionally, a tunnel in a teak sapling may extend for 120 cm. At intervals in its course circular holes are cut to the outer surface through which the borer ejects its frass and excrement, which is in the form of yellowish or reddish rounded pellets (Plate 9.30), usually gummy and gathering in small lumps to the bark or collecting in a heap on the ground below (Plate 9.30).

Feeding by the larva lasts 60-120 days in the tropics and for the greater part of a year in colder northern climates. Pupation takes place at the end of tunnels, with the head towards the exit hole, usually head downwards.

The pupal periods last from 3 weeks to 1 month. The moth emerges, leaving the empty pupal skin protruding from the hole in the bark; it takes about 20 minutes for the wings to expand and dry. The female lays 500-1,000 eggs in 1-2 weeks.



Plates 9.29-30. Left: entry point of the coffee borer. Right: Pellets of excrement ejected through a hole made by larva, piled as a heap on the gound near the stem.

The cycle of development of *Zeuzera coffeae* lasts 4-5 months in southern India and at low elevations, and probably extends to a year at higher elevations and in northern India. In Myanmar (Burma), there are two generations a year. It is capable of breeding continuously year-round and may be found in almost every stage of development in each month; there is therefore no marked seasonal sequence of generations (Beeson 1961).

The caterpillar bores a longitudinal tunnel in the drying wood. Also typical are the cylindrical reddish-brown or yellow faecal pellets ejected from the tunnels that accumulate at the base of infested trees. The borers may leave their tunnels and penetrate in another spot, usually lower on the plant. The moths are nocturnal. Oviposition occurs at random. Total development takes 4-5.5 months in the lowlands. Natural enemies of the larvae include woodpeckers, a braconid (*Bracon zuezerae*), and several tachinids—*Isosturmia chatterjeena* (Bar.) and *Carcelia kockiana* Towns—but the greatest mortality occurs when the young larvae hatch.

Economic Importance

This species is often an important pest of forest crops, injurious principally to one-year-old seedlings and small saplings in nurseries and plantations. It is reported to have ruined plantations of *Eucalyptus deglupta* in Malaysia (Streets 1962), with larval attack causing the death of the distal part of the branch.

Control

In young eucalyptus plantations, it is common to see broken stems or death of the top due to girdling by the larvae. The only effective method is to inject insecticide into the holes where larvae push out their frass. To save the trees, this direct injection must be done at the earliest detection of fresh and small amounts of frass.

Future Research

Only four of the insects described in this chapter (*Sternocera aequisignata, Coptotermes curvignathus, Sinoxylon* sp., and *Zeuzera coffeae)* can be considered serious pests. More effective means of controlling these four should be priority research topics. Although early starts have been made in biological control, further efforts are needed in this area.

For the other pests, a better understanding of when and how they multiply to epidemic levels would be helpful in formulating management measures. It is particularly critical to learn this information for conditions in which *A. mangium* is the main host, not just one of many hosts.

Summary

The descriptions of 30 insect species in this chapter, together with the 48 species in the appendix, include all types of insect pest characteristics (i.e., defoliators, branch and stem borers, root destroyers, and sap feeders). Although the number of species would appear to suggest that *A. mangium* is very susceptible to insect pests, most of these are not serious pests on *A. mangium*; many of them are major pests of other crops and are found to attack *A. mangium* as defoliators, without serious damage.

Only a few species could be described as serious pests with profound and serious attacks: root feeders (*Sternocera aequisignata* and termites), branch and stem borers (*Sinoxylon* spp.), and the red coffee borer (*Zeuzera coffeae*). These can cause death, deformity, or reduced biomass production of *A. mangium*, and thus are the insects that must be carefully monitored and for which preventive measures should be employed.

Still, less serious insect pests should not be overlooked, since their populations can build to epidemic levels when environmental conditions are conducive. Foresters and forest plantation managers working with *A. mangium* should therefore be prepared to prevent insect attack. By identifying insects in their plantation based on the phenology and descriptions provided in this chapter, they can decide on the most effective prevention measures for guarding against insect pests and achieving the highest yield at harvest.

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References

Abe, Ken-ichi. 1986. *Plantation Forest Pests in Sabah*. FRC Publication No. 8. Sandakan, Sabah, Malaysia: FRC.

Ahmad, M. 1965. *Termites (Isoptera) of Thailand*. Bull. American Museum of Natural History. Vol. 131: Article 1. Washington, D.C.: Smithsonian Institution.

Anonymous. 1986. *Biology and Control of Insect Pests*. Research Pamphlet No. 100. Report of Forest Research Institute 3536. Kepong, Malaysia: FRIM.

Baltazar, C.R. 1965. A new species of ichneumon fly and a chalcid wasp parasitic on slug caterpillar in Basilan Island. *Rev. Appl. Ent.* Ser. A 56:1186.

Baltazar, C.R. and N.P. Salazar. 1979. *Philippines Insects: An Introduction*. Quezon City, Philippines: University of the Philippines Press.

Beeson, C.F.F. 1961. *The Ecology and Control of Forest Insects of India and Neighbouring Countries*. Delhi: Government Printing Office.

Braza, R.D. 1987. Resistance of seedling of four plantation tree species to white grub, *Leucopholis irrorata* (Chavrolat)(Coleoptera: Scarabaeidae). *Sylvatrop* 12(1-2):1-7.

———. 1988. Insect attacking *Acacia mangium* seedlings. *NFT Res. Rpts.* 6:29-30.

———. 1990a. Psyllids on nitrogen fixing trees in the Philippines. *NFT Res. Rpts.* 8:62-63.

———. 1990b. Laboratory evaluation of *Metarhizium anisopliae* (Metch.) Sorokin against *Leucopholis irrorata* (Chevrolat)(Coleoptera: Scarabaeidae). *Philippines Entomologist* 8(1):671-675.

———. 1991a. Psyllid infestation on *Acacia* species in the Philippines. *NFT Res. Rpts* 9:42.

———. 1991b. Beetles attacking *Acacia mangium* in the Philippines. *NFT Res. Rpts.* 9:40-41.

Browne, F.G. 1968. *Pests and Diseases of Forest Plantation Trees.* Oxford: Clarendon Press.

Chey, V.K. 1987. *Insect Defoliators of Forest Plantation Trees in Sabah.* FRC Publ. No. 32. Sandakan, Sabah, Malaysia: FRC.

Choonhawongse, W., A. Kongkanjana, A. Wongkorbrat, M. Chavanaponge, K. Chumroenma, and B. Meksongsri. 1982. Study on the biology and host plants of green snout weevil. *Entomol. Res. Rpt.* Bangkok: Dept. of Agric. 23p. (In Thai.)

Glover, N. and J. Heuveldop. 1985. Multipurpose tree trials in Acosta-Puriscal, Costa Rica. *NFT Res. Rpts.* 3:4-6.

Gray, B. 1972. Economic forest entomology. *Ann. Rev. Entomol.* 17:313-354.

Hamid A.A. 1987. Insect pests of *Acacia mangium* Willd. in Sarawak. Forest Research Report FE1. Sarawak, Malaysia: Forest Department, Sarawak. 10p.

Harris, W.V. 1964. *Termites: Their Recognition and Control,* 2nd edition. London: Longman.

Hutacharern, C. and A. Choldumrongkul. 1989. A note on the insect pests of multipurpose tree species in Thailand. *J. Trop. For. Sci.* 2(1):81-84.

Hutacharern, C., C. Choldumrongkul, S. Eungwijarnpanya, A. Choldumrongkul, and P. Pholwicha. 1988. *Check Lists of Forest Insects in Thailand.* Bangkok: Royal Forest Department.

Jirapan, P. 1979. Biology and chemical control of slug caterpillar (*Thosea sinensis* Walker). M.Sc. Thesis, Kasetsart University, Bangkok, Thailand. (In Thai, with English abstract.)

Kalshoven, L.G.E. 1981. *The Pests of Crops in Indonesia.* Revised and translated by P.A. Van der Laan. Jakarta, Indonesia.

Kitnijtee, S. 1993. Personal communication.

Luego, J.N. 1990. Mirid bug (*Helopeltis* sp.): A threat to *Acacia mangium. NFT Res. Rpts* 8:105-106.

Madamba, J.C. 1975. *The Philippines Recommends for Coconut.* Los Baños, Philippines: Philippines Council for Agriculture and Resources Research and Development. 62 p.

Mathew, G. and K.S.S.Nair. 1985. Insect associated with forest plantations of *Paraserianthes falcataria* in Kerala, India. *Malaysian Forester* 48(3-4):200-205.

Menon, K.D. 1963. Defoliation of teak in north-west Malaysia. *Malaysian Forester* 26:209-210.

Metcalf, C.L. and W.P. Flint. 1962. *Destructive and Useful Insects: Their Habits and Control,* 4th edition. Revised by R.L. Metcalf. New York: McGraw-Hill.

Mongkolkitti, S. 1981. Grasshoppers and their control. Technical Paper No. 22. Bangkok: Entomology Division, Department of Agriculture. (In Thai.)

Morimoto, K. and R.S. Raros. 1979. Forest and forest products pests problems in the Philippines. TARC Tech. Bull. No. 10. Los Baños, Philippines: Trop. Agric. Res. Center.

National Research Council. 1983. *Mangium and Other Fast-growing Acacias for the Humid Tropics.* Washington, D.C.: National Academy Press.

Nobuchi, A. and Ir. Hariyono. 1987. Insect pests of plantation trees at the trial plantation project (ATA-186) in Banakat, South Sumatra. Jakarta: Japan International Corporation Agency.

Pholwicha, P. 1991. Teak twig borer. *The Vanasam* 49/1:22-23. (In Thai).

Punpen, Jirapan. 1979. Biology and chemical control of slug caterpillar (*Thosea sinensis* Walker). M.Sc. Thesis, Kasetsart University, Bangkok, Thailand. (English abstract.)

Roffey, J. 1979. Locust and grasshoppers of economic importance in Thailand. Anti-Locust Memoir 14. London: Centre for Overseas Pest Research.

Sajap, A.S. and P.T. Jan. 1990. Pathogenecity of two entomogenous fungi, *Beauveria bassiana* and *Metarhizium anisopliae*, on the termite, *Coptotermes curvignathus*. In *Pests and Diseases of Forest*

Plantations in Asia-Pacific Region, proc. IUFRO workshop held in Bangkok, Thailand; eds. C. Hutacharern, K.G. MacDicken, K.S.S. Nair, and M.H. Ivory; 266-270. RAPA Pub. 1990/9. Bangkok: FAO-RAPA.

Sarakawi, .M.U. 1986. Common insect pests in forest nurseries and forest plantations in Sarawak. Paper presented at the Ninth Malaysia Forestry Conference, Kuching, Sarawak. Kuching: Forest Department, Sarawak.

Selander, J. 1990. Forest pests and diseases of plantation trees. Technical Report No. 8. FINNIDA in cooperation with The Ministry of Forestry, Indonesia. Jakarta: FINNIDA.

Sharma, P.C. 1966. A note on the control of *Sternocera aequisignata* (Buprestid root borer). *Rev. Appl. Ent.* 54:663.

Stebbing, E.P. 1914. *Indian Forest Insects of Economic Importance (Coleoptera)*. New Delhi: Indian Government Publications.

Streets, R.J. 1962. *Exotic Forest Trees in the British Commonwealth*. Oxford: Clarendon Press.

Tayade, D.S. 1979. Bionomics of *Sagra femorata* Drury (Sagrinae: Coleoptera). *Rev. of Appl. Entomol.* Ser. A 67(11):557.

Turnbull, J.W. ed. 1986. *Multipurpose Australian Trees and Shrubs: Lesser-known Species for Fuelwood and Agroforestry*. Canberra, Australia: ACIAR.

Uvarov, B.P. 1928. *Locusts and Grasshoppers: A Handbook for Their Study and Control*. London: The Imperial Bureau of Entomology.

Appendix. Reported insect pests of *A. mangium* not described in detail in the text, with references.

Name	Source
Adoretus compressus	Chey 1987
Apogonia sp.	Chey 1987
Aphids	Braza 1988
Astycus latéralis	Hutacharern et al. 1988
Atractomorpha psittacine de Haan	Chey 1987
Atta sp.	Glover and Heuveldop 1985
Botyodes asialis Guenee	Chey 1987
Calliteara horsfieldii Saunders	Chey 1987
Camponotus sp.	NRC 1983
Chalcoselis albiguttatus	Chey 1987
Chalioides sumatrensis Heylaerts	Chey 1987
Cletus trigonus	Hutacharern et al. 1988
Dasychira inclusa	Chey 1987
Dasychira sp. *basinigra* (Heylaerts)	Chey 1987
Deretina sp.	Braza 1991b
Diapromorpha sp.	Hutacharern et al. 1988
Ericeia sp.	Chey 1987
Eumeta sp.	Chey 1987
Eunococephalus sp.	Hutacharern et al. 1988
Euproctis bicolor	Chey 1987
Eusceletanla immodica Meyrick	Chey 1987
Homoeocerus walkeri Kirby	Hutacharern et al. 1988
Hyposidra talaca	Chey 1987
Leaf folders	Braza 1988
Lepidiota sp.	Hutacharern et al. 1988
Leptocentrus sp.	Hutacharern et al. 1988
Locusta migratoria manilensis	Chey 1987
Looper	Braza 1988
Lymantria sp.	Chey 1987
Odontodus nigricornis Stal	Hutacharern et al. 1988
Pagodiella hekmeyeri	Chey 1987
Parasa sp.	Hutacharern et al. 1988
Pempelia sp.	Chey 1987
Penthicodes farinosa	Chey 1987
Phytoscaphus triangularis Olivier	Hutacharern et al. 1988
Piezoderus rubrofasciatus F.	Hutacharern et al. 1988
Polyrhachis sp.	Chey 1987
Polyura schreiber tisamenus (Fruhstorfer)	Chey 1987
Pteroma pendula	Anon. 1986
Ropica griseosparsa Pic.	Nobushi and Hariyono 1987
Scale insect	Braza 1988
Seed borers	Turnbull 1986
Sinoxylon sp.	Hutacharern et al. 1988
Stenocantatops splendens	Chey 1987
Taragama (*Streblote*) *dorsalis* Walker	Hutacharern et al. 1988
Tettigonia sp.	Chey 1987
Trichochrysea severini (Jacoby)	Hutacharern et al. 1988
Xylotrupes gideon L.	Kitnijtee 1993

Chapter 10

Diseases

Lee Su See

Introduction

In South and Southeast Asia, the land area coming under forest plantations has increased tremendously over the last decade. In Malaysia alone, the land area under forest plantations has increased from about 50,000 ha in 1984 to about 97,000 ha in 1992. Most of these plantations have been planted with fast-growing, exotic tree species, often in monocultures or with a few high-yielding varieties. For higher yields, growers tend to further narrow the genetic base of a species, and often the species may be planted out of its natural range. The reduction in species diversity, age diversity, and genetic diversity in plantations produces conditions favorable for development and spread of disease pathogens. There are many examples: pink disease of selected *Hevea* clones and local outbreaks of *Cylindrocladium* leaf blight of *Eucalyptus camaldulensis* in Malaysia, *Dothistroma* needle blight of radiata pine in New Zealand (Chou 1991), and mycoplasmas of *Paulownia* (Jin cited in Hubbes 1992) in China. Clearly, recognition and control of diseases will play a key role in these intensively managed forest plantations if they are to realize the expected high yields and large investment costs.

To date there are no reports of any serious disease outbreaks in *Acacia mangium* plantations. However, the species is not totally free from disease. Observations and reports have shown that the species is affected by several diseases, some of which may become serious under predisposing conditions.

This chapter brings together all available reports of diseases of *A. mangium*, including both research data and personal observations. Bacteria, nematodes, and fungi have been reported as disease agents of *A. mangium* but most diseases are associated with or caused by fungi. To date, there are no known reports of diseases caused by viruses, mycoplasmas, or abiotic agents (such as air pollutants). The available literature (for example, Bowen and Eusebio 1982) and checks with the Seed Technology section of the Forest Research Institute of Malaysia (FRIM) confirm that *A. mangium* is not susceptible to diseases caused

by seed-borne pathogens. Even seeds coated with fungal hyphae and spores have been observed to germinate and develop normally.

Seedling Diseases

Although the pathogens may not be the same, adult trees and seedlings share many diseases in common; for example, foliage diseases and root rots. However, some diseases are unique to or more prevalent on seedlings, mainly due to the conditions of nurseries. The intensive, repeated cultivation of tree seedlings in nurseries creates ideal conditions for the build-up and spread of diseases that generally do not pose a serious threat to natural seedling regeneration. The main diseases of *A. mangium* seedlings are: damping off, powdery mildew, stem galls, dieback, leaf spots, charcoal root disease, and root knot.

Damping-Off

Damping-off is a common disease in nurseries, and is most severe when conditions favor growth of the fungus and not the host. It can attack seedlings during germination (pre-emergence damping-off) or after germination, while the tissues are still succulent (post-emergence damping-off).

There are few reports of damage to *A. mangium* by damping-off: up to 30% of seedling stock in Peninsular Malaysia, 50% of seedling stock in Sabah (Liew 1985; Maziah 1990), and a high incidence (no figures available) in a nursery in Gogol, Papua New Guinea (Sahashi and Mukiu 1992; Plate 10.1).

Symptoms

In pre-emergence damping-off, the germinating seedlings are killed before they can emerge from the soil, resulting in very sparse or no germination at all. This is sometimes mistaken as a symptom of poor seed viability. In post-emergence damping-off, seedlings are rotted at soil level and subsequently collapse and die.

Causal Organisms

The associated fungi have been identified as: *Chaetomium* sp., *Curvularia* sp., *Cylindrocladium* sp., *Fusarium solani, Fusarium* sp., *Pythium* sp., *Phytophthora* sp., and *Rhizoctonia solani* (Khamis 1982; Lee 1985; Liew 1985; Lee and Goh 1989; Maziah 1990; Norani 1987).

Etiology

The seed or the emerging seedling is infected either by spores or vegetative hyphae present in the soil. Infection of the host tissue results in enzymatic degradation of the host cell wall and death of host tissue. This is seen as water

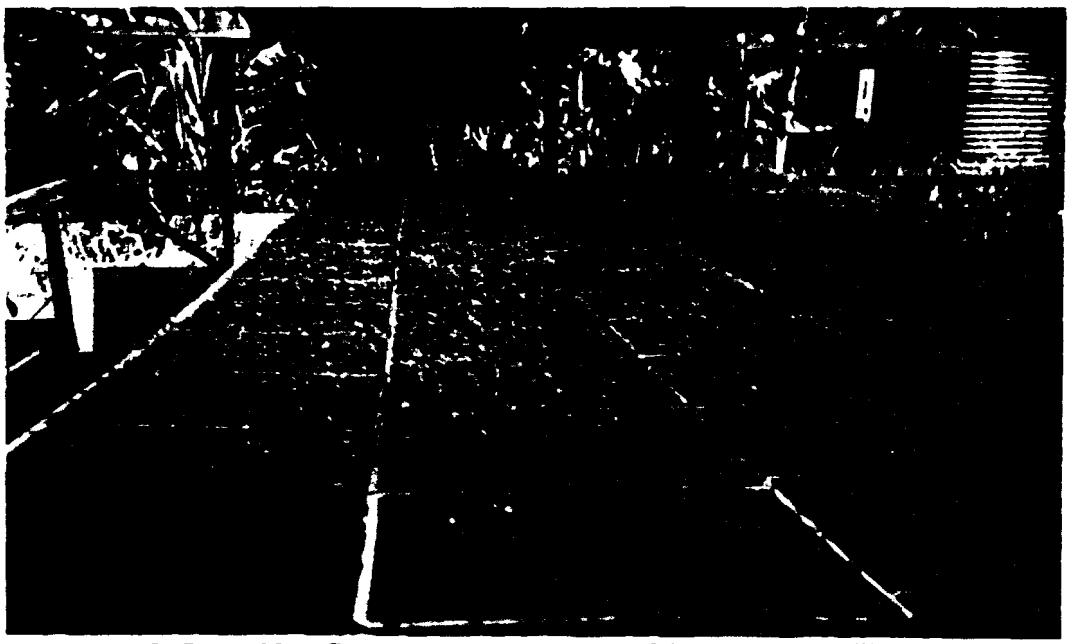


Plate 10.1. In Papua New Guinea, poor germination of *A. mangium* seedlings due to damping-off is ameliorated by pretreatment with Thiram.

soaking, browning, or shrivelling of the stem tissue at soil level and collapse of the seedling. Most of the damping-off fungi cause disease only at the seedling stage; as the seedlings grow and the tissue becomes lignified, they become more resistant to infection.

Factors influencing the severity of damping-off include: soil moisture, temperature, soil pH, host vigor, host density, and inoculum density. Conditions that favor damping-off by one fungus species, however, may not be favorable for another fungus. For example, damping-off by *Pythium* or *Phytophthora* is most severe at high moisture levels, which favor development of zoospores that readily infect young seedlings. *Fusarium*, however, grows best in dry soil.

Control

The best means of controlling damping-off is by preventing pathogenic fungi from entering the sowing medium or seedbed. This disease can be avoided by adopting good nursery techniques and sanitation. Excessive watering, organic matter high in nitrogen content, and the use of heavy shading should all be avoided. Seeds should not be sown too densely, to prevent the build-up of conditions conducive to the spread of the pathogen.

Soil fumigation with methyl bromide, chloropicrin, or Vorlex before sowing are effective but dangerous unless conducted by experienced operators. A more common practice is soil drenching with sulfuric acid or 0.5-1.0% formalin solution about a week before sowing. Seed dressing with fungicides can also be used but results are inconsistent (Aniwat 1990). Some of the more recent systemic fungicide mixtures are effective but can be costly.

Powdery Mildew

Powdery mildew has been observed on *A. mangium* seedlings in nurseries in Malaysia (Maziah 1990; Lee, unpublished data), Thailand (Aniwat 1987; Kiyoshi and Aniwat 1990), and Hawaii (National Research Council 1983). While the incidence and impact of powdery mildew has been low in Malaysia, it has caused heavy losses in Thailand. A serious outbreak in 1984 resulted in 90-100% infection and caused 75% mortality of affected seedlings in the Sakaerat experimental site in Thailand (Kiyoshi and Aniwat 1990).

Plate 10.2. Powdery mildew on *A. mangium* seedlings. The upper leaf surfaces are coated with a white powdery growth of hyphae and spores of *Oidium* sp.

Symptoms

Infection usually begins as solitary cobweb-like to powdery white patches on the primary (juvenile) leaves. As the infection develops, spreading rapidly to the secondary leaves or phyllodes, the upper leaf surfaces become heavily coated with a white powdery growth of hyphae and spores (Plate 10.2). The leaves look as though dusted with powder, hence the name. The symptoms are also sometimes mistaken for road dust, especially on plants planted near dirt roads. When the fungus dies, it leaves yellow blotches on the leaf surface. Heavy infection results in premature defoliation of both the juvenile leaves and phyllodes, retarding subsequent growth.

Causal Organism

The pathogen, *Oidium* sp., is a member of the Fungi Imperfecti (Deuteromycotina) (Aniwat 1987; Kiyoshi and Aniwat 1990; Maziah 1990). In Thailand, it has been suggested that the perfect state of the fungus is *Erysiphe acaciae* and that the fungus might be indigenous to acacias and other trees (Kiyoshi and Aniwat 1990).

Etiology

The fungus penetrates the leaf epidermal cells, forming absorbing structures known as haustoria through which it obtains nourishment from the host cells. Hyaline, barrel-shaped conidia (Form genus *Oidium*) produced in large numbers on the leaf surface are wind blown to other susceptible hosts, initiating new infections. The perfect stage of the fungus has not been observed on *A. mangium*. Plants growing under shady conditions are usually more susceptible.

Control

Since damage is usually slight, control is seldom warranted. Surface application of fungicides, such as Benomyl (Aniwat 1990), and sulphur dusting can control the disease. Destroying fallen leaves may help to limit potential inoculum.

Stem Galls

An isolated case of stem galls was observed in early 1992 on 2.5- to 3-month old *A. mangium* seedlings in a nursery on the east coast of Peninsular Malaysia. Over 70,000 seedlings were affected. This disease has not been reported elsewhere.

Symptoms

Stems of seedlings between the root collar and the apical shoot are covered with small, rounded galls measuring 1-2 mm in diameter (Plate 10.3). These galls usually occur in clusters, and are brown and smooth.

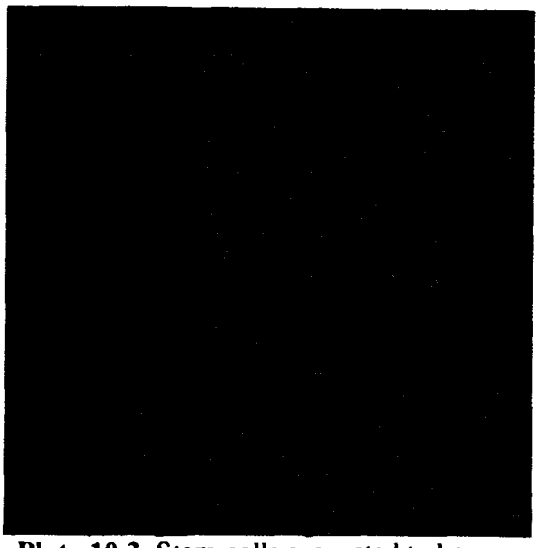


Plate 10.3. Stem galls suspected to be caused by bacteria.

Causal Organism

Smears on slides and isolates from the galls consistently yielded bacterial colonies. The bacteria were rod shaped and gram negative. On glucose peptone agar, the bacteria were evident after 24 hours as shiny, cream-colored colonies becoming yellowish to pale orange with age. The identity of the bacteria could not be determined.

Etiology

Bacteria are typically not obligate parasites and are unable to penetrate plant tissues directly. They can thus only enter the host through natural openings such as stomata and lenticels or through wounds. They can be transmitted by wind and rain, insects, nematodes, other animals, and humans and their cultural practices. They may also be transmitted in seed or vegetative planting material.

Control

Detailed knowledge of the disease, the crop, and the bacterium is needed to choose the most effective method of breaking the disease cycle at its weakest point. Effective control of bacterial diseases is primarily by sanitation or by use of resistant varieties. Care should also be taken to prevent wounds during planting and cultivation. Infected plants should be removed and destroyed. Bacteriacides are available but can be expensive.

Diseases

Dieback

Occurrence and Importance

Although Maziah (unpublished data) has observed shoot dieback on seedlings in the nursery, the outbreak was not serious and only a few seedlings were affected.

Symptoms

Tips of affected seedlings wilt and become necrotic, with the necrotic lesions progressing down the shoot.

Causal Organisms

Fusarium oxysporum, Phoma sp. and *Lasiodiplodia theobromae* were isolated from affected tissue but pathogenicity was not established.

Control

Since damage is usually slight, control is seldom warranted. However, fungicide sprays should prove effective.

Leaf Spots

Occurrence and Importance

Leaf spots normally do not cause extensive damage and are not serious unless associated with heavy defoliation. Leaf spots have been reported on *A. mangium* seedlings of various ages, but to date there are no reports of heavy damage or major outbreaks.

Symptoms

On *A. mangium* seedlings leaf spots normally occur not on the juvenile leaves, but on the phyllodes. The leaf spots are usually slightly elongated and brown, with a dark margin (Plate 10.4).

Causal Organisms

Fungi commonly associated with leaf spots of *A. mangium* seedlings include: *Colletotrichum gloeosporioides, Glomerella cingulata, Lasiodiplodia theobromae, Fusarium* sp., *Gloeosporium* sp., *Corynespora* sp., and *Hendersonula* sp. (Lee and Goh 1989; Maziah, unpublished data).

Etiology

The etiology of leaf spot pathogens of *A. mangium* has not been studied but the associated fungi are known to cause similar disease symptoms on other hosts. The fungus usually enters the host through stomata, infecting epidermal and mesophyll cells. Proliferation of the fungus results in rupture of the infected cells or formation of sporodochia (depending on the fungus species) and release of

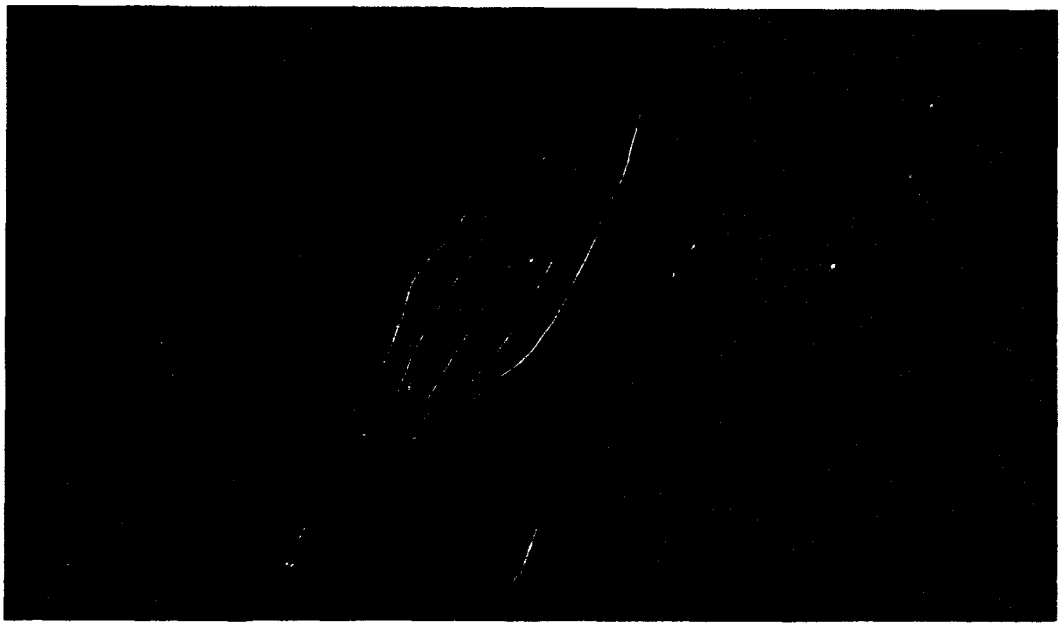


Plate 10.4. Typical leaf spot symptoms, progressing in severity from left to right.

spores. The fungi thrive under damp conditions and are dispersed by rain splash or in currents of damp air.

Control

At present, the disease is not considered serious enough to warrant control efforts. However, regular spraying with fungicides such as Daconil or Benlate are known to be effective.

Charcoal Root Disease

This disease has only been reported on *A. mangium* seedlings in Sabah (Khamis 1982). That report included no indication of severity or impact of the disease.

Symptoms and Causal Organism

Affected seedlings were stunted and chlorotic. There was no description of the symptoms on the roots, but from its name, presumably the roots turn black. The disease was associated with a fungus, *Macrophomina* sp., a fungus known to cause root diseases in many plant species (Manion 1981).

Etiology and Control

The fungus invades root tips, lateral roots, and the root collar region. This gradual destruction of the root system causes seedlings to become stunted and chlorotic, and ultimately to die. In the absence of hosts, the pathogen forms sclerotia for survival in the soil. These sclerotia make thorough fumigation of the soil the only practical treatment for controlling the disease.

Diseases

Root Knot

Nematodes are found in the soil and normally do not pose a serious threat to seedling growth and production unless present in abnormally high numbers (more than 1,000 per half liter of soil).

To date, root knot of *A. mangium* seedlings caused by nematodes has been reported only in Sarawak, Malaysia (Chin 1986). In 1984, 15-20% of 60,000 potted seedlings at Niah Forest Research Station, Sarawak, were damaged by nematode attack. The following year, approximately 40% of the seedlings at Sabal Forest Nursery, Sarawak, were similarly damaged.

Symptoms

Seedlings were stunted, possessed few pale-green to yellowish leaves, and were prone to wilting, especially during hot times of the day. Affected seedlings had swollen basal stems and root knot galls. The galls were woody and irregular to roughly spherical, measuring 1.5-2.5 cm by 1.0-2.0 cm (Chin 1986).

Causal Organisms

Several species of plant parasitic nematodes have been found in seedlings and soil sampled from forest nurseries in Sarawak. However, in the two cases mentioned above, root knot nematodes of *Meliodogyne* spp. were found to be the causal organism (Chin 1986).

Etiology

Root knot nematodes are widely distributed in forest soils up to a depth of 60 cm. The female nematode penetrates the plant tissue by means of a stylet; feeding by the female causes formation of giant cells in the root. Cell walls between adjacent root cells dissolve, nuclear division increases, and cells enlarge. The female *Meliodogyne* nematode is an endoparasite and spends her entire life in one location in the root gall, feeding on the few giant cells formed. The eggs are formed parthenogenically in the adult female and the extruded eggs remain together in a saclike membrane on the surface of the root gall. When the young hatch, they often penetrate the root in the same general area as the parent, thus accentuating gall formation.

Control

Nematodes are generally controlled by soil application of nematocides and sterilants. Furadan 3G applied at a rate of 0.5 g per seedling before five weeks of age provided effective control in Sarawak. Soil drenching with a solution of 4-5% formalin (applied at a rate of 8 ml per 470 ml water per 900 cm^2 soil 5-7 days before sowing) also gave effective control (Chin 1986). Crop rotations, interplanting non-host cover crops, fallow periods between crops, sanitation, and use of resistant varieties are other options for control.

Total elimination of nematode problems is unlikely and nematode-induced losses may have to be accepted as part of the cost of raising seedlings.

Tree Diseases

The importance of tree diseases is often evaluated on the basis of their lethal effects. However, many diseases do not directly result in the death of the tree, but cause reduced vigor and growth rates that can lead to growth losses and increased susceptibility to damage by other pest organisms and abiotic disease agents.

With the increase in forest plantations, while more wood will be produced, more losses due to tree diseases are also expected (Manion 1981).

The list of diseases affecting *A. mangium* trees described below is by no means exhaustive and only represents those observed to date. No doubt other diseases exist that have not been reported or perhaps not yet observed, since *A. mangium* is still a relatively new plantation species.

Root Rots

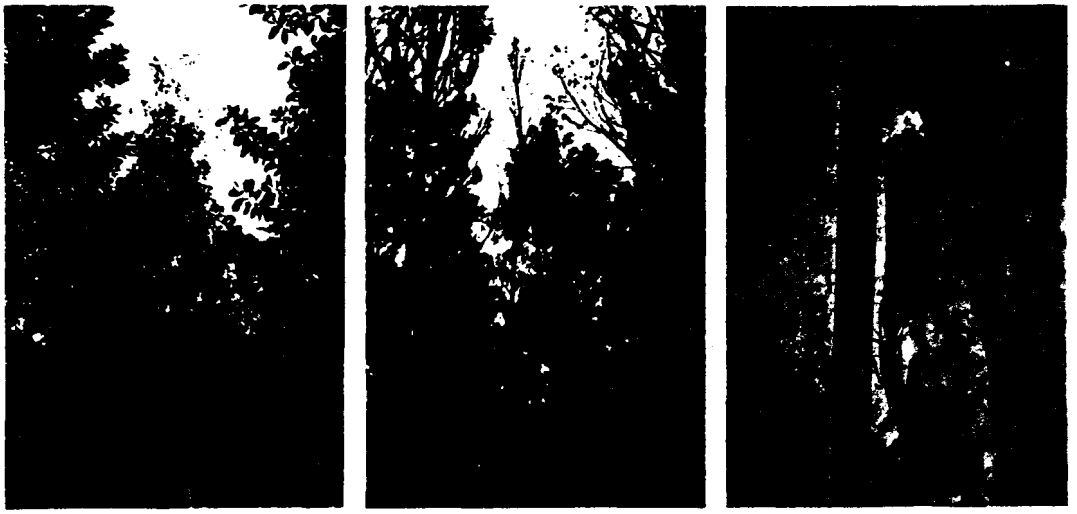
Root diseases found in *A. mangium* plantations include a brown root disease caused by *Phellinus*, reported in Sabah, Malaysia (Khamis 1982) and the Philippines (Almonicar 1992). In both instances, no mention was made of the age or number of trees affected. This fungus has also been observed on diseased roots of trees of 1-9 years old at various locations in Peninsular Malaysia (Maziah, Philip, unpublished data). Lee (1985) observed a red root disease associated with *Ganoderma* sp. in a three-year-old plantation in Kemasul, Peninsular Malaysia. Studies are underway to determine the severity and spread of this disease in *A. mangium* plantations of different ages located in different parts of Peninsular Malaysia. An unknown fungus with characteristics similar to those of *Ganoderma* has also been reported causing root rot of *A. mangium* trees one year and older in the Philippines (Almonicar 1992).

In the Gogol valley of Papua New Guinea, Arentz (1986) recorded 29% mortality of *A. mangium* trees after five years due to root disease caused by *Ganoderma* sp.

These are currently the only reports of root disease in *A. mangium* plantations. This may be due either to the absence of the disease or the lack of observations and studies on the disease.

Symptoms

Initial symptoms of root rot resemble those of nutrient deficiencies. The foliage becomes yellow and smaller due to reduced water and mineral uptake. Young shoots may also wilt. In more advanced stages when a major portion of the roots have decayed, fallen trees or standing dead trees are good indicators of root



Plates 10.5-7. Root rot symptoms. Left: a tree with wilted and dead foliage and branches. Center: A pocket of root rot in a plantation is indicated by a group of dead and dying trees; trees at the periphery have smaller and sparser foliage. Right: A portion of *A. mangium* root attacked by root rot is covered by a dark reddish crust, and the wood is fibrous and bleached a pale straw color.

disease (Plate 10.5). Very often small foci of dead trees in a plantation are surrounded by trees with small or yellowing foliage (Plate 10.6).

Signs of the disease are only evident on the roots after the tree has fallen over or upon excavation of the roots. Depending on which fungus causes the disease, there may be a dark reddish crust (Plate 10.7), a granular rusty brown incrustation, or white thread-like rhizomorphs on the surface of the roots. All three types of fungal structures have been found on *A. mangium* roots suffering from root rot.

Causal Organisms

The most common form of root rot in most *A. mangium* plantations appears to be associated with *Ganoderma* sp., which forms a dark reddish, crust-like rhizomorphic skin on the main lateral roots. In an ongoing survey of root disease in some *A. mangium* plantations in Peninsular Malaysia, this characteristic incrustation has been found on roots of 3- to 10-year-old dead or dying trees. Some basidiomes of a *Ganoderma* sp. have been collected from dead trees and studies are underway to identify the fungus (or fungi) responsible, and to determine the spread of the disease. One basidiome of *G. weberianum* has been collected from a decayed *A. mangium* stump in the Gogol valley of Papua New Guinea (Arentz 1990).

Phellinus spp. have also been found on diseased roots of *A. mangium* in Peninsular Malaysia (Maziah, Philip, unpublished data), Sabah (Khamis 1982), and the Philippines (Almonicar 1992). The species in the Philippines has been identified as *Phellinus noxius*; the identity of those in Malaysia have not yet been confirmed. *Phellinus* spp. produce a rusty brown rhizomorphic skin on the root that darkens with age. In Peninsular Malaysia, this fungus has been found on

roots of trees between one to eight years old, but its incidence is much lower than that of *Ganoderma* sp.

Rigidoporus lignosus, the fungus producing white rhizomorphs on the root surface, has only been observed twice at two locations in Peninsular Malaysia (Lee, Maziah, unpublished data). There are no studies of this fungus in *A. mangium* plantations to date.

Etiology

The pathogens associated with or causing root diseases of *A. mangium* are soilborne fungi able to persist for long periods as saprophytes on dead plant materials.

Ganoderma sp. can persist as a saprophyte on dead roots and spread to healthy roots by means of the red rhizomorphic skin. On *Hevea brasiliensis* the fungus is known to be able to infect cut surfaces by means of spores. In the early stages of infection, the wood is pale brown and hard. As the rot progresses, the wood becomes pale, light, spongy when wet and friable when dry.

Like *Ganoderma*, *Phellinus* sp. can persist on dead roots and stumps and spread to healthy roots by the brown rhizomorphic skin. On rubber trees it is known to infect cut stumps from spores. The infected wood is initially pale brown, with brown zigzag lines appearing later. In the advanced stage, the wood becomes friable, light and dry, permeated with sheets of yellowish brown fungal hyphae that form a honeycomb structure.

Rigidoporus lignosus causes the most serious root disease in rubber but its impact on *A. mangium* has been fairly negligible. On rubber trees, this fungus spreads from root to root by means of the white rhizomorphs. It can also infect cut stumps from spores under favorable circumstances.

Control

Like many other root diseases spread by root contact, there are no specific control recommendations for these three fungi in *A. mangium* plantations. The disease may perhaps be prevented by ensuring that the trees are vigorous and that there is no accumulation of stumps, dying trees, and other woody debris in the vicinity of the future crop trees.

The usual method of controlling root rot caused by fungi that spread by root contact is to remove and destroy all diseased roots and woody debris. This is very costly and impractical in logged-over lowland rainforest areas intended for reforestation with *A. mangium*.

Arentz (1986) suggested that unless varieties can be found with a high degree of resistance to root pathogens, it may be necessary to abandon *Acacia* spp. for reforestation in Papua New Guinea, due to their susceptibility to root rot and the fact that little can be done to control the disease.

The impact of root rot in *A. mangium* plantations is still not fully known. While the situation appears quite bad in reforested lowland rainforest areas of Papua New Guinea, it may be different in other areas. Preliminary results from

Peninsular Malaysia show that incidence and spread of the disease varies from site to site.

Pink Disease

Pink disease is widely distributed in the tropics and has been reported on various crop plants and timber trees. In Malaysia, it is a well known disease of rubber and pepper, especially in high-rainfall regions. It has also been found on *Paraserianthes falcataria* in Sabah.

In Malaysia, pink disease was first reported on *A. mangium* trees from Niah Forest Reserve, Sarawak, in 1979. In 1986, it was found in four other forest reserves in different parts of Sarawak (Chin 1990). An estimated 17% of the *A. mangium* trees planted in Sarawak are infected with pink disease, with infection being most serious in Sabal Forest Reserve. The only two other reported occurrences of pink disease in *A. mangium* plantations have been in Sabah (Khamis 1982) and Peninsular Malaysia (Lee 1985). In neither case was there a serious outbreak or spread of the disease.

Symptoms

Early symptoms of this disease are wilted and shrivelled foliage on dead branches (Plate 10.8). In later stages, twigs and branches are girdled. Cracking of the bark and cankers on the stem are also symptoms (Plate 10.9). If infection is not severe, the tree will recover and develop epicormic shoots below the dead branches, with one shoot becoming the leader. In severe cases, however, the tree dies.

Early signs of the disease are pink pustules or pink to white patches on dead bark in the region of the main forks in the tree. Later a conspicuous, pink mycelial layer, which may break up into patches, spreads over the bark. This layer usually fades to a dirty white incrustation at a later stage.

Causal Organism

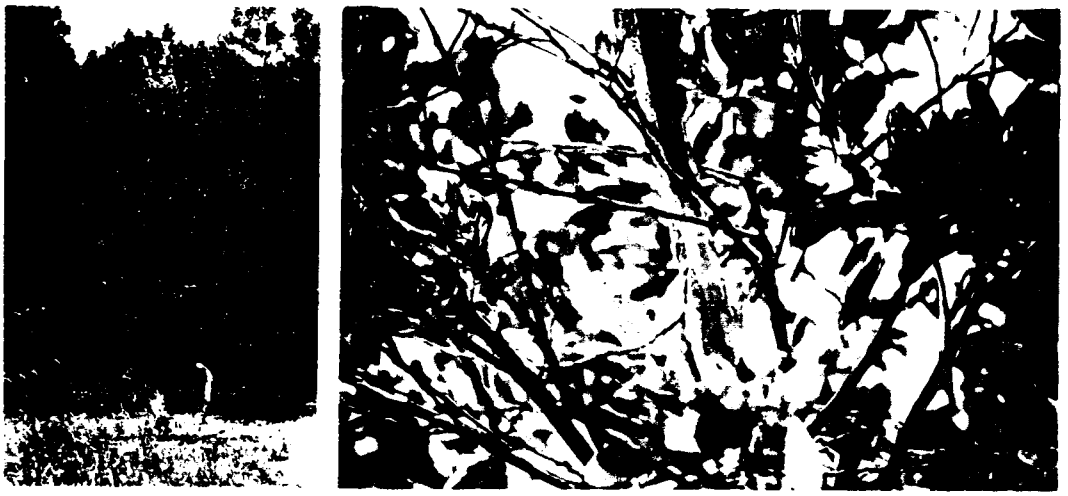
The causal organism is a basidiomycete fungus *Corticium salmonicolor* Berk. & Br., which produces a resupinate basidiocarp closely adpressed to the substratum.

Etiology

The fungus spreads by wind-dispersed spores. Disease dispersal mainly occurs during wet weather when the fungus sporulates freely and the surface of the bark is sufficiently moist to favor spore germination and hyphal growth. The fungus invades healthy branches and stems through natural openings such as stomata and lenticels, or through wounds. The disease may possibly also be transmitted by an insect vector, *Penthicodes farinosa* (Chin 1990).

Control

Trees normally recover if the disease is not serious. Removal and disposal of



Plates 10.8-9. Symptoms of pink disease. Left: An early symptom is wilting of a tree's top shoots. Right: The bark beneath the wilted shoot is covered by a light pinkish layer and may often be cracked.

infected fallen branches and twigs prevents build-up of inoculum in the plantation. However, although expensive and uneconomical, chemical protection may be necessary in a serious outbreak, as the disease can easily reach epidemic proportions. In Sarawak, pink disease was successfully controlled with Perenox, a copper-based fungicide (Chin 1990). In rubber plantations, Bordeaux mixture and a brush-on formulation of Calixin Ready-Mixed (tridemorph) have also been used with success.

The best way to prevent pink disease is to plant resistant varieties. In rubber plantations, this has been achieved through tree selection and breeding.

Heart Rot

Progressive decay of the heartwood is termed heart rot. Normally, fungi that decay heartwood do not attack sapwood; such trees continue to grow to maturity and may outwardly appear healthy and vigorous. However, since heart rot is progressive, there is considerable decay cull at the end of a rotation.

Heart rot in *A. mangium* was first reported in 1981 in Sabah by Gibson (1981), who noticed a white fibrous decay with a peripheral stain in 12% of 44-month-old thinnings. Similar observations were made in four year-old thinnings from Kemasul plantation (Lee 1985) and in five and six year-old thinnings from Rantau Panjang plantation (Hashim et al. 1990), both in Peninsular Malaysia. Results of a study of four, five and six year-old *A. mangium* trees in Kemasul by Lee et al. (1988) revealed that discoloration and heart rot were associated with fungal invasion of poorly healed wounds, especially those left by branch stubs. In Sabah, Ito (1991) also found that the heart rot fungus invaded mainly through dead branches.

The rot is often confined to small pockets in the heartwood, but is occasionally found throughout the length of the bole, especially in older trees. However,

the overall volume of wood affected is normally small—about 10% (FRIM internal report).

The high incidence of heart rot in *A. mangium* trees in Peninsular Malaysia recently led the Ministry of Primary Industries of Malaysia to place a temporary moratorium on planting the species.

Symptoms

The disease is only evident upon felling of the tree. However, the presence of dead or broken branches, wounds, and cankers are good indicators of the presence of heart rot (Lee et al. 1988). The type of rot found in *A. mangium* heartwood is a white rot caused by white rot fungi able to digest and use both cellulose and lignin (Lee et al. 1988; Ito 1990). Based on differences in color, texture, and general appearance of the heartwood, seven types of rot have been recognized (Lee and Maziah 1993). All are still categorized as white rots as the resulting rotted wood is a whitish, spongy, or stringy mass.

Causal Organisms

A variety of basidiomycete fungi have been collected or isolated from heart rotted *A. mangium* wood (Gibson 1981; Thomas & Kent 1986; Lee et al. 1988; Hashim et al. 1990; Ito 1991). However, no positive identifications of the fungi have been made. Recently, Lee and Maziah (1992) isolated 25 basidiomycete fungi from heart rotted *A. mangium* trees of various ages and from different locations in Peninsular Malaysia. In the absence of basidiomes, identification was based on cultural and microscopic characteristics. Only one fungus, *Phellinus noxius*, could be positively identified (Plate 10.10). Basidiomes of a *Trametes* sp. and a *Fomes* sp. have also been collected from trees with heart rot.

Plate 10.10. Heartwood of a seven-year-old *A. mangium* affected by heart rot. The honeycomb pattern is characteristic of rot caused by *Phellinus noxius*.

Etiology

The starting point for discoloration and decay in living trees is a wound. Wounds commonly found on *A. mangium* trees are branch stubs left after self-pruning, singling, and artificial pruning, broken branches, and mechanical injuries. *A. mangium*'s high susceptibility to heart rot may be partially attributed to its mode of self-pruning. During self-pruning, the branch dies slowly, allowing infection by decay fungi and entry of the fungi into the tree trunk before the branch stub has occluded.

As soon as a tree is wounded, micro-organisms on the bark and in the air contaminate the wound surface. A succession of micro-organisms followed by decay fungi occurs on the wound. Pioneer micro-organisms such as *Ceratocystis fimbriata, Chalara* sp., and *Phialophora* sp. found in discolored heartwood (Lee 1986; Lee et al. 1988) break down the host defenses and invade the xylem, which then allows decay fungi with the ability to degrade cellulose and lignin of the cell walls to become active.

Control

At present, there are no practical control measures against *A. mangium* heart rot. Wound dressings that have long been used as a preventive measure are now known to be ineffective and may in fact create conditions favorable for invasion of the wound by decay fungi.

The incidence of heart rot in *A. mangium* plantations in Sabah appears to be much lower than in Peninsular Malaysia. This may be related to site and/or genetic factors.

Foliage Diseases

Leaf spots, lesions, and the occasional dieback have been observed on *A. mangium*, but there have been no reports of any serious outbreaks or epidemics. Probably these diseases have received little attention since they rarely kill trees in a single season. Only the more frequently observed or more important foliage diseases are discussed below.

Sooty Mold

The most common foliage disease on *A. mangium* is sooty mold. Sooty molds are saprophytic epiphytes and are not parasitic on their hosts. They normally obtain nourishment from the honeydew secreted by aphids, mealy bugs, scale insects and other sucking insects. In cases where insect infestation is absent, as in *A. mangium*, the fungi obtain their nourishment from plant leachates leached into water deposited on the leaf surface as rain, dew, and mist. Surface water together with insects are important in dispersing sooty molds.

Extensive growth of sooty mold markedly reduces a tree's effective photosynthetic area, resulting in reduced vigor and growth. Many sooty molds also

absorb water readily and keep the leaf surface moist for long periods. This creates a very humid environment within the tree canopy, allowing the spread of other diseases.

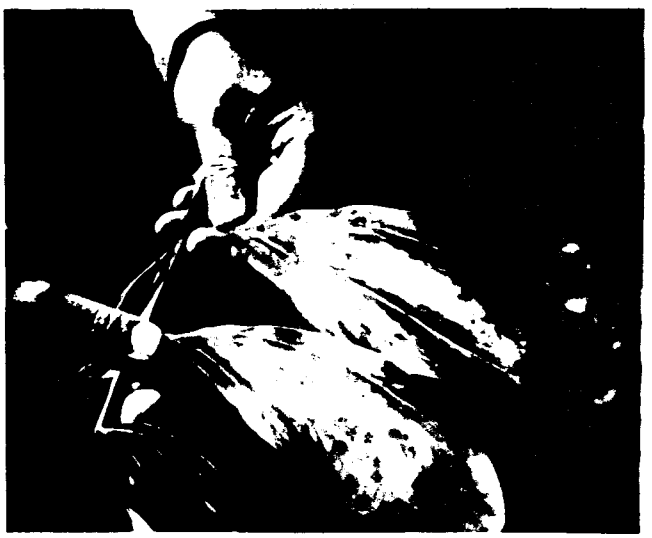


Plate 10.11. Sooty mold forming thin, black patches of hyphae on the leaf surface.

Symptoms

Sooty molds can occur on trunks, branches, twigs, leaves, and fruits. On *A. mangium* they are normally found on the upper leaf surface, occurring as a sparse, black network of hyphae or a thin, effuse, black, papery layer (Plate 10.11). Incidence of sooty mold on *A. mangium* is relatively low and usually confined to plants in nurseries and the lower foliage of two- to four-year-old trees. The molds tend to disappear as trees grow older and are not known to cause any serious reduction in tree vigor or growth.

Causal Organisms

The fungi causing sooty mold on *A. mangium* have not been identified. Several *Meliola* species, *Irenopsis bergrennii*, and other fungi are known from Australasia and the Far East, causing sooty mold on other *Acacia* species (Fraser 1935; Hansford 1955). *Meliola*, however, is now classified as an obligate parasite causing black mildew rather than sooty mold (Lim and Khoo 1985).

Leaf Spots and Leaf Lesions

Isolated cases of leaf spots and leaf lesions have been observed in several areas in Kemasul plantation, Peninsular Malaysia, usually in the dry months just after a long wet spell. These diseases have not been observed to cause heavy defoliation or growth retardation.

Symptoms

Symptoms on the foliage of adult trees are similar to those on phyllodes of seedlings (see Plate 10.4 and Symptoms paragraph for leaf spots on seedlings).

Causal Organisms

Fungi most frequently isolated were *Glomerella cingulata*, *Khuskia oryzae*, and *Pestalotiopsis neglecta* (Maziah 1990).

Etiology and Control

Fungi causing leaf spots and leaf lesions on *A. mangium* belong to the group of Fungi Imperfecti. The mode of dispersal and spread of such fungi are discussed in the section on leaf spots and leaf lesions of seedlings.

Usually control is not warranted as the diseases are not serious. If necessary, fungicide sprays may be applied, but this can be uneconomical and of limited use, especially if the trees are tall and the areas extensive.

Other Tree Diseases

Dieback

A dieback disease due to unknown causes has been reported in Sabah (Khamis 1982). All trees growing on poor podzolic soil at Bunang, Sook, exhibited shoot tip dieback with yellow and premature defoliation. A hardpan was found 40 cm beneath the soil surface. There were no further reports of the condition of the trees thereafter. The symptoms and conditions under which the trees were growing would appear to indicate impeded root growth, resulting in the manifestation of the visual symptoms.

Peeling and removal of the bark by squirrels has also caused dieback of *A. mangium* trees planted in a golf course. The terminal branches wilt and die above the girdled portion where the bark has been removed. The trees often produce epicormic shoots below the girdled portion; repeated damage results in low bushy trees with staghorn-like dead branches.

Stem Canker

In Thailand, a stem canker on the lower bole of *A. mangium* has caused bark rupture (Choldumrongkul et al. 1990). However, that report does not mention the extent or severity of the disease, or its cause.

Thelephora ramarioides Reid

Basidiomes of *Thelephora ramarioides* Reid are often found growing in association with *A. mangium* seedlings raised in polybags in the nursery. Initially, researchers thought that the fungus was mycorrhizal with *A. mangium*. However, anatomical studies revealed that the fungus was a facultative parasite on the roots of the host (Lee 1990). It is probably a nuisance fungi like *Thelephora terrestris* in temperate pine nurseries.

There is a brief report of *Clavaria* sp. being ectomycorrhizal with *A. mangium* in the Philippines (Anino 1992), but the information given is insufficient to permit any conclusions regarding its identification as an ectomycorrhizal fungus.

Diseases Caused by Noninfectious Agents

Noninfectious diseases are caused by abiotic (non-living) agents. There has been considerable debate about what should be considered a disease, injury, or disor-

der; the confusion is best summarized by Blanchard and Tattar (1981): the disorder expressed by a diseased tree may be the result of chemical injury. In any case noninfectious agents cause tree health problems which then become the concern of the tree pathologist.

Noninfectious diseases of trees are environmentally induced. Temperature and moisture extremes, nutrient abnormalities, and people-pressure diseases (PPD)(Blanchard and Tattar 1981) such as air pollution, chemical injury, and construction injury are well-known abiotic disease agents. Noninfectious diseases are recognized by their uniform symptom expression and the lack of progressive symptom development on the plant.

Although few noninfectious diseases have been observed on *A. mangium*, one should still be able to recognize them and be aware of their damage potential. The main ones observed on *A. mangium* are caused by drought and fire. Herbicide injury has also been observed, but noninfectious diseases due to PPD have yet to be reported.

Drought-stressed *A. mangium* seedlings wilt but recover when watered, unlike seedlings suffering from root rot or vascular wilt. The foliage may become chlorotic and the trees may lose their leaves. In prolonged drought, seedlings may die.

A. mangium trees damaged by fire may recover if the fire is not too intense, but sublethal temperatures may reduce tree vigor and predispose them to attack by infectious agents. Symptoms of fire damage are scorched foliage and bark, fissured bark, and dieback. Fissures in the bark become infection courts for infectious agents and insects. Extensive borer infestation has been observed in outwardly healthy *A. mangium* trees about six months after a fire. Signs of a fire may also include charred debris and charred tree bark.

Sudden exposure of previously shaded seedlings and trees to sunlight can also cause scorching of leaves, scalding of bark, and dieback.

Future Research

Much remains to be studied on the effects of local site and environmental conditions on the incidence and spread of infectious diseases in *A. mangium*. In particular, the incidence and spread of root (and butt) rot and heart rot need to be studied in detail, ideally using comparable techniques in all countries where *A. mangium* is grown in plantations. This would provide a better understanding of the pathogens involved, their mode(s) of infection, and rate of spread in relation to host provenance, local weather and climatic conditions, soil factors such as fertility and moisture availability, and microsite conditions.

Summary

The diseases of *A. mangium* seedlings are common seedling diseases of many tree species, with the possible exception of bacterial stem galls. Such diseases and an occasional disease outbreak in any seedling nursery is not uncommon and can usually be controlled using conventional nursery management techniques and prophylactic fungicidal sprays. However, economic costs should be carefully weighed against the potential benefits of chemical control.

As the plants grow older, it is increasingly apparent that *A. mangium* is susceptible to several diseases, most notably heart rot and root rot. Heart rot has been reported in plantations in Sabah and Peninsular Malaysia; root rot has been reported from plantations in Sabah, Peninsular Malaysia, and Papua New Guinea. Although the incidence of heart rot is high in Peninsular Malaysian plantations, the figures are much lower in Sabah. Could this be due to differences in site conditions and/or genetic factors? Root rot, however, appears to be more widespread, reported not only in Malaysia but also in Papua New Guinea. Its incidence appears to be site related. Control of both these diseases is difficult, however, and other management strategies may have to be employed.

The occurrence of pink disease, on the other hand, appears to be closely related to local environmental conditions; it is prevalent only in Sarawak and has very minor impact elsewhere.

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References

Almonicar, R.S. 1992. Two types of root rot diseases affecting *Acacia mangium*. *NFT Res. Rpts* 10:94-95.

Amino, E.O. 1992. Natural ecto-mycorrhiza of *Acacia mangium*. *NFT Res. Rpts* 10:96.

Aniwat Chalermpongse. 1987. Current potentially dangerous forest tree diseases in Thailand. In *Forest Pests and Diseases in South East Asia*, eds. E.D. de Guzman and S. Taka Nuhamara; 77-90. BIOTROP Special Publication No. 26. Bogor, Indonesia: BIOTROP.

Aniwat Chalermpongse. 1990. Introduction to forest pathology in Thailand. In *Proceedings of the IUFRO Workshop on Pests and Diseases of Forest Plantations in the Asia-Pacific Region*, eds. C. Hutacharern, K.G. MacDicken, M.H. Ivory, and K.S.S. Nair; 107-113. RAPA Publication 1990/9. Bangkok, Thailand: FAO-RAPA.

Arentz, F. 1986. Forest Pathology Lecture Notes. Papua New Guinea Forestry College, Bulolo.

_____. 1990. Diseases of forest plantation trees in Papua New Guinea. In Proc. 3rd. Int. Conf. Pl. Prot. in Tropics, Vol IV. Genting Highlands; 151-155.

Blanchard, R.O. and T.A. Tattar. 1981. *Field and Laboratory Guide to Tree Pathology*. New York: Academic Press.

Bowen, M.R. and T.V. Eusebio. 1982. Seed handling practices: Four fast-growing hardwoods for humid tropical plantations in the eighties. In Proc. 8th Malaysian Forestry Conference, Kota Kinabalu; 406-428.

Chin, F.H. 1986. *Meloidogyne* spp. - Cause of root knot of *Acacia mangium* Willd. seedlings. Forest Research Report No. FP4. Kuching, Sarawak, Malaysia: Sarawak Forest Department.

Chin, F.H. 1990. Pink disease - its incidence and economic importance in Sarawak, Malaysia. In Proc. 3rd. Int. Conf. Pl. Prot. in Tropics, Vol IV. Genting Highlands; 156-160.

Choldumrongkul, A., C. Hutacharern, and P. Pholwicha. 1989. Response of multipurpose tree species towards insects and disease. In *Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sh. Ali Abod, Paridah Tahir, M.T. Lim, Nor Aini Ab. Shukor, Ahmad Said Sajap and Doraisingan Manikam; 514-521. Serdang, Malaysia: Universiti Pertanian Malaysia.

Chou, C.K.S. 1991. Perspectives of disease threat in large-scale *Pinus radiata* monoculture - the New Zealand experience. *Eur. J. For. Path.* 21: 71-81.

Fraser, L. 1935. An investigation of the sooty molds of New South Wales. III. The life histories and systemic positions of *Aithaloderma* and *Capnodium* together with description of new species. IV. The species of Chaetothyriae. *Proc. Linn. Soc. New South Wales* 60: 79-118.

Gibson, I.A.S. 1981. Seed source establishment and tree improvement - Sabah, Malaysia. Forest Mycology Consultant's Report No. 3. FAO/UNDP-MAL/78/009. Rome: FAO. 45 pp.

Hansford, C.G. 1955. Tropical fungi. IV. New species and revisions. *Proc. Linn. Soc. London* 165:166-177.

Hashim Md. Noor, Maziah Zakaria, and Sh. Ali Abod. 1989. The incidence of heart rot in *Acacia mangium* Willd. plantations: A preliminary observation. In *Malaysian Forestry and Forest Products Research*, eds. S. Appanah, F.S.P. Ng, and Roslan Ismail; 54-59. Kepong, Malaysia: FRIM.

Hubbes, M. 1992. Forest pathology of the future. Paper presented at IUFRO Div. 5 Meeting, Nancy, France.

Ito, S. 1991. A survey of heart rot in *Acacia mangium*. Report to SAFODA. Sabah, Malaysia: Sabah Forest Development Authority.

Khanis, S. 1982. Pests and diseases of forest plantation trees with special reference to SAFODA. In Proc. 8th Malaysian Forestry Conference, Kota Kinabalu; 512-524.

Kiyoshi Tanaka and Aniwat Chalermpongse. 1990. Notes on forestry nursery diseases in Thailand. In Proc. 3rd. Int. Conf. Pl. Prot. in Tropics, Vol IV, Genting Highlands; 161-163.

Lee, S.S. 1985. Tree diseases and wood deterioration problems in Peninsular Malaysia. Occasional Paper No. 5. Serdang: Faculty of Forestry, Universiti Pertanian Malaysia.

Lee, S.S. 1986. Discoloration of the heartwood of *Acacia mangium* - A preliminary report. In Proc. 2nd. Int. Conf. Pl. Prot. in Tropics; 331-332.

_____. 1990. The association of *Thelephora ramarioides* Reid with *Acacia mangium* Willd. In Proc. 3rd. Int. Conf. Pl. Prot. in Tropics, Vol IV, Genting Highlands; 171-173.

Lee, S.S. and L.K. Goh. 1989. Seedling diseases of *Acacia mangium* Willd. and *Gmelina arborea* Roxb. in a forest nursery. In *Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sh. Ali Abod, Paridah Tahir, M.T. Lim, Nor Aini Ab. Shukor, Ahmad Said Sajap, and Doraisingan Manikam; 505-513. Serdang, Malaysia: Universiti Pertanian Malaysia.

Lee, S.S. and Maziah Zakaria. 1993. Fungi associated with heart rot of *Acacia mangium* Willd. in Peninsular Malaysia. *J. Trop. For. Sci.* (in press).

Lee, S.S., S.Y. Teng, M.T. Lim, and Razali Abd. Kader. 1988. Discoloration and heart rot of *Acacia mangium* Willd. - Some preliminary results. *J. Trop. For. Sci.* 1(2):170-177.

Liew, T.C. 1985. Present state of knowledge and research priorities of forest plantations in Sabah. In Proc. Seminar on Forest Plantation Development in Malaysia, eds. T.C. Liew, M.P. Udarbe, H.T. Tang, R.I.E. Tang, and Y.F. Lee; 83-98. Sabah: Forest Department, Sabah.

Lim, T.K. and K.C. Khoo. 1985. *Diseases and Disorders of Mango in Malaysia*. Kuala Lumpur: Tropical Press.

Manion, P.D. 1981. *Tree Disease Concepts*. New Jersey: Prentice-Hall, Inc.

Maziah Zakaria. 1990. Diseases of forest plantation species in Peninsular Malaysia. In *Pests and Diseases of Forest Plantations in the Asia-Pacific Region*, eds. C. Hutacharern, K.G. MacDicken, M.H. Ivory, and K.S.S. Nair; 94-99. RAPA Publication 1990/9. Bangkok: FAO-RAPA.

National Research Council. 1983. *Mangium and Other Acacias for the Humid Tropics*. Washington, D.C.: National Academy Press.

Noram Ahmad. 1987. Current potentially dangerous diseases of plantation trees and ornamental trees in Malaysia. In *Forest Pests and Diseases in South East Asia*, eds. E.D. de Guzman and S. Taka Nuhamara; 105-117. BIOTROP Special Publication No. 26. Bogor, Indonesia: BIOTROP.

Sahashi, N. and J. Mukiu. 1992. Preliminary report on some tree diseases in Papua New Guinea. Lae: PNG Forest Research Institute. 15 pp.

Thomas, K.I. and G.A. Kent. 1986. Report submitted to Sepilok Forest Research Centre, Sabah Forest Department.

Chapter 11

Properties and Utilization

Razali Abdul-Kader and Mohd. Hamami Sahri

Introduction

Acacia mangium wood can be used in solid form, in wood-based panels, or in pulp and paper-making. Increasingly, with advanced utilization technologies like those used in processing small-diameter rubberwood logs, the options for utilization of *A. mangium* are broadening to include wood composite materials. The growing scarcity of large-diameter hardwood logs will continue to drive advances in these technologies that use suitable fast-growing species like *A. mangium*. In many cases, the technologies are already available to process the wood into highly desirable commercial products.

This chapter discusses the basic properties of *A. mangium* wood and the panel products into which it can be converted, as well as chemical and other nonconventional products.

Wood Properties

Anatomical Properties

A. mangium is a diffuse, porous wood. Its basic anatomical description is outlined below (Peh and Khoo 198;, Wu et al. 1988; Wu and Wang 1988; Mohd. Hamami et al. 1992).

Growth rings: Rather indistinct

Parenchyma: Parenchyma tissue is distinct under a hand lens and lighter in color than the fiber cells. It is of paratracheal type, some conspicuously surrounding the vessels or vessel groups, whereas the others consist of narrow sheaths around the vessels. Some axial parenchyma cells contain crystal deposits of calcium compounds.

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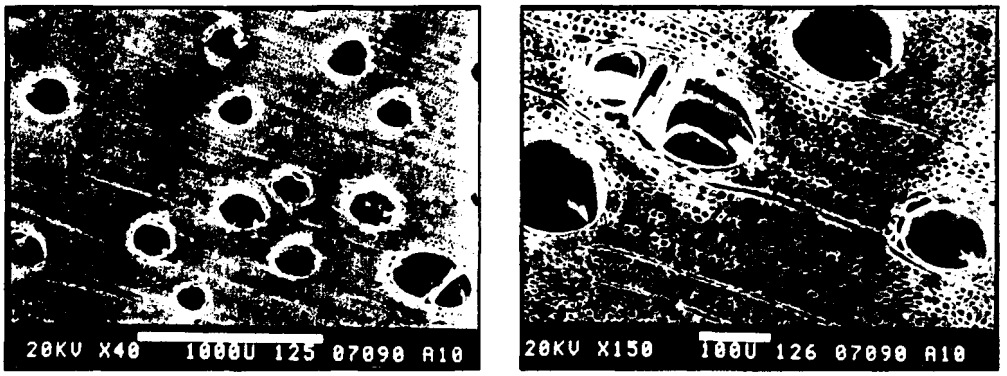
Rays: Ray tissue is rather fine and distinct under a hand lens and lighter in color than fiber cells. It is widely spaced and uniformly distributed. Barely visible to the naked eye on cross section and not prominent on radial surface.

Fibers: A fiber of *A. mangium* is imperforated, axially elongated and tapered to pointed tips. Fiber length and the length-width ratio are shorter and lower than for other hardwoods. The average cell-wall thickness ranges from 3.3 to 4.2 micrometer (μm).

Vessels: Simple perforation, medium sized to moderately large; few to moderately few in number; mostly solitary; the rest in radial pairs and radial multiples of three (rarely more); 6-8 vessels/mm^2. Diffused with a tendency to align in oblique lines; tyloses generally absent; gumlike deposits present (Plates 11.1 and 11.2).



Plates 11.1-2. Scanning electron micrographs showing: (left) the distribution pattern of axial parenchyma tissue-vasicentric paratracheal type; (right) solitary and multiple vessels and thick-walled fiber cells.

Physical Properties

Ong (1984) has reported that green wood moisture content varies from 75% at the top of the trunk to 105% at the bottom. In that study the moisture content was not affected by sites, but there were considerable differences between the trees growing on similar sites.

A. mangium has distinct sapwood and heartwood (Plate 11.3); the former is light cream in color and the latter is dark brown. The wood is hard, dense, and straight grained. The density ranges from 420-483 kg/m^3 based on green soaked volume; at dry condition it varies between 500-600 kg/m^3 (Razali and Kuo 1991; Wang et al. 1989; Peh and Khoo 1984; Logan and Balodis 1982; Peh et al. 1982). Sining (1988) noted that plantation-grown timber shows a lower range of air-dry specific gravity (i.e., 0.43-0.47) for six-year-old plantation wood from Sabah. It is a fairly stable timber with green to air-dry shrinkage of 6.4% tangentially and 2.7% radially (Salleh and Wong 1991). Ong (1985) recorded lower shrinkage values of 2.61% for tangential and 1.35% for radial directions.

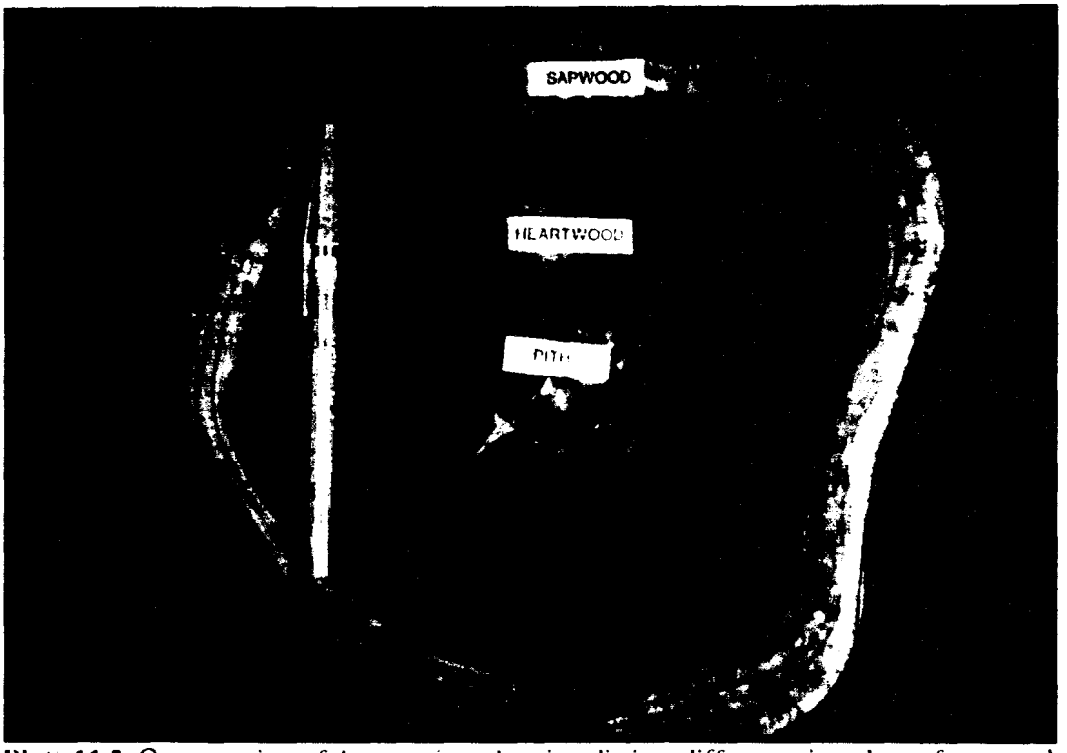


Plate 11.3. Cross section of *A. mangium* showing distinct difference in colors of sapwood and heartwood.

Fiber Morphology and Paper-making Properties

The basic fiber morphology of *A. mangium* has been well studied and is summarized in Table 11.1.

Table 11.2 summarizes the proximate chemical composition of *A. mangium*. Generally, the chemical composition indicated in the table does not reflect any unfavorable features for use in pulping, although the holocellulose, alpha-

Table 11.1. Fiber morphology of *Acacia mangium*.

	Value
Fiber length	0.94-1.12 mm
Fiber width	21.8-25.0 um
Fiber lumen	16.3-18.8 um
Fiber wall thickness	3.3-4.2 um
Runkel ratio	0.32-0.34
Coefficient of suppleness	74.5-75.3
Felting power	37.7-51.3

Sources: Mohd. Hamami et al. (1992); Pensook (1990); Alloysius (1989); Logan and Balodis (1982); Peh et al. (1982)

Table 11.2. Proximate chemical composition of *Acacia mangium*.

Chemical Constituents	%
Holocellulose	69.4-73.8
Alpha-cellulose	44.0-49.5
1% NaOH Solubles	11.4-14.8
Hot water solubles	0.9-9.8
Pentosans	16.0-18.2
Ash	0.33-0.68
Lignin	19.7-25.0

Sourrces: Alloysius (1989); Jegatheswaran (1988); Peh et al. (1982); and Khoo et al. (1991)

cellulose and pentosans contents are slightly lower than average temperate hardwood (Khoo et al. 1991).

Mechanical Properties

A. mangium falls under the Light Hardwood classification, i.e., with low to moderate strength properties. Table 11.3 shows the basic mechanical properties of 12-year-old *A. mangium* compared with other popular furniture species. With younger stock, Wang et al. (1989) indicated marginally lower strength properties:

MOR (modulus of rupture) = 74.5 N/mm^2

MOE (modulus of elasticity) = 9,908 N/mm^2

Mohd. Zin et. al. (1991), however, indicated that the strength properties of *A. mangium* are not affected by tree age. Their study also revealed that the values of specific gravity, MOR, MOE, and shear parallel to the grain were significantly different within trees of the same age (Table 11.4).

Nonetheless, with good machining properties, *A. mangium* makes good furniture timber. Peh and Khoo (1984) found no problems in sawing the wood, and the timber planes well and results in a smooth and lustrous surface. Sanding is easy, with no problem of torn fibers. *A. mangium* is also easy to drill and turn, as long as the turning pressure is not excessive (NRC 1983).

Solid Wood Utilization

A. mangium wood makes attractive furniture and cabinets, moldings, and door and window components (NRC 1983). The timber kiln dries well and fairly rapidly, without serious defects when suitable kiln schedules are used. The wood is also suitable for light structural works, agricultural implements, boxes, and crates.

Chan (1983) reported low sawing recovery rate, ranging from 37-40% for sawn timber production. Recovery can be increased by modifying the sawing technique; a 49.7% yield was achieved using "modified live sawing," compared with 34.6% using conventional live sawing (Anon. 1984). The low recovery could be attributed to four factors: small diameter of sample logs, fluting, knots, and heart rot. Some 93% of the knots were considered unsound and the frequency of knots was between 1-1.5 per m length.

A. mangium has a high incidence of knots, which causes good-quality sawn timber to be unobtainable in significant quantities. Knots can be eliminated through proper pruning regimes. The presence of flutes and incidence of rots and termite attack all detract from both the quality and quantity of sawn timber

Table 11.3. Strength properties of *Acacia mangium* and some popular furniture species.

Species	Density (Kg/m³)	Static Bending		Compression parallel to grain (N/mm)	Compression perpendicular to grain (Stress at limit of proportionality)	Side-Hardness (load to embed 0.0113 diameter steel sphere to half its diameter) (N)	Shearing strength parallel to grain (N/mm)
		Modulus of rupture (N/mm)	Modulus of elasticity (N/mm)				
Hevea brasiliensis	650	66.0	9,240	32.2	4.69	4,350	11.0
Shorea platyclados	610	77.0	12,100	30.6	4.14	3,650	8.7
Shorea leprosula	575	75.0	13,600	41.4	2.51	2,940	6.8
Sindora coriacea	690	92.0	13,600	46.3	5.93	5,210	13.6
Palaquium gutta	675	79.0	12,200	44.5	-	5,430	11.0
Gonystylus bancanus	675	88.0	15,900	48.8	-	4,500	8.5
Acacia mangium (12-year-old firebreak)	570	97.0	10,891	43.4	-	3,550	6.8

Source: Razali and Hamami (1992)

Table 11.4. Mechanical properties* of *Acacia mangium* grown in three sites in Malaysia.

Location	Age (years)	Specific Gravity	Static Bending (N/mm^2) Fiber Stress	Modulus of Rupture	Modulus of Elasticity	Maximum Compressive Stress Parallel to the grain (N/mm^2)	Maximum Shear Parallel to the grain (N/mm^2)
Lahad Datu, Sabah	9	0.48	56.39	113.50	10718.00	43.31	17.28
S.D.		0.04	9.69	20.30	2401.00	6.20	2.04
c.v.		9.27	17.18	17.29	17.89	13.11	11.81
Sabal Plantation, Sarawak	8	0.48	56.39	97.00	9544.00	45.22	17.27
S.D.		0.05	7.85	15.00	1397.00	3.89	2.16
c.v.		17.18	16.08	15.46	14.64	11.81	12.51
Kemasul C.P., P. Malaysia	6	0.52	46.16	102.40	10771.00	48.49	15.81
S.D.		0.06	8.19	11.90	1248.00	6.08	2.45
c.v.		10.33	17.74	11.52	11.90	12.54	15.81

*Properties adjusted at 12% moisture content. *Source*: Mohd. Zin et al. (1991)

obtainable from *A. mangium* logs (Chan 1983). Tree improvement work should therefore aim to produce trees of better form with resistance to termites and fungal attack.

A. mangium timber is generally regarded as non-durable. Nilsson (1982) noted the uneven microdistribution of copper chrom arsenate (CCA) preservative in its fibers. The treated wood may not give good performance in ground contact. It has a relatively narrow sapwood band and is not a suitable species to be used for exterior and outdoor purposes.

Composite Wood Products

Due to some of the constraints mentioned above and changes in wood utilization technology, *A. mangium* has greater potential as a component of composite wood products. Furthermore, in view of the changing picture of available wood resources, composite products in general will become increasingly important in meeting the demand for wood products.

Composite wood products (or simply, wood composites) make up a family of materials distinct from solid wood; they are composed of wooden elements of varying sizes (including fibers), held together by an adhesive bond. The bonding agent is either natural or synthetic in origin. The following are some examples of the products that have been made using *A. mangium*.

Veneer and Plywood

The conversion of *A. mangium* into veneer and plywood is feasible with no specific processing requirements needed. In conventional rotary peeling studies by Wong et al. (1988), Chai (1989), and Salim (1992), the peeling process was rated as easy and the green veneers produced were tight, smooth, and of acceptable quality. They dried easily following the normal commercial species schedule to the desired moisture content. The green veneer recovery however, was found to range from 35-45%. This fairly low return could be due to the facts that the logs were young (7-15 years old) and small in diameter with fluted boles. Wong et al. (1988) and Chai (1989) also found numerous knot marks, and some sapwood veneers marred with borer holes.

At present, not many plywood plants have the facilities to peel small-diameter logs. In Malaysia, for example, only six or seven companies have such equipment. But as the appropriate processing technologies become more available, the authors believe that better recovery will be obtained. Improved tree form and knot reduction through silvicultural practices will further improve the recovery from peeling.

On the production of decorative veneers from *A. mangium* , the slicing of green flitches was also rated as easy and the veneers were smooth even around

Table 11.5. Knife tests of urea and phenolic-bonded plywood from *Acacia mangium* (UF Board: pressed for 3 min at 100°C; PF Board: pressed for 6 min at 109°C).

Adhesive	DRY	INT	BR	MR	WBP
Urea	7	4	-	1	-
Phenol	8	-	7	-	6

DRY= dry condition; INT = interior condition; BR = boil-resistant condition; MR = moisture resistant condition; WBP = weather-boil-proof. *Source:* Wong et al. (1988)

the solid knots (Wong et al. 1988). The thin veneers (0.26-0.28 mm) dried well to the desired moisture content.

Table 11.5 shows the results of the knife tests of plywood bonded with standard amount of urea formaldehyde (UF) and phenol formaldehyde (PF) resin adhesives (Wong et al. 1988). The evaluation, carried out in accordance with the British Standards, indicated that the UF plywood was poor when tested under the moisture-resistant (MR) condition. Under the less severe interior (INT) condition, the performance was just below the acceptable grade. The knife tests for those panels bonded with PF resulted in acceptable quality under the weather-boil-proof (WBP) grade and very good results were obtained when tested under the boil-resistant (BR) procedures. On the whole, these trials showed that the PF panels were of acceptable quality but the UF-bonded plywood were unsatisfactory. In order to improve the MR on INT grade panels, the UF resin adhesives need to be reformulated to suit the substrates, or the woods need to be physically reevaluated to identify a compatible environment. In a study on the wettability of *A. mangium* veneers, Chai (1989) indicated that PF resins would be more favorable with *A. mangium*. Similar results were obtained by Mohd. Hamami et al. (1991), who worked on wood lamination, and Salim (1992), who worked on laminated veneer lumber (LVL)(Table 11.6).

Wong et al. (1988) rated as attractive trial decorative or fancy plywood panels made using *A. mangium* sliced veneers as the faces. No difficulty was encountered in assembling the panels. Although the panels had more knots than sliced *Tectona grandis* and *Palaquium xanthochymum* decorative plywood, the plywood is nonetheless suitable for panelling, cabinets, and furniture manufacture. Sliced *A. mangium* veneers should also be suitable for veneer-wrapping works if compatible adhesives are employed.

Table 11.6. The average glue line shear strength and wood failure of different species combinations glued with phenol-resorcinol formaldehyde (PRF) and urea formaldehyde (UF) under dry condition[1].

Species combination	Shear strength (MPa)		Reduction in shear (%) based upong PRF strength	Wood failure (%)	
	PRF	UF		PRF	UF
A. mangium - *A. mangium*	9.88 a	2.97 a	69.9	28 b	2
Paraserianthes falcataria - *P. falcataria*	5.28 d	5.22 d	1.1	84 a	85
Gmelina arborea - *G. arborea*	7.37 c	2.32 c	50.5	15 c	1
A. mangium - *P. falcataria*	5.58 d	4.91 c	6.5	91 a	73
A. mangium - *G. arborea*	8.36 b	2.91 a	65.2	26 b	1
P. falcataria - *G. arborea*	5.32 d	3.61 c	32.1	87 a	52

[1] Each reading is an average of 15 replicates. Means in the same column followed by the same letter are not significantly different at 0.05 level of confidence using Duncan's New Multiple Range Test.*Source:* Mohd. Hamami et al. (1991)

Laminated Veneer Lumber (LVL)

LVL is a material made by parallel lamination of veneers instead of placing adjacent veneer layers with their grains at right angles, as in plywood. LVL is generally fabricated to thicknesses common in solid sawn timber; the veneers currently used vary from 2 to 3.2 mm in thickness. Laminating lower strength timber (such as *A. mangium*) reduces the strength variability within the timber and consequently raises the strength value. This ultimately permits an increase in allowable working stresses (Plate 11.4).

Research in conversion of *A. mangium* into LVL, which has potential for structural applications, has been conducted by Sasaki et al. (1990), Wang et al. (1990), and Salim (1992). In all these trials, the results indicated that the LVL's bending and shear strengths were much greater than the minimum values required by Japan Agricultural Standards for first-grade structural LVL. The resin adhesives used were phenol formaldehyde and phenol melamine formaldehyde, which are exterior grade adhesives. The increase in the average bending strength and stiffness, as indicated in Tables 11.7 and 11.8, was partly due to increased density.

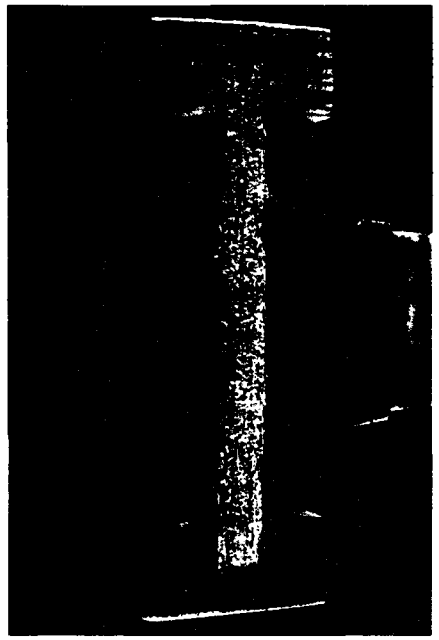


Plate 11.4. *A. mangium* laminated veneer lumber (LVL) used as the compression and tension layers in experimental I-beam. The web is particleboard from *Anthocephalus chinensis*.

Table 11.7. Shearing strength and delamination of LVL.

Species	Density (g/cm)	Moisture content (%)	Shearing strength (kgf/cm^2) Dry	Shearing strength (kgf/cm^2) Wet	Delamination (%)
Acacia mangium	AV 0.55	11.4	63.5	39.0	20.8
	SD 0.02	0.40	22.6	11.9	28.4
	CV 2.87	3.52	35.5	30.5	136
Eucalyptus deglupta	AV 0.50	11.6	43.0	33.1	5.63
	SD 0.02	0.59	2.91	3.27	2.55
	CV 4.52	5.05	6.67	9.88	45.3
Gmelina arborea	AV 0.56	11.1	80.4	52.7	7.38
	SD 0.01	0.27	9.91	3.67	2.67
	CV 1.61	2.41	12.31	6.96	36.2
Paraserianthes falcataria	AV 0.33	10.8	41.0	27.2	1.17
	SD 0.01	0.52	3.74	2.47	3.32
	CV 4.31	4.76	9.14	9.07	283

Source: Wang et al. (1990)

Table 11.8. Shear strength, bending strength and stiffness of solid wood and LVL.

	Solid Wood (N/mm^2)			LVL (N/mm^2)		
Species	Shear strength	MOE	MOR	Shear strength	MOE	MOR
Acacia mangium	10.40	10,100	75.9	9.17	28,951	205
Hevea brasiliensis	11.0	9,200	66.0	8.34	27,716	141
Dipterocarpus spp.	9.2 -	22,300	133.0	10.69	40,984	218

Source: Salim (1992)

Particleboard

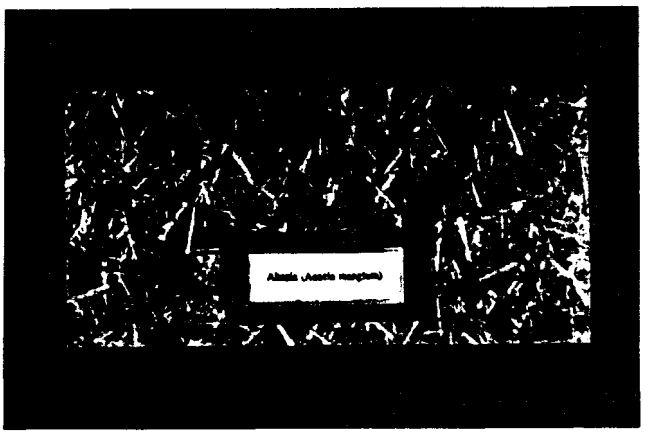


Plate 11.5. Particleboard (flakeboard) from *A. mangium*. Note the distinct colors of the sapwood and heartwood particles.

Woods of different-aged *A. mangium* have been successfully converted into particleboards bonded with urea formaldehyde and isocyanate resin adhesives. Chew et al. (1991) demonstrated that single-layer *A. mangium* boards, or three-layer boards in mixture with other species, could be fabricated to exceed the minimum strength requirements of Type 1 board of the British Standards. Similarly, Razali and Kuo (1991) found that particleboards made from thinnings of *A. mangium* singly or in mixture with *Gmelina arborea* had strength properties exceeding the Type 200 board of the Japanese Industrial Standards specifications for particleboard. Increasing the density and resin content of the panels resulted in a corresponding increase in mechanical properties. *A. mangium* is suitable for conversion into low- and medium-density particleboards, and if the panel color is considered not attractive enough (due to the darkness of the heartwood)(Plate 11.5), the boards can easily be overlaid with veneer or other resin-impregnated papers.

Cement-Bonded Particleboard (CBP)

Besides resin adhesives, wood particleboard can also be bonded using mineral binder, such as ordinary portland cement. A few researchers have investigated

Table 11.9. Bending strength (kgf/cm^2) of cement-bonded particle boards.

	Ordinary portland cement				Rapid hardening portland cement			
Species	CaCl	MgCl	FeCl	AlCl	CaCl	MgCl	FeCl	AlCl
Paraserianthes falcataria	148.2	159.5	145.6	146.4	152.8	194.2	175.6	169.9
Acacia mangium	13.6	126.4	110.4	115.0	98.3	154.6	148.2	133.4
Eucalyptus deglupta	97.1	89.2	78.1	87.9	104.7	108.3	87.6	93.4
Gmelina arborea	121.2	122.0	123.3	127.9	143.0	134.5	127.6	129.6
Chamaecyparis obtusa	138.0	132.6	158.9	137.0	160.8	159.5	150.4	159.2

the variables involved in manufacturing cement-bonded particleboard. Tachi et al. (1988), Rahim and Wan Asma (1989), and Rahim et al. (1991) studied the effects of various wood-to-cement ratios and chemical additives (cement-hardening accelerators) on board properties. Table 11.9 shows the bending strength of CBP made from *A. mangium* and other plantation species having a wood:cement ratio of 1:2.5 (w/w) and accelerator:cement ratio of 0.02:1 (w/w). CBP of *A. mangium* is best when added with magnesium chloride or aluminum chloride hardening accelerators. The bending strength is lowest when ordinary portland cement and calcium chloride were used as accelerator.

Tachi et al. (1989) later found that mangium has a cement-hardening inhibitory component called teracacidin, with 7, 8 - dihydroxyl group in a leucoanthocyanidin structure, which retards hardening even in the presence of calcium chloride. Rahim and Wan Asma (1989) reported *A. mangium* to have a low sugar content (only 0.54%) below the cement-setting inhibition level of 0.5-0.6%. On the other hand, Jegatheswaran (1989) investigated the effects of particle pretreatment with 1% sodium hydroxide solution on the final board properties. Pretreatment of wood particles promoted better adhesion between wood and cement binder. The research indicated that the mechanical properties increase with increasing cement content, and that pretreated particles have better strength properties than the controls.

Medium Density Fiberboard (MDF)

Research in converting *A. mangium* into MDF has been conducted by Tomimura et al. (1987), Khoo and Matsuda (1990), and Pensook (1990). Wood chips were cooked under different conditions to produce acceptable quality fibers. Boards bonded with urea, urea melamine, and isocyanate resin adhesives were found to

meet various grade requirements of the Japanese Industrial Standards (JIS A5906) for MDF. The boards' mechanical properties were greatly influenced by the density, and isocyanate proved superior to other adhesives tested for MDF. Furthermore, MDF made from *A. mangium* were better than those of Japanese softwoods studied: *Pinus densiflora* (Akamatsu), *Cryptomeria japonica* (Sugi), *Chamaecyparis obtusa* (Hinoki), and *Larix leptolepis* (Karamatsu)(Tomimura et al. 1987).

Chemical Uses

Pulp and Paper

The pulping and paper-making properties of *A. mangium* have been studied in depth by Logan and Balodis (1982), Peh et al. (1982), Khoo et al. (1991), and Alloysius (1989). With 25% sulphidity and active alkali of 11-12%, sulphate pulping yields were 46.9-49.6% for four-year-old materials and 49.8-52.3% for nine-year-old materials, with Kappa Number below 25. The neutral sulphite semi-chemical (NSSC) pulping of *A. mangium* gave yields of 61-75%. Logan and Balodis (1982) concluded that the paper-making properties of *A. mangium* and *A. auriculiformis* are generally similar, but the former was postulated to fetch a lower free on board (FOB) price for wood chip export. *A. mangium* is currently being grown with primary use for pulp and paper in Sumatra, Sabah, and Vietnam.

Tannin and Fuel

Preliminary investigations on the bark properties of *A. mangium* have shown that it has good reactivity towards formaldehyde, and therefore should have good adhesive properties. Chew et al. (1992) noted that 5- to 9-year-old *A. mangium* barks have high tannin content (18-39%), justifying possible commercial exploitation of the tannins. They also found that hot water could be used as the most economical and suitable solvent for tannin extraction (Table 11.10).

Although the tree has generally not been grown in plantations for fuelwood, it appears well suited for this purpose. *A. mangium* wood produces relatively high calorific value (4,800-4,900 KCal per kg) and the wood makes good fuel (Mohd. Hamami et al. 1989). It produces reasonably good-quality charcoal and is suitable for the manufacture of charcoal briquettes and activated carbon.

Table 11.10. Extractive and Tannin contents of *Acacia mangium* barks of different age groups and locations in Malaysia.

Sample	Tree age (yrs.)	Source	Hexane (%)	Ethyl Alcohol (%)	Acetone (%)	Methanol (%)	Total (%)	Tannin (%)
A	5	Forestry Headquarters	0.9	9.2	7.0	11.9	29.0	32.9
B	5	Kemasul	0.6	10.4	14.5	19.2	44.7	31.6
C	6	Kinarut	1.3	9.5	13.2	8.6	32.6	15.9
D	6	Karamatoi	0.8	20.2	17.9	2.8	41.7	28.2
E	7	Batu Arang	0.4	11.2	13.2	16.2	41.0	27.7
F	7	Bukit Hari	0.4	9.1	5.3	11.4	26.2	18.4
G	7	Ulu Sedili	0.6	9.6	9.8	17.6	37.6	39.1
H	8	Melima	1.3	16.3	14.8	12.8	45.2	25.3
I	9	Sandakan	0.7	6.6	7.7	7.3	22.3	18.2
J	9	Kinarut	1.3	10.7	15.4	7.9	35.3	19.1

Source: Chew et al. (1992)

Use of Foliage

Although it is not recognized as a fodder species, there is evidence that young shoots are browsed by buffaloes and cattle. A preliminary study indicates that the species has a high crude protein content but low in *in vitro* dry matter digestibility (Table 11.11). Compared to species like *Leucaena leucocephala, Cassia siamea,* and *Gliricidia sepium,* this suggests that *A. mangium* ranks very low as a fodder species.

Table 11.11. Chemical characteristics and *in vitro* dry matter digestability of *A. mangium* leaf tissues.

Moisture (%)	Crude fiber (%)	Fat (%)	Ash (%)	Crude protein (%)	Carbo-hydrate (%)	Phos-phorus (%)	Potass-ium (%)	IVDMD* (%)
9.41	23.09	4.39	4.22	15.26	43.62	0.22	0.61	8.59

**In vitro* dry matter digestability *Source*: Yantasath et al. (1992)

Future Research

Future demand for wood products and their supply will be affected by increasing environmental consciousness, concern over endangered and rare species, and the openness of foreign markets. With these developments, tropical plantation forests will certainly play a growing lead role. Future research will continue to emphasize production of raw materials (logs) with fewer natural defects (fewer knots, straighter grain, and more rounded boles) to result in more competitive products in the open market. Research in developing new types of wood products will go hand-in-hand with new manufacturing and construction technologies, thus increasing the awareness in dealing with "new" raw materials. The needs to produce wood-based products in combination with synthetic materials, resulting in lightweight, strong, biodegradable (where necessary), and environment-friendly building materials, will enhance the utilization of plantation species like *A. mangium*.

Summary

Being small in diameter, the use of *A. mangium* wood in solid form may be limited. However, it is easily processed and glued for conversion into glued laminated timber products or laminated veneer lumber, where dimensions and strength can be controlled and tailored to detailed consumer demand specifications. It can also be converted to desirable panel products, for which the market is more universal, and pulp and paper. These products can be treated with wood preservatives if durability is questionable. The economics of processing and conversion, transportation, and marketing need further study.

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References

Alloysius, D. 1989. Pulp and paper properties of 4-year old *Acacia mangium*. B.S. For. Project Report, Faculty of Forestry, Universiti Pertanian Malaysia, Serdang.

Anon. 1984. Report on second sawing test of *Acacia mangium*. C. Itoh and Co. Ltd. (unpublished).

Chan, H.H. 1983. Graded sawn timber recovery study of *A. mangium*. Forest Research Centre Pub. No. 11. Sandakan, Sabah: FRC. 14 pages.

Chai, S.H. 1989. Wood and veneer quality studies of *Acacia mangium*. B. For. S. (Wood Industry) Project Report, Faculty of Forestry, Universiti Pertanian Malaysia, Serdang.

Chew, L.T., M.N. Nurulhuda, C.L. Ong, and S. Rahim. 1991. Particleboard from some plantation species. In *Recent Development in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 708-724. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

Chew, L.T., M.N. Nurulhuda, B. Saimin and N. Yamada. 1992. Chemical properties of *A. mangium* barks of different ages and locations. In Proc. Second Chemistry Div. Seminar, eds. W.A.K. Wan Rashidah et al.; 7-12. Kepong, Selangor: FRIM.

Jegatheswaran, R. 1989. Effects of extractives content reduction on some mechanical properties of *Acacia mangium* cement bonded board. M.S. Project Report, Faculty of Forestry, Universiti Pertanian Malaysia, Serdang.

Khoo, K.C. and T. Matsuda. 1990. Medium density fiberboard from some compensatory forest plantation species. Paper presented at the Joint FRIM-JICA Seminar, March 20, Kuala Lumpur, Malaysia.

Khoo, K.C., M.Y. Mohd. Nor, and T.W. Lee. 1991. Some compensatory forest plantation species for paper pulp. In *Recent Development in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 764-773. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

Logan, A.F. and V. Balodis. 1982. Pulping and papermaking characteristics of plantation-grown *Acacia mangium* from Sabah. *Malay. Forester* 45(2): 217-236.

Lee, Y.H., Engku Abdul Rahman Chik, and Y.P. Chu. 1979. The strength properties of some Malaysian timbers. Mal. For. Ser. Trade Leaflet No. 34 (revised ed.). Kuala Lumpur: Forest Department.

Mohd. Hamami Sahri, Razali Abdul-Kader, and T.K. Kee. 1991. Gluing properties of three fast growing plantation species. In *Recent Development in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 692-707. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

Mohd. Hamami Sahri, N. Ahmad Ainuddin, and L.C. Lee. 1991. Calorific value and the potential of some plantation species for energy production. In *Recent Development in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 809-820. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

Mohd. Hamami Sahri, F.H. Ibrahim, and A.S. Nor Aini. 1992. Anatomy of *A. mangium* grown in Malaysia. Paper presented at a conference on Diversity of Pacific Basin Woods: In Past, Present and Future, held August 14-16, 1992 in Hawaii.

Mohd. Zin, J., D. Jewan, and Mohd. Hamami Sahri. 1991. Physical and mechanical properties of *Acacia mangium* Willd. of selected ages grown in Malaysia. In *Recent Development in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 774-781. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

National Research Council. 1983. *Mangium and Other Acacias for the Humid Tropics*. Washington, D.C.: National Academy Press.

Nilsson, T. 1992. Microdistribution of wood preservatives. In *Development of Sawmilling, Kiln Drying and Preservation Research in Sabah*. FAO/UNDP-MAL/78/004 Field Document No. 4. Kuala Lumpur: FAO and UNDP.

Ong, S.H. 1985. Physical and mechanical properties of *Acacia mangium* timber from Ulu Kukut in Sabah. Forest Research Centre Pub. No. 23. Sandakan, Sabah, Malaysia: FRC.

Ong, S.H. 1984. Moisture content of wood in *Acacia mangium* living trees. Forest Research Centre Pub. No. 16. Sandakan, Sabah: FRC.

Peh, T.B. and K.C. Khoo. 1984. Timber properties of *Acacia mangium*, *Gmelina arborea*, and *Paraserianthes falcataria* and their utilization aspects. *Malay. Forester* 47(4):285-303.

Peh, T.B., K.C. Khoo, and T.W. Lee. 1982. Sulphate pulping of *Acacia mangium* and *Cleistopholis glauca* from Sabah. *Malay. Forester* 45(3): 404-418.

Pensook, S. 1990. Production and properties of isocyanate-bonded MDF manufactured from *Acacia mangium*. M.S. Project Report, Faculty of Forestry, Universiti Pertanian Malaysia, Serdang.

Rahim, S., L.T. Chew, S. Khozirah, and M.A. Zakaria. 1991. Cement bonded particleboard from some plantation species in Malaysia. In *Recent Development in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 725-738. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

Rahim, S. and I. Wan Asma. 1989. Cement bonded particleboard from *Acacia mangium* - A preliminary study. *J. Trop. For. Sci.* 2(4):267-273.

Razali Abdul-Kader and Mohd. Hamami Sahri. 1992. Processing and utilization of acacias, focussing on *Acacia mangium*. In *Tropical Acacias in East Asia and the Pacific*, eds. Kamis Awang and D.A. Taylor; 86-89. Proc. of a first meeting of the Consultative Group for Research and Development of Acacias (COGREDA) held in Phuket, Thailand, June 1-3, 1992. Bangkok: Winrock International.

Razali Abdul-Kader and H.S. Kuo. 1991. Properties of particleboards manufactured from fast-growing plantation species. In *Recent Development in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 685-691. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

Salleh, M.N. and W.C. Wong. 1991. Utilization of forest plantation trees. In *Recent Development in Tree Plantations of Humid/Subhumid Tropics of Asia*, eds. Sheikh Ali Abod et al.; 672-684. Proc. of a regional symposium held June 5-9, 1989 in Serdang, Malaysia. Serdang: Universiti Pertanian Malaysia.

Salim, A. 1992. Properties of laminated veneer lumber (LVL) manufactured from three selected tropical hardwood species. B.For.S. (Wood Industry) Project Report, Faculty of Forestry, Universiti Pertanian Malaysia, Serdang.

Sasaki, H., Q. Wang, S. Kawai, and Razali Abdul-Kader. 1990. Utilization of thinnings from Sabah hardwood plantation: properties of LVL and the application to flanges of composite beams with particleboards web. In *Proc. 1990 Joint International Conference on Processing and Utilization of Low-grade Hardwoods and International Trade of Forest-related Products*, eds. S.Y. Wang and R.C. Tang; 173-182. Taipei: National Taiwan Univ. Pub.

Siming, U. 1989. Some wood properties of *Acacia mangium* Willd. from three provenances grown in Sabah. M.S. Project Report, Faculty of Forestry, Universiti Pertanian Malaysia, Serdang.

Tachi, M., W. Nagadomi, J. Tange, S. Yasuda, and N. Terashima. 1988. Manufacture of wood cement boards II: Cement bonded particleboards from Malaysian fast-growing trees. *Mokuzai Gakkaishi* 34(9):761-764.

Tachi, M., J. Tange, W. Nagadomi, Y. Suzuki, N. Terashima, and S. Yasuda. 1989. Manufacture of wood-cement boards IV: cement-hardening inhibitory components of the Malaysian fast-growing tree, *Acacia mangium*. *Mokuzai Gakkaishi* 35(8):731-735.

Tonumura, Y., K.C. Khoo, and I. Suzuki. 1987. Manufacture of medium density fiberboard (MDF) from Malaysian *Acacia mangium*. *Mokuzai Gakkaishi* 33(4):335-338.

Wang, Q., H. Sasaki, and Razali Abdul-Kader. 1989. Properties of tropical fast-growing timbers from plantation thinnings in Sabah, Malaysia. Wood Research and Technical Note No. 25:45-51.

Wang, Q., T. Hayashi, H. Sasaki, and Y. Nagaya. 1990. Utilization of LVL from Sabah plantation thinnings as beam flanges I. *Mokuzai Gakkaishi* 36(8):624-631.

Wong, W.C., K.S. Ho, and C.N. Wong. 1988. *Acacia mangium* from Sabah for plywood and decorative panel manufacture: initial trials. *J. Trop. For. Sci.* 1(1):42-50.

Wu, S.C., R.S. Hsieh, and Y.J. Wong. 1988. Studies on the anatomical structure of *A. mangium*. *Q. J. Expt. Forest. N.T.U.* 2(2):27-42.

Wu, S-C. and Y-C. Wang. 1988. The wood properties of *Acacia mangium* and *Acacia auriculiformis*. *Q. J. Expt. Forest. N.T.U.* 2(4):59-88.

Yantasath, K., S. Patanawibul, W. Supatanakul, I. Ungwichian, and S. Chantrasiri. 1992. Field trials and multipurpose testings of selected fast-growing, nitrogen-fixing trees in Thailand. *Thai J. Ag. Sci.* 25:141-169.

Chapter 12

Economics and Market Prospects

Mohd. Shahwahid Haji Othman and Raymund Tan Get Seng

Introduction

Economic and marketing aspects are crucially important in stimulating development of a country's forest plantation sector. Research on these aspects can catalyze the private sector to participate in tree growing. This chapter examines the economic aspects of growing *A. mangium* . Two case studies from Malaysia illustrate public and private sector perspectives. The chapter also looks at marketing prospects for *A. mangium* products in the changing international market.

Economic Reasons for Forest Plantations

Economic reasons for growing *A.mangium* in plantations can include:

- averting anticipated domestic timber shortages
- increasing profitability of degraded land resources through conversion into plantations of fast-growing timber trees
- creating employment opportunities to compensate for those lost due to dwindling timber production from natural forests
- alleviating the hardship of low-income groups by involving them in the production of general-utility timber, and selling it at affordable prices
- reducing excessive drain on foreign exchange through import substitu tions of timber and tree products

By 1995, Malaysia, for example, is predicted to have a total domestic supply deficit of 3.5 million m^3 of logs based on the current requirements of its process-

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ing industry. In the best-case scenario, this deficit would continue until the year 2010; in the worst case, Malaysia would face a deficit of 3 million m^3 in the year 2020. The magazine *Asia Pacific Forest Industries* conjectured that this surplus/deficit situation would lead to closure of mills, mills running below capacity, or importation of logs to supplement mill demand (Anon. 1992).

Although these broader economic rationales for timber growing have been recognized, the tree plantation sector in Malaysia, and in other tropical countries, remains in the doldrums. Worldwide, however, over 150,000 ha of *A. mangium* have been planted, and further expansion is anticipated, particularly in Indonesia, Malaysia, Thailand, and Vietnam, involving private and government sectors. Economic and financial analysis can clarify the distinction between a project's benefits for a national economy and those for private ventures. A look at changes in the international market and in the status of forest resources will also help to understand this apparent contradiction.

Determining Financial Feasibility of Plantations

Financial and economic analyses in the literature (Kanapathy et al.1986; Golokin and Cassels 1987; and Johari 1987) can be used to assess the financial viability of plantations of *A. mangium*. For such assessments, financial and economic analyses may consist of calculating the three most common cost-benefit analysis instruments: net present value, benefit-cost ratio, and internal rate of return.

Net present value (NPV) measures the discounted net returns (discounted revenues minus discounted costs).

Benefit-cost (B/C) ratio divides discounted revenues by discounted costs, resulting in a number independent of currency units.

Internal rate of return (IRR) is the rate of discount that would ensure the project breaks even (in other words, it realizes an NPV of zero).

Basically, these analyses attempt to incorporate the elements of opportunity cost on capital over the duration of the project. The value that one dollar receives at different times during that period is not the same. As a result, the time flows of monetary values—both costs and revenues—should be discounted to a common basic point in time, at the beginning of the project.

The opportunity cost of the capital must be considered in order to compare the prospects of the plantation enterprise (in this case) with the potential of the many alternative projects in which the capital could be invested, both in and outside of forestry.

A project is deemed viable when it results in a positive NPV value and a B/C ratio greater than 1. Similarly, when the IRR exceeds either the interest rate on borrowed capital or the rate of returns that an equity capital could fetch from an alternative investment with equal risk, then the project is deemed viable.

A project's objective determines whether financial and/or economic analyses are conducted to evaluate its viability. Both types of analysis use the tools of NPV, B/C ratio, and IRR, but with different elements of the cost and revenue. In a *financial analysis*, market prices directly provide the cost and revenue values. But in an *economic analysis*, the prices of these cost and revenue elements are adjusted to account for the opportunity cost to society as a whole. These adjusted prices are known as the *shadow prices*. The approach often adopted in adjusting market prices to shadow prices is to use conversion factors developed by the Economic Planning Unit, following the methods of Little and Mirrlees and Squire van der Tak.

Economic analysis is normally conducted to obtain a holistic picture of a project's economic impact to the nation, especially when a project involves a large budget and is to be financed by a government. The government would conduct an economic analysis, for example, to determine if its expenditure would benefit as many of its citizens as possible.

Financial analysis, on the other hand, is often used when a project is to be financed by a private company. The company is interested in the project's financial viability based on actual incurred costs and prices, and may not be concerned with the impact to the economy of the nation at large.

In the literature, there is not a single report on the evaluation of financial viability of planting *A. mangium* as a monoculture in any forest plantation project. Analyses have been done on a project basis, in which *A. mangium* is one of several species grown. In Malaysia, a plantation project would usually include *Gmelina arborea* and *Paraserianthes falcataria* on different sites. Because many such projects use *A. mangium* as their primary species, though, these analyses are still a good gauge of the costs of production and revenues related to this species.

Because cost and price structures vary from place to place, feasibility studies should be examined on a case-by-case basis.

Case Studies of Financial and Economic Analyses

The two case studies presented here are that of Sabah Softwoods Senderian Berhad (SSSB), a private company that grows *A. mangium* for pulpwood, and the Compensatory Forest Plantation Project (CFPP). CFPP was set up by the Forestry Department of Peninsular Malaysia to grow (primarily *A. mangium*) trees for general utility to meet the anticipated log deficit as natural forests are depleted.

Sabah Softwoods Forest Plantation Project for Pulpwood Production

In 1986, SSSB computed the financial returns for a 10-year rotation for *A. mangium*, and a 8-year rotation for *G. arborea*. For export as chips at the market price, this scheme was very attractive. The IRR ranged from 12.8% at MAI 20 m^3/ha/year to 15.9% with MAI of 25 m^3/ha/year for new planting. With replanting, the IRR improved to 19.1% (Table 12.1).

These returns from a 20,000-ha plantation, averaging 10 years old, could be realized assuming a total investment of US$14.4 million for chip mill machinery, a loading terminal, and working capital. The chip mill could process up to 600,000 m^3 of plantation timber annually, producing over 200,000 board metric tons (BDMT) of chips.

However, these findings contradict those of Golokin et. al. (1987), who estimated the financial return of *A. mangium* planted for pulpwood on a rotation of 8 years, with an MAI of 25 m^3/ha/year or a timber yield of 200 m^3/ha. That analysis used an FOB (*free-on-board*, meaning the price includes loading) sales price of export pulpwood of about US$30 per m^3, and considered that no royalty or other taxes were charged on exports of plantation wood. SSSB was reported to have incurred a total cost of US$59.2 million as of 1987; 70% of this was invested in timber-growing activities. The estimated financial IRR was 4.54%, far below that of the capital's opportunity cost. This suggests that growing *A. mangium* for pulpwood was not viable under those conditions. That report did not include any economic analysis of the project's impact on the national economy.

Compensatory Forest Plantation Project for General Utility Logs

Kanapathy et al. (1986) estimated financial and economic analyses of CFPP's production of general-utility timber on a 15-year rotation in Kemasul Forest Reserve, Pahang and in Ulu Sedili Forest Reserve, Johore, Peninsular Malaysia. The analyses assumed an MAI for *A. mangium* of 20 m^3/ha, with expected yields of 80 m^3/ha of thinnings in Year 8 and final harvest of 220 m^3/ha in Year 15.

For these analyses, the price of *A. mangium* logs had to be proxied (that is, represented by the price for another product), because *A. mangium* did not yet have a commercial value in the Malaysian timber market since none had yet been harvested. Kanapathy et al. used the average log price of mixed light hardwood timber in Peninsular Malaysia as a proxy; in the early 1980s, this ranged from US$28.8-40.8 per m^3. The analyses assumed an average proxy price of US$36.

Government charges (premium, royalty, and silviculture taxes) levied on the extraction of logs varied from 13-15% of the logs' value, depending on the state. Log haulage costs absorbed another 30-40%. Thus for calculating the net selling price of logs (stumpage value per m^3), the analysts estimated government charges at 14%, and transport charges at 35%. The net selling price worked out to be US$18.4 per m^3.

Table 12.1. Financial return on 8-year rotation of *Gmelina arborea* and 10-year rotation of *Acacia mangium*. Amounts are expressed in RM/ha (RM2.5 = US$1).

	New Plantings					Replantings				
Year	Direct Costs	Over-head[1]	Total	Revenue[2]	Net Inflow/ Outflow	Costs	Over-head[3]	Total	Revenue	Net Inflow/ outflow
MAI 20										
1	1035	1449	2484	-	-2484	835	1169	2004	-	-2004
2	244	341	585	-	-585	153	214	367	-	-367
3	43	60	103	-	-103	43	60	103	-	-103
4	43	60	103	-	-103	43	60	103	-	-103
5	43	60	103	-	-103	43	60	103	-	-103
6	43	60	103	-	-103	43	60	103	-	-103
7	43	60	103	-	-103	43	60	103	-	-103
8	43	60	103	-	-103	43	60	103	-	-103
9	43	60	103	-	-103	43	60	103	-	-103
10	43	60	103	10200	10097	43	60	103	10200	10097
			IRR = 12.8%					IRR = 15.9%		
MAI 22										
1	1035	1449	2484	-	-2484	835	1169	2004	-	-2004
2	244	341	585	-	-585	153	214	367	-	-367
3	43	60	103	-	-103	43	60	103	-	-103
4	43	60	103	-	-103	43	60	103	-	-103
5	43	60	103	-	-103	43	60	103	-	-103
6	43	60	103	-	-103	43	60	103	-	-103
7	43	60	103	-	-103	43	60	103	-	-103
8	43	60	103	-	-103	43	60	103	-	-103
9	43	60	103	-	-103	43	60	103	-	-103
10	43	60	103	11220	11117	43	60	103	11220	11117
			IRR = 14.1%					IRR = 17.2%		
MAI 25										
1	1035	1449	2484	-	-2484	835	1169	2004	-	-2004
2	244	341	585	-	-585	153	214	367	-	-367
3	43	60	103	-	-103	43	60	103	-	-103
4	43	60	103	-	-103	43	60	103	-	-103
5	43	60	103	-	-103	43	60	103	-	-103
6	43	60	103	-	-103	43	60	103	-	-103
7	43	60	103	-	-103	43	60	103	-	-103
8	43	60	103	-	-103	43	60	103	-	-103
9	43	60	103	-	-103	43	60	103	-	-103
10	43	60	103	12750	12647	43	60	103	12750	12647
			IRR = 15.9%					IRR = 19.1%		

[1] Overhead taken as 140% of direct costs.

Source: Tan Get Seng (1992)

[2] Revenue based on average return to plantation from fully financed chipmill per the feasibility study.

[3] With coppice rotations, overhead is taken at $175/ha/yr which, for a fully developed plantation of 51,000 ha, would be $8,925,000 annually. This figure could be applied to all establishment regimes once the total area is developed.

At the time of the analysis, thinnings from plantations had never been marketed in the peninsula. The closest proxy for thinnings was mixed forest cut-offs bought by chipboard mills from agricultural conversion areas at an average price of US$21.2 per m^3. After allowing for collection and transportation charges amounting to US$12 per m^3, the net selling price amounted to about US$9.2 per m^3. This figure was used as the net selling price of thinnings from CFPP.

The production costs for CFPP were assessed from records at both the Kemasul and Ulu Sedili Forest Reserves (Table 12.2). Most of these costs are based on the contract work system.

Table 12.2. Production cost of establishing the Compensatory Forest Plantation Project.

Contracted Jobs	Cost (US$ per ha/year)
Semi-detailed soil survey	4.40
Site preparation	282.20
Road construction (additional to roads constructed by loggers)	22.56
Seedling production	70.20
Planting	118.60
Weeding	48.00
Pruning	40.00
Administrative and other expenses	2.00
Forest Department salary and wages and other fixed costs	not released

Source: Kanapathy et al. (1986)

Table 12.3 gives the projected cashflows of the plantations. These streams of cashflows were used to compute NPV, IRR, and B/C ratio to determine the CFPP's financial profitability. The projected cashflow for establishing 40,000 ha of plantation was spread over three years; trees planted the second year would be harvested in Year 16; trees planted in Year 3 would be harvested in Year 17.

The analysis indicated that the forest plantation project would derive a total revenue of US$184.8 million, with about 16.0% coming from the sale of thinnings. CFPP would achieve a positive net cumulative cashflow only in Year 16, after the second harvest.

Forest plantations have long gestation periods and by nature are difficult to finance commercially. Thus the analyses by Kanapathy et al. assumed that the Project would be financed at a subsidized interest rate, and used a discount rate of 10%.

Table 12.3. Projected cashflow of the CFPP (US$ thousand).

Project Year	Total Revenue	Total Cost	Projected Cash flow	
			Net annual	Net cumulative
1	0	5,903	(5,903)	(5,903)
2	0	12,663	(12,663)	(18,566)
3	0	24,203	(24,203)	(42,769)
4	0	5,282	(5,282)	(48,051)
5	0	4,440	(4,440)	(52,491)
6	0	1403	(1,403)	(53,894)
7	0	245	(245)	(54,139)
8	4,416	365	4,051	(50,088)
9	8,832	486	8,346	(41,742)
10	16,193	690	15,503	(26,239)
11	0	343	(343)	(26,582)
12	0	437	(437)	(27,019)
13	0	624	(624)	(27,643)
14	0	256	(256)	(27,899)
15	24,288	635	23,653	(4,246)
16	48,576	976	47,600	43,354
17	82,506	1,524	80,982	124,336
	184,810	60,475	-	-

Note: Figures in parentheses denote negative values. Totals do not add up due to rounding of figures. Adapted from Kanapathy et. al. (1986)

The resulting IRR is 10.11% (Table 12.4), and NPV is US$1.64 million, or US$40.8 per ha. The B/C ratio obtained is slightly above 1. Thus, given the above conditions, *A. mangium* plantations in CFPP are barely financially viable.

Given Malaysia's favorable economic conditions, however, a discount rate of 15.0% is a more appropriate measure of the cost of capital in the economy. If the discount rate is raised to 15.0%, the project's NPV turns negative, and the B/C ratio decreases to 0.63. The project appears nonviable if the capital is not subsidized. At an IRR of 10.11%, the returns cannot possibly match the assumed 15% opportunity cost of capital invested in the project.

Table 12.4. Financial profitability of the CFPP.

Discounted rate	NPV (US$ thousands)	B/C ratio	IRR (%)
10%	1,643.6	1.04	10.11
15%	(13,793.6)	0.63	10.11

Figures in parentheses denote negative values.

Sensitivity Analysis

Risks and uncertainties affect investment decisions. Profitability—and hence decision making—depends on the accuracy of figures for prices, yields, and costs of production. In view of this, three highly variable constraints—prices, yields, and cost of production—are subjected to *sensitivity tests* to determine the extent to which project profitability is affected by these variations. Table 12.5 shows the sensitivity test for CFPP and the effects of changed assumptions on the project cashflow.

The long time scales in forestry make it difficult to forecast prices and costs. As rubberwood has become commercialized in recent years, it has provided a better proxy of *A. mangium*'s log price than mixed light hardwood. Rubberwood is considered a plantation timber crop with log sizes very close to those expected for *A. mangium*. The rubberwood log price is currently about 60% that of mixed light hardwood. Thus, the US$9.2/m^3 price used in the analysis above should be subjected to a 40% price reduction sensitivity.

Yield sensitivity attempts to account for less favorable soil, terrain, and drainage conditions as well as the occurrence of heart rot, which may reduce usable volume of timber for sawn timber.

Cost of production sensitivity attempts to account for costs otherwise left out of financial calculations, such as rental charges for the lease of the land.

Table 12.5. Sensitivity of the CFPP with respect to price, yield, and cost of production.

Simulations	NPV at 15% (US$ thousand)	IRR (%)
Price or yield decrease by		
10%	(15,990)	9.41
20%	(18,370)	8.27
30%	(20,750)	6.98
40%	(23,130)	5.56
Cost of production increase by		
10%	(17,552)	9.76
20%	(21,311)	8.62
30%	(25,070)	7.84
40%	(28,829)	7.14

Figures in parentheses denote negative values. The market prices for both cost and revenue items were adjusted to make them more representative of the opportunity cost to society. The conversion factors used were developed by the Economic Planning Unit.

The sensitivity test in Table 12.5 suggests that the project returns are sensitive to a fall in prices and yield, or to a rise in production costs. When these adverse simulated assumptions are applied to the analysis above, planting *A. mangium* becomes commercially nonviable .

Economic Analysis of CFPP

Under the simulated assumptions on price, production cost, and yield, the financial analysis revealed that CFPP is not profitable for a commercial venture. To assess the effect on the country's economy, however, it would be useful to examine the effect on the results when the prices of all the cost and revenue elements are adjusted to their shadow prices. The project may not be financially viable to the investor establishing the project, but it may still be viable to the national economy at large.

Table 12.6 shows the economic IRR, NPV, and B/C ratio for CFPP. Discounting the net economic cashflow of the direct costs and benefits at 10%, the NPV becomes US$216.7 million and the B/C ratio is 5.13. The IRR is 24.16%. At a higher discount rate of 15.0%, the NPV is still positive but decreases by half to US$85.1 million, while the B/C ratio decreases to 2.82.

Table 12.6. Economic feasibility of CFPP.

Discounted rate	NPV (US$ million)	B/C Ratio	IRR (%)
Discounted at 10%	216.7	5.13	24.16
Discounted at 15%	85.1	2.82	24.16

The investment criteria suggest that under these conditions, plantations of *A. mangium* are feasible and beneficial to the national economy, although not financially profitable for a private investor without subsidy.

From the above analyses, we can see that if private investment funds in *A. mangium* plantations are subsidized by the government in view of the project's projected benefits for the national economy, an investor may find the project profitable, albeit marginally. This conclusion supports the call frequently made by private investors for a package of investment incentives for forest plantation projects.

Incentives for Plantation Establishment

For the private sector to become more involved in forest plantation, investment incentives should be instituted to outweigh the investment disadvantages of:

- high initial capital investment for plantation establishment
- the long period between planting and harvesting, and the related concern for high capital or interest costs carried until harvest
- high risks involved in forest plantations due to biological and economic factors
- difficulty in acquiring access to suitable land with conditions favorable to the investors
- unattractive and inappropriate investment incentives
- large labor requirements in the initial stages

Despite these disadvantages, the private sector in Indonesia has entered into tree plantation on a large scale. Among the leaders is the Indah Kiat Group, which has planted 35,000 ha of *A. mangium*, with an annual planting target of 20,000 ha until they reach their target of 200,000 ha. The Indah Kiat Group has its own pulp and paper mill, consuming 500 metric tons of pulp per day. Barito Pacific, another Indonesian conglomerate, has planted 65,000 ha. In all, about 29 timber companies in Indonesia are committed to reforestation and afforestation. More can be done in other countries.

In Malaysia, Mohd. Shahwahid and Saroni (1992) interviewed several companies and government agencies interested in forest plantation investments. The overwhelming conclusion was that better incentives are needed to attract private sector involvement in forest plantation establishment. There, the government should examine ways for stimulating private sector investment, and identify arrangements by which land can be made available for plantation establishment. New fiscal incentives also need to be formulated and adequate financial facilities provided.

The investment tax incentives for forest plantations offered by the Malaysian government were first prepared for the manufacturing sector, and do not substantially compensate for the high risk and long gestation period involved in forestry. The existing incentives are only beneficial for a company as long as it continuously generates income. Alternative incentives should help to offset a forest company's large initial costs against aggregate earnings from all sources for cost savings and to reduce risks over the period of one rotation.

In the case of Malaysia, proposed incentives for planting *A. mangium* on a plantation scale include the extension of the 70% tax relief period (qualified under the Pioneer Status) to the first full harvesting income, instead of the existing five-year period. Another proposal is to include flexibility due to unforeseen changes in the market price of timber, improvements in technology, and changes in tree growth due to site and soil factors and management costs.

A further incentive that merits consideration is "group relief". Group relief encourages established wood-based industries and companies with other business ventures to undertake forest plantation by allowing them to offset losses incurred in the initial years of plantations against income of other profitable ventures. Incentives can also be provided at the state government level. The Sabah State Government provides SSSB with exemption from royalty payments and quit rent for at least the first rotation.

Another important issue is the often controversial one of land tenure. Competing demands for land frequently complicate a company's search for an area that is large, preferably contiguous, and well-situated for a tree plantation, with suitable infrastructure. In the interests of both private plantation companies and the communities near the proposed plantations, government clarification and streamlining of land tenure policy for tree-growing is important.

One option for dealing with problems of land tenure is the type of project initiated by the Paper Industries Corporation of the Philippines (PICOP) and by Sabah Forest Industries, mentioned in the Introduction. In these schemes, companies contract with many small-scale growers to produce logs for milling and further processing.

Market Prospects

Constraints

Like woods of other fast-growing tree species, wood from acacia plantations has the inherent potential disadvantages of:

- small diameter
- knottiness
- low density
- low strength
- large portion of reaction wood
- greater incidence of spiral growth
- greater growth stress
- greater proportion of juvenile wood (Chung 1992)

The effect of these on the utilization of acacia wood for different products is summarized as follows:

- *Sawn lumber*: all of these are severe constraints
- *Block board*: the above features are not constraints
- *Pulp and paper*: low wood density may increase costs of production; otherwise, acacia woods are excellent for pulping
- *Reconstituted panel board*: the above features do not pose problems. Acacia woods are excellent materials for this use.
- *Pulpwood/veneer:* the above features represent severe constraints

Commercial Prospects

Despite the constraints, recent research and market demand offer clear evidence that *A. mangium* is very acceptable for:

- wood chips for particle board and medium density fiberboard (see Chapter 11)
- wood chips for pulp and paper industries
- lumber and veneer, provided good genetic material and silvicultural man agement for straight-boled trees (see Chapters 3 and 7)
- fuelwood, due to the wood's good calorific value

Hardwood Chips

In the Asia-Pacific region, wood chips from plantations would find ready markets in the Northeast Asian countries, particularly Japan, South Korea, and Taiwan (Republic of China). Because of their bulk and relatively low value, chip shipments are almost invariably confined to single port of loading and discharge, and freight costs favor making shipments as large as possible.

Hardwood pulp is used primarily to produce coated and uncoated printing paper, fine printing paper, and "fluff pulp" used in household tissues, diapers, and sanitary products.

Among the Northeast Asian countries, Japan imports the largest volume of wood chips annually. In 1991, Japan imported about 22 million m^3 of wood chips, of which hardwood chips comprised 13 million m^3 (59%), and softwood chips (conifer chips) comprised 9 million m^3 (41%). Japan was envisaged to

import only about 5% less in 1992, but the proportion of hardwood chips to softwood chips will probably remain the same (59% to 41%). Most of Japan's 1992 supply of hardwood chips was expected to come from the United States, Australia, and Chile (Table 12.7).

The demand for hardwood chips in both Taiwan and South Korea is about 1 million m^3.

Table 12.7. Expected 1992 supply of hardwood chips to Japan, by country

Country	Volume (m^3)	% of total	Wood source
USA	4,200,000	34.0	Mixed hardwood species
Australia	4,200,000	34.0	Eucalyptus
Chile	2,600,000	21.1	Eucalyptus
China	450,000	3.6	Eucalyptus
Indonesia	320,000	2.6	Mangrove
Others	580,000	4.7	
Total	12,350,000		

Source: Tan Get Seng (1992)

Reconstituted Wood Products

With the recent advances in processing technology (see Chapter 11), facilities for processing wood materials will change, most likely toward reconstituted wood products rather than solid wood panels.

Traditionally, tropical hardwoods are associated with large-diameter logs, and so European and Japanese buyers are accustomed to specifying first grade wood with average widths of 8 inches (about 20 cm) and wider, and lengths of 366-426, excluding defects like pinholes, shot-holes, and unsound knots. They are also used to buying BBCC grade plywood (the letters indicating second and third levels of acceptability out of four, 'A' being defect-free) with perfect face veneer in 4 x 8 feet sizes (about 122 x 244 cm), free from defects.

With the depletion of large-sized trees, however, the shift to small-diameter logs and toward reconstituted wood is unavoidable.

In view of *A. mangium*'s fast growth rate and its acceptable density for hardwood pulp, other reconstituted wood products for which it could have potential are:

- *Block board*: Plantation logs can be cross-cut into billets of suitable lengths for conversion into 5 cm thick boards. After kiln drying, the boards can be ripped to a thickness of 18 mm for block board core. The strips can be composed to become 4 x 8 ft. edge-glued reconstituted block board, which is widely used for case-goods furniture.

- *Finger-jointed, edge-glued materials* with removal of defects (for example, unsound knots) and the irregular lengths. Strips can be finger-jointed to obtain lengths up to 50 cm long and then edge-glued to obtain the desired widths. Finger-jointed, edge-glued workbenches and shelves can substitute for wider boards from natural forest trees.

- *Particleboard*: *A. mangium* has proven suitable as raw material for particleboard, supplementing the available wood residue from timber-processing mills (see Chapter 11).

- *Medium-density fiberboard (MDF)* : Although it involves a very high capital cost for machinery, MDF is an increasingly prominent solid-wood substitute for furniture, such as tabletops and cabinets. *A. mangium* is known to produce good chips suitable for processing into MDF. MDF panels have relatively uniform density and smooth, tight edges, and can be machined like solid wood into moldings. MDF can also be turned. The fine surface quality is amenable to high-quality finishing and it can be easily overlaid with fine and decorative veneers and other laminates to further enhance the appearance (see Chapter 11).

- *Scrimber:* This is a product developed for structural applications using round material, such as small-diameter logs and forest thinnings. These are flattened longitudinally without rupture across the grain. The result ing long strands are spread laterally to form uniform mats, with the stands remaining interconnected. With the adhesive and wax mixture, reconstituted long and large sections of scrimber can be produced. Large scrimber blocks can be sawn into sizes suitable for building materials.

Future Research

For economics and marketing studies, the following topics are of primary importance:

- Economic viability of alternative silvicultural practices and processing technologies, especially for small-sized trees

- Economic analyses on the impact of various government investment incentives on plantation development

- Cost-benefit analysis of new products intended for production

- Assessment of market acceptance of the new products

- Assessment of potential arrangements for local processing of tree products
- Supply and demand of *A. mangium* in the wood industry
- Production cost structure analysis of existing processing facilities, for deriving competitive market log price

Summary

Growing plantations of *A. mangium* can serve purposes of both forest resource use and economics, for the production of a range of products. Economists use the analytical instruments of net present value, internal rate of return, and benefit-cost ratio in financial and economic analyses to assess the viability of plantation projects. Sensitivity tests attempt to account for variations in key determinants of investment decisions.

Under current conditions in countries like Malaysia, financial analysis suggests that these plantations may not directly provide investors with adequate financial rewards. However, economic analysis shows that such plantations benefit the national economy. With appropriate government incentives and/or arrangements between processing companies and tree growers, *A. mangium* growing can be a profitable enterprise.

As the international wood products market adjusts to the dwindling supply from natural forests, it is clear that *A. mangium* is a most suitable species for large-scale tree plantations to provide raw material for pulp, paper, and reconstituted wood products such as particleboard and medium-density fiberboard.

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References

Anonymous. 1992. Forest plantations - too little, too late? *Asia Pacific Forest Industries* 4(4):12-18.

Chung, H.H. 1992. Research on economics and marketing of acacias. In *Tropical Acacias in East Asia and the Pacific*, eds. Kamis Awang and D. A. Taylor; 92-95. Bangkok, Thailand: Winrock International.

Golokin S. L. and P. K. Cassels. 1987. An appraisal of Sabah softwoods Sdn. Bhd. 12 years after establishment. In proc. of a seminar on the Future Role of Forest Plantations in the National Economy and Incentives Required to Encourage Investments in Forest Plantation Development, held November 30 - December 4, 1987 in Kota Kinabalu, Malaysia; 107-116.

Johari Baharudin. 1987. An appraisal of the Compensatory Forest Plantation Project in Peninsular Malaysia. In proc. of a seminar on the Future Role of Forest Plantations in the National Economy and Incentives Required to Encourage Investments in Forest Plantation Development, held November 30 - December 4, 1987 in Kota Kinabalu, Malaysia; 117-134.

Kanapathy, Vijayakumari, Ismail Mohd. Salleh, and Abdul Rauf Salim. 1986. Forest land use and management: a review of development strategies. An Institute of Strategic and International Studies confidential report. Kuala Lumpur, Malaysia: ISIS.

Mohd. Shahwahid Haji Othman and Saroni Judi. 1992. Forest plantation: viewpoints of the private sector. In proc. of the National Seminar on Economics of Forest Plantations, held February 24-26, 1992; 109-126. Kuala Lumpur: Forestry Department.

Tan Get Sang, Raymund. 1992. Economics of planting and marketing of Acacia mangium. In *Tropical Acacias in East Asia and the Pacific*, eds. Kamis Awang and D. A. Taylor; 96-102. Bangkok, Thailand: Winrock International.

Summary

Acacia mangium is relatively easy to propagate (either from seed or by vegetative means), shows fast early growth, and can grow satisfactorily on otherwise unproductive sites. It is particularly suited for controlling soil erosion and weeds in areas heavily infested with *Imperata* grass. Its wood is used for pulp, sawn timber, chips, and firewood.

Its natural distribution stretches from the islands of Sula, Ceram, and Aru in Indonesia, through the Western Province of Papua New Guinea, to northeastern Queensland, Australia. It is typically a low-elevation species associated with rainforest margins and disturbed sites on well-drained, acid soils. On favorable sites in its natural range it grows to a height of 25-35 m and a diameter at breast height (dbh) of over 60 cm. It prefers wet sites; prolonged dry periods slow its growth.

The area under plantation with this species is rapidly expanding, with 150,000 ha already planted worldwide and another half million ha committed for planting for the paper industry. So far the area dedicated to *A. mangium* plantation is greatest in Southeast Asia, particularly Indonesia and Malaysia.

Reproductive Biology and Hybridization

A. mangium starts to flower and produce seeds 18-20 months after planting. Flowering consists of six stages of floral events, from initiation of inflorescence to shedding of flowers, lasting about 89 days from inflorescence to anthesis. Mature fruits occur three to four months after the flowering period. The time from the onset of flower buds to pod maturity is about 199 days.

A. mangium is generally an outcrossing species with the tendency toward selfing. It requires biotic agents to transfer pollen from the anthers to the stigmas. The hybrid *A. mangium* x *A. auriculiformis* has potential to become an important source of planting material in plantation forestry, as its general tree form is satisfactory where it inherits the better stem straightness of *A. mangium* and self-pruning ability and better stem circularity of *A. auriculiformis*. The physical and mechanical properties of the hybrid are intermediate between the two parent species (that is, better than *A. mangium*), and appears to be resistant to the heart rot to which *A. mangium* has shown susceptibility.

Hybridization techniques have been developed with and without emasculation, in the latter case through the use of the anther method. Hybrid plantlet production could be accelerated through tissue culture, which has shown promise.

Genetics and Tree Improvement

Like other acacias, *A. mangium* possesses a somatic chromosome number of 2n=26, with a greater proportion of the chromosomes of the short type.

Provenance differences exist in many characteristics, reflecting the variation in the total genetic composition of the species.

- *Seeds* of Papua New Guinean provenances are generally oblong in shape and larger than those from Queensland and Indonesia; seeds of Indonesian provenances are round and relatively smallest; Queensland provenances are intermediate. Seedling growth follows the same pattern.

- In *leaf characteristics*, little provenance variation is found in terms of phyllode shape, size, and veination. However, stomatal density varies significantly.

- *Physiological processes* of transpiration, photosynthesis, and nutrient uptake also vary. Papua New Guinea provenances appear more drought resistant, but with lower photosynthetic rates, than Indonesian provenances studied. Nutrient uptake differs in K, Ca, and Mg, but not in N, P, and micronutrients.

- In terms of *flowering and seed production*, development time is shorter for Indonesian provenances, although those from Queensland produce the most seed.

- *Heartwood formation* varies significantly with provenance, but not basic density.

- *Growth* in provenance trials shows a significant interaction of site x provenance. In general, growth is faster near the Equator. Papua New Guinean provenances consistently show better height, diameter and form, closely followed by the Claudie River provenance from far north Queensland. Provenances from the Queensland Cairns region, and from Ceram and Irian Jaya, Indonesia are almost always slower-growing than those from Papua New Guinea and far north Queensland.

Plus trees have been selected in several countries where *A. mangium* is planted on a large scale, and progeny testing of the selected materials is underway. There are country-by-country differences in how seed stands, seed production areas, and seed orchards are developed. Growth and flowering have been found to differ among different families in a seed orchard.

Vegetative Propagation

Where conditions permit, vegetative propagation can be more cost-effective and can result in more uniform growth. *A. mangium* stem cuttings can be easily rooted, but rooting percentage declines with older stock plants. For better rooting, auxins, such as the growth hormone Seradix 3 or indole butryic acid (IBA) should be applied at appropriate concentrations and cuttings with one or one-half phyllodes should be used. Rooting medium should have a relatively high pH and good moisture-holding capacity; a mixture of sand and Irish Sphagnum peat has been found quite good.

A technique for micropropagation from aseptically germinated seedlings has also been successfully developed. For optimum induction of multiple shoots, Murashige and Skoog basal medium supplemented with 0.5 mg/l of benzylamino purine (BAP) is best. This medium gives an average of 25.4 shoots per explant. Excised shoots longer than 0.5 cm can easily be rooted in a humidified rooting chamber. Number of shoots per explant and shoot length increase with increasing culture cycles. An estimated 219 million shoots of greater than 0.5 cm in length can easily be produced from a single germinated seedling, but the rooting percentage decreases with increasing numbers of culture cycles.

Nursery Propagation

Nursery propagation is still the most common method, maintains a broad genetic base, and is often still the cheapest technique, with costs in Asia and the Pacific around US$0.02-0.031. Nursery practices for *A. mangium* are not very demanding, and with the establishment of seed production stands and seed orchards in countries where *A. mangium* is grown on a large scale, seeds are now easily available (see Appendix A). With that start, there remains a need for good-quality seeds of specific, potentially better provenances from virgin populations.

Seeds require pretreatment; hot water treatment has yielded best germination results. Damping off is the most serious disease during the nursery stage, but it can be controlled by use of fungicide and cultural practices. Best results have been obtained using seedling containers of up to 300 cc and a standard uniform substratum—either topsoil mixed with compost or a mixture of tropical peat and rice husk (70:30).

Summary

The optimum height of seedlings for outplanting is 25-40 cm, which could be achieved in 12 weeks with proper fertilizer application, allowing another 3-4 weeks for hardening. Only the best seedlings should be planted out after proper grading.

Symbiotic Associations

A. mangium's success in reclaiming adverse sites (*Imperata* grasslands, acidic soils and soils low in nitrogen and phosphorus) is often best exploited through the species' natural associations with both *Rhizobium* bacteria and vesicular-arbuscular mycorrhizal (VAM) fungi. *A. mangium* appears to be more specific in its *Rhizobium* associations than other *Acacia* species, meaning that many *Rhizobium* strains isolated from *A. mangium* do not cross-inoculate other acacias. Some rhizobial strains are more effective than others in promoting tree growth. VAM fungus species found to be more efficient in promoting *A. mangium* growth are *Gigaspora margarita, Glomus etunicatum*, and *Scutellispora calospora.*

Used together, effective *Rhizobium* strains and effective VAM fungi can increase early seedling growth on marginal sites, and can substitute for large portions of early chemical fertilizer requirements in such areas.

The major constraint in the large-scale use of mycorrhiza in the establishment of *A. mangium* is the availability of cheap but effective mycorrhizal inoculants. Commercial VAM inoculants are available in the Asia-Pacfic region, in potting medium and granulated form.

Silvicultural Practices

The method of site preparation, using controlled burning and either mechanical (including semi-mechanical) or manual methods, depends on: past and present vegetation, climate, topography, soil type, equipment, and availability of labor. Depending on the objective of raising *A. mangium* plantations, initial spacing can vary from 2 x 2 m to 4 x 4 m. More research is needed on optimum spacing.

Where weeds abound (particularly on *Imperata* grassland sites), a weeding schedule should be prepared, using chemical and/or manual control methods. Weeding costs on *Imperata* sites can make up a large portion of plantation costs.

Research on fertilizer application has yielded some general guidelines, but site-specific research is still needed.

Singling is an important operation on many sites and with many genotypes, and should be carried out 4-6 months after planting. Pruning and thinning schedules have yet to be conclusively determined, although schedules recommended in

Peninsular Malaysia can form a basis for practice. Standard fire prevention and control measures are needed in every large plantation project using this species.

Growth and Yield

Quite a bit has been published on the growth and yield of *A. mangium*. Studies have confirmed it can achieve a mean annual increment (MAI) of 5 cm in dbh and up to 5 m in height in the first four or five years. However, growth declines rapidly after seven or eight years, and except under ideal conditions or over a long period of more than 20 years, the tree will probably not grow beyond 35 cm dbh and 35 m tall.

Volume yield estimates from dbh and height growth using several yield tables appear quite similar for a sample tree with dbh 20 cm (values ranging from 0.185-0.220 m^2). Biomass estimates of the same sample tree using biomass equations for plantation conditions range from 160-183 kg, suggesting that these equations may be more generally applicable.

Height, dbh, and even site index have been used to model *A. mangium* yield. There is a case for using the minimum number of variables for more cost-effective models that are sufficiently accurate and reliable. The high N content of the leaf litter contributes another advantage for planting.

Insect Pests

The rapid increase in forest plantation establishment in South and Southeast Asia with fast-growing, exotic tree species like *A. mangium*, often in monocultures or with a few high-yielding varieties, tends to narrow the genetic base. Particularly for an exotic species, this reduction in diversity of species, tree age, and genetic variation produces conditions favorable to the spread of pest and disease pathogens.

Although very few insects cause significant problems to *A. mangium,* foresters and forest plantation managers should be prepared to prevent insect attack. Some major pests of agricultural crops are found to attack *A. mangium* as defoliators, without serious damage. Only a few species could be described as serious pests with profound and serious attacks. These include root feeders (*Sternocera aequisignata* and termites), branch and stem borers (*Sinoxylon* spp.), and the red coffee borer (*Zeuzera coffeae*). These can cause death, deformity, or reduced biomass production of *A. mangium*, and should be carefully monitored.

In general, a pest management program should be introduced only when the population reaches an economic threshold, that is, the point at which the cost of damage is equal to the cost of preventing that damage. The costs of insect

damage and control are measurable not just in terms of the economic value of the crop; costs to the local environment as a whole should also be estimated and included.

Diseases

As with control of pests, recognition and control of diseases will play a key role if forest plantations are to realize high yields and large investment costs. To date there are no reports of any serious disease outbreaks in *A. mangium* plantations. The diseases of *A. mangium* seedlings are common seedling diseases of many tree species, with the possible exception of bacterial stem galls. Such diseases and an occasional disease outbreak in any seedling nursery is not uncommon and can usually be controlled using conventional nursery management techniques and prophylactic fungicidal sprays. Like pest control, economic and environmental costs of chemical disease control should be carefully weighed against the potential and expected benefits.

Mature *A. mangium* plants are susceptible to several diseases, most notably heart rot and root rot. Heart rot has been reported in plantations in Sabah and Peninsular Malaysia, while root rot has been reported from plantations in Sabah, Peninsular Malaysia, and Papua New Guinea. Root rot appears to be the more widespread of the two, reported both in Malaysia and in Papua New Guinea. Its incidence also appears to be site related. Control of both these diseases is difficult, however, and other management strategies may have to be employed. Pink disease is a problem in Sarawak but has very minor impact elsewhere.

Utilization

The species has potential for use as wood-based panels, and with technological advances in the utilization of small-diameter logs and processing of composite products, such as laminated veneer lumber and particleboard, *A. mangium*'s potential uses are increasing. For such composite products it is easily processed and glued, and dimensions and strength can be tailored to detailed market specifications. Mangium can also be converted to many desirable panel products for which the market is more universal. Recent developments in using *A. mangium* as pulpwood have confirmed its suitability for making quality paper, and it is already supplying the large wood chips market. In rural systems, it can be used for fuelwood and charcoal.

For non-wood products, it appears suitable for tannin production, and although it is generally not considered a fodder species, young shoots can be browsed by buffaloes and cattle. It is also profitably used as a substrate for cultivation of edible mushrooms in Taiwan.

Economics and Market Prospects

Economic and marketing aspects are crucially important in stimulating development of a country's forest plantation sector. *A.mangium* plantations have economic benefits in that they can help avert anticipated domestic timber shortages, generate income, increase profitability of degraded land resources, and reduce the drain on a country's foreign exchange reserves.

Economists use the analytical instruments of net present value, internal rate of return, and benefit-cost ratio in financial and economic analyses to assess the viability of plantation projects. Because production costs and market prices vary from place to place, analyses must be done on a case-by-case basis. Sensitivity tests attempt to account for variations in key determinants of investment decisions.

In some countries, financial analysis suggests that these plantations may not directly provide investors with adequate financial rewards to offset the long maturation period, capital requirements, and other risks involved with plantation forestry. However, economic analysis shows that such plantations benefit the national economy. With appropriate government incentives and/or arrangements between processing companies and tree growers, *A. mangium* growing can be profitable.

As the international market for wood products adjusts to the dwindling supply from natural forests, market acceptance of fast-growing tree products is unavoidable. Despite constraints common to fast-growing plantation species that limit its marketability as sawn lumber and certain veneers, *A. mangium* is very suitable for pulp, paper, and the growing industry of reconstituted wood products (particleboard, medium-density fiberboard, etc.).

Priorities for Future Research

Table 13.1 summarizes the priority research gaps identified for the areas described above. More details are available in the respective chapters.

Research on any species does not proceed in isolation of findings on other species. In terms of crop compatibility, relative productivity, and local suitability, scientists at a given planting site will naturally need to weigh the benefits of *A. mangium* with those of other crops. This type of assessment is needed not only at the outset of a program but again at key points in the life of the planting program. In agroforestry, this need for comparison of planting options is even greater, and the options more diverse.

Summary

Ensuring a stable long-term supply of tree products involves balancing the needs of industrial production with those of environmental stability and rural development. Increasingly, forest managers are being called on to consider all of these aspects, and to optimize arrangements within the constraints of their situation.

Table 13.1. Priorities for future research.

Reproductive Biology	Determine breeding values and structured observations of hybrid performance in the field in order to obtain the optimum hybrid combinations and their site specificity.
Genetics and Tree Improvement	Make further seed collections from unexplored natural stands, combined with studies of stand ecology.
	Make further collections of superior provenances identified in range-wide provenance trials.
	Select plus trees for breeding programs.
	Conduct physiological studies of *A. mangium* biomass production in *Imperata* grassland, and physiological adaptations to acidic, flood- or drought-prone, and saline sites.
	Establish advanced-generation seed orchards.
	Improve exchange of germplasm and results internationally.
	Breed for resistance to diseases such as heart rot.
Micropropagation and Macropropagation	Effect of environmental factors on rooting of stem cuttings
	Effect of carbohydrate content and position of stem nodes on rooting of stem cuttings
	Determine the cause of mortality of stem cuttings in rooting beds
	Study the anatomy of stem cuttings at different ages of stock plants to observe development of the scleren-chymatous ring on older stock plants and its effects on root development
	Study coppicing habits of *A. mangium* seedlings and rooting performance of stem cuttings taken from coppiced shoots
	Compare growth performance of vegetatively propagated stock plants produced from stem cuttings and from tissue culture
	Develop tissue culture techniques for mature *A. mangium* trees, especially important for mass-producing genetically improved plus trees
	Study protoplast culture of *Acacia* species
Nursery Propagation	Determine appropriate fertilization.

Table 13.1, continued.

Silviculture	Determine optimum silviculture schedules, particularly pruning and thinning.
	Determine the susceptibility of *A. mangium* to fire.
	Develop direct seeding techniques.
	For agroforestry, determine spacing and pollarding.
Symbiotic Associations	Identify superior *Rhizobium* strains for nitrogen fixation.
	Determine efficiency of *Rhizobium* strains under varying site conditions.
	Study the occurrence of ectomycorrhizal associations.
	Optimize combinations of rhizobia, mycorrhiza, and improved tree materials.
Growth and Yield	Determine coppice regrowth.
	Determine nutrient cycling.
Pests	Continue pest surveys. In particular, monitor root feeders (*Sternocera aequisignata* and termites), branch and stem borers (*Sinoxylon* spp.), and the red coffee borer (*Zeuzera coffeae*d.
Diseases	Study effects of local site and environmental conditions on the incidence and spread of infectious diseases, particularly detailed studies of incidence and spread of root (and butt) rot and heart rot, preferably using comparable techniques in all countries.
Properties and Utilization	Continue basic research on solid wood and fiber/particle characteristics of recently introduced materials.
	Appropriate machinery development (harvesting saw logs, peeling, chipping, defibrating).
	Develop local processing technology, including products for community consumption.
	Improve utilization of small-size logs.
	Improve development and utilization of non-wood products.
Economics and Marketing	Assess silvicultural and processing alternatives.
	Analyze economic impact of government investment incentives on plantation development.
	Conduct cost-benefit analysis of new products and assess market acceptance.
	Assess potential arrangements for local processing.
	Study supply and demand of *A. mangium* in the wood industry.

Appendix A: Seed Suppliers

This list provides an indication of seed availability only.

Australia Tree Seed Centre
CSIRO Division of
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Products
P.O. Box 4008
Queen Victoria Terrace
Canberra ACT 2600,
Australia
Phone: (062) 818203

Australian Tropical Plant
Supplies
P.O. Box 5, Mount Molloy
Queensland 4880,
Australia
Attention: Vincent K.
Moriarty

Dendros Seed Supplies
P.O. Box 144,
Weston Creek
ACT 2611, Australia
Phone: (062)-881490

H.G. Kershaw Pty., Ltd.
P.O. Box 84
Terry Hills, N.S.W. 2084
Australia
Phon: 02-450-2444

M.L. Farrar Pty., Ltd.
P.O. Box 1046
Bomaderry, N.S.W. 2541
Australia
Phone: 044-217692

Queensland Department of
Forestry
P.O. Box 944
Brisbane, Qld 4001,
Australia
Phone: (07) 224-8335

Forest Research
Development Center
Jalan Gunung Batu
P.O. Box 66
Bogor, Indonesia

Forest Research Institute
Chungyangni-Dong
Dongdaemun-Ku
Seoul, Korea
Phone: 966-8961-5

Seed Officer
Forest Research Center
P.O. Box 1407
Sandakan, Sabah, Malaysia
Phone: 214179

Senior Research Officer
Pusat Penyelidi-kan Hutan
P.O. Box 1407
Sandakan, Sabah Malaysia

Sabah Softwoods Sdn. Bhd.
P.O. Box 137 Tawau,
Sabah, Malaysia

Sabah Forestry Develop-
ment Authority
(SAFODA)
Locked Bag 122
Kota Kinabalu
Sabah, Malaysia

Tree Seed Unit
Hattisar, Naxal,
Kathmandu
Nepal
Phone: 412004

National Tree Seed Center
Papua New Guinea Forest
Research Institute
P.O. Box 314, Lae,
Papua New Guinea
Tel: 675-42-4188
Fax: 675-42-4357

Development Alternatives,
Inc.
c/o DENR Visayas Avenue
Quezon City
Philippines

Ecosystems Research and
Development Bureau
Seed Bank
College of Forestry, UPLB
College, Laguna 4031,
Philippines

Export-Import Trading
Corp. (Int) or
Greenworld Agri-Farm Int.
Center (Loc)
809 Sandres St.
Melati, Manila, Philippines
Phone: 59-10-98

Manila Seedling Bank
Foundation, Inc.
Quezon Ave. Ext.
Cor. E. de los Santos
Quezon City
Philippines
Phone: 99-50-51/99-50-52

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Paper Industries Corporation of the Philippines
Forest Research Department
Tabon Bislig
Surigao del Sur 8311
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P.A.T. Marketing
#8 Forestry St., Proj. 6
Quezon City, Philippines

Rayos Marketing
78 Molave St., Proj. 3
Quezon City, Philippines

Visayan Seedling Center
P.O. Box 879 Rm. 219 LK Bldg.
Subangdaku
Mandaue City, Cebu
Philippines
Phone: 8-15-26/8-17-09

Outside Asia

Latin American Forest Tree Seed Bank
CATIE
Turrialba, Costa Rica
Phone: 56-6021

Centre Technique Forestier Tropical
45bis, Avenue de la Belle Gabrielle
94130 Nogent sur Marne
France

Setropa, Ltd.
P.O. Box 203
1400 AE Bussum
Netherlands
Phone: 2152 58754

Southern Forest Experiment Station
Institute of Tropical Forestry
P.O. Box AQ Rio Piedras
PR 00928
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Phone: 809-753-4335

Appendix B: Scientists Studying *Acacia mangium*

This list, although incomplete, provides a 'snapshot' of researchers working with *A. mangium*, in addition to the chapter authors. The list focuses on the Asia-Pacific region. Areas of interest for each entry are indicated after each name, using the codes below.

AF = Agroforestry Systems; B = Biotechnology; C = Climatology; Co = Conservation; Cu/M = Cultivation/Management; DM = Data Management; D/A = Design/Analysis; ED = Econ. Development; FE = Forest Economics; FPU = Forest Products and Utilization; G/B = Genetics/Breeding; G/YM = Growth/Yield Models; I = Irrigation; LU = Land Use; M = Marketing; Me = Mensuration; N/SO = Nurseries/Seed Orchards; PP = Plant Protection; P/Pl = Policy and Planning; RE = Resource Economics; SC/P = Seed Collection/Production; S = Silviculture; So = Sociology; Sp/P = Species and Provenance Trials; SR = Soil Relatoins; TP = Tree Physiology.

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Index

Acizzia spp. 165
Africa 2, 166, 174, 175
Archips micacaena 166
Acacia auriculiformis 2, 9, 15, 27, 28, 29, 30, 31, 104, 165, 169, 173, 177, 178, 183, 184, 187-189, 196, 237
Australia 1, 2, 3, 5-7, 11, 16, 25, 51, 78, 174, 255
  Cape York 5
  Queensland 1, 3, 5, 6, 16, 37, 38, 39, 40, 43, 45, 51, 54, 55, 76, 79

bare-root seedlings 91
biomass 13, 45, 50, 53, 55, 93, 103, 151, 154-158
breeding 22, 26, 31, 52, 53, 54, 59, 137

Callimetopus gloriosus 167
Charaxes solon sulphureus 168
China 13, 15, 16, 43, 44, 103, 126, 132, 203, 254
chromosomes 35-36, 54
climate 3, 13, 77, 92, 113, 144
Compensatory Forest Plantation Project 119, 131, 245, 246, 258
composite wood products 15, 231-237, 255-256
Coptotermes curvignathus 170, 171, 198, 202
cost 95-96
Cryptothelea sp. 171

damping off 84, 86, 204
dieback 14, 150, 204, 208, 217, 219-220
distribution 37
Dysdercus cingulatus 173

economics 21, 35, 77, 109, 136, 137, 219, 221, 239, 243-257
eucalyptus 1, 5, 7, 9, 27, 28, 32, 61, 66, 67, 68, 71, 138, 140, 203
Eurema hecabe 174
evapotranspiration 91

fertilizer 51, 60, 64, 71, 92, 93, 103-107, 109, 114, 118, 120, 123, 129, 131, 132, 145
fiber morphology 227
fiberboard 236, 254, 256, 257
Fiji 44, 175
fire 7, 220
fire protection 120, 141-142
floral morphology 22
flower 2, 11, 22, 23, 24, 25, 26, 40, 52
flowering 11, 22, 24, 25, 28, 40, 52, 53, 77
foliar nutrients 123, 126
form 8, 10, 27, 28, 43, 45, 50, 51, 55, 95, 118, 119, 136, 137, 140, 231
fuelwood 1, 14, 50, 113, 118, 150, 151, 157, 158, 159, 237, 254

growth 45, 52, 54, 55
growth rate 68, 117, 118, 136, 152, 154

heart rot 15, 27, 54, 215-217, 220, 221, 228, 250
Helopeltis spp. 175, 176
hormones 62, 69
hybrid 2, 27-31, 36, 38, 52, 53
Hypomeces squamosus 177

Imperata cylindrica 1, 9, 10, 14, 16, 53, 101, 109, 113, 115, 116, 119, 120, 123, 131, 141
Indarbela quadrinotata 178
India 101, 168, 171, 172, 173, 174, 175, 179, 182, 184, 185, 186, 187, 190, 191, 192, 194, 195, 198
Indonesia 2, 3, 5, 9-11, 14, 15, 16, 37, 44, 45, 50, 51, 52, 54, 76, 85, 87, 89, 97, 143, 154, 163, 170, 171, 172, 176, 181, 182, 184, 190, 191, 192, 244, 252
  Ceram 3, 10, 16, 37, 38, 39, 40, 45, 55
  Irian Jaya 3, 7, 9, 55, 76
  Java 16, 153
  Kalimantan 15, 17, 85, 87-95, 116, 119-121, 125, 126, 131, 132, 133, 140, 141, 153, 154
  Maluku 9, 10, 18
  Sumatra 14, 15, 18, 85, 88, 113, 115, 119, 153, 154, 237
inflorescence 2, 3, 11, 22-25, 27, 31
internal rate of return 244-249, 251

Japan-New Guinea Timber Pty. 119, 136, 137

knot 253, 255, 256

laminated veneer lumber 232, 233, 235-239
Laos 13
leaf lesions 218, 219

leaf spots 204, 208, 217-219
Leucopholis irrorata 180

macropropagation 59-64
Malaysia 1, 13, 16, 17, 18, 25, 28, 64, 104, 154, 163, 170, 171, 173, 174, 175, 176, 181, 182, 183, 184, 190, 191, 192, 194, 195, 198, 231, 243, 244, 245, 249, 252, 253, 257
  Peninsular Malaysia 25, 28, 114, 119, 121, 123, 131, 134, 135, 136, 137, 139, 145, 204, 207, 211, 212, 213, 214-218, 221, 245, 246
  Sabah 1, 14, 16, 18, 25, 28, 30, 31, 53, 77-80, 113, 115, 117, 118, 119, 120, 121, 126, 129, 136, 137, 140, 141, 154, 204, 209, 211, 212, 214, 215, 217, 219, 221, 226, 237, 253
  Sarawak 18, 156
market price 245, 246, 253
marketing 239, 253-258
Microcerotermes distans 181
micropropagation 59, 65, 72
morphology 1, 2, 11, 12, 36, 69, 71
Myanmar (Burma) 168, 174, 178, 183, 187, 198
mycorrhiza 14, 54, 101, 102-106, 219

natural distribution 1, 3-12, 16
Nisitrus sp. 181
nutrition 92, 123

Orgyia spp. 182, 183

PT. Indah Kiat Pulp and Paper 15, 52, 85, 88, 94, 252
paper 16, 225, 227, 235, 237, 239, 252, 254, 257
Paper Industries Corporation of the Philippines 253
Papua New Guinea 2, 3, 5, 7-11, 13, 16, 37-40, 43, 44, 45, 52, 54, 55, 76, 77-80, 86, 116, 119, 120, 121, 136, 145, 140, 143, 176, 204, 211, 212, 213, 221
particleboard 235-236, 256-257
phenology 24, 25, 150
Philippines 13, 16, 48, 50, 51, 52, 53, 91, 93, 104, 105, 107, 163, 165, 167, 168, 171, 176, 180, 191, 192, 211, 212, 219
photosynthesis 13, 39, 40, 69
pink disease 203, 214-215
planting program 15
plus tree 48, 50, 53, 55, 72
plywood 231-233, 255
pods 11, 30, 76, 77, 78, 79, 80, 97
population types 7, 10, 37, 39, 40
potting 64, 71, 87-88, 105
powdery mildew 204, 206
propagation 21, 36, 52
properties 235
  anatomical 225
  mechanical 27, 228, 236, 237
  physical 137, 226
  wood 50
protection 215
provenance 220
provenance trials 43, 50, 53, 55
pruning 12, 27, 28, 50, 60, 119, 129, 133-137, 139, 140, 143, 149, 150, 151, 217, 228
Pteroma plagiophleps 184
pulp 1, 15, 16, 113, 119, 133, 136, 159, 237, 239, 245, 246, 252, 254, 255, 257

rainfall 3, 48, 91, 92, 113, 115, 214
Rhizobium 14, 93, 101-109
root 15
root formation 60, 61, 62, 63, 64, 69
root knot 204, 210
root length 157
root pruning 93, 94, 117
root rot 204, 211, 212, 213, 220, 221
rooting medium 60, 63, 72

Sabah Forest Development Authority 87
Sabah Forest Industries 253
Sabah Softwoods Senderian Bhd. (SSSB) 1, 51, 119, 136, 245-246
Sagra femorata purpurea 186
saw logs 113, 118, 133, 137
sawn timber 27, 228, 233
seed 1, 2, 7, 11, 12, 25, 30, 31, 35, 37, 38, 40, 50, 51, 59, 117, 140, 203
  collection 76, 77
  extraction 77
  size 37
  storage 78
  weight 79
  yield 30
seed orchard 51, 52, 55, 76, 97
seed production area 51
seed stands 50, 51, 55
shadow price 245, 251
shoot multiplication 65-68
Sri Lanka 13, 172, 173, 174, 176, 184, 194, 195
singling 133, 145
Sinoxylon anale 187
site preparation 51, 114-116, 120, 144
soil 1, 3, 8, 10, 11, 14, 15, 16, 39, 89, 101, 103, 104, 107, 109, 113, 119, 120, 121, 123, 129, 141, 145, 210
sooty mold 217-218
sowing 81-85, 90, 96, 118
spacing 51, 84, 116, 118-120, 131, 133, 135, 136, 137, 140, 145, 151, 157
stem canker 219
stem cutting 59-64, 70-72
stem gall 204, 207, 221
Sternocera aequisignata 188, 198
Sternocera ruficornis 190
Stettin Bay Lumber Co. 119

Taiwan (Republic of China) 25, 44, 50, 51, 191, 254, 255
tannin 237

temperature 5, 13, 15, 39, 59, 60, 65, 70, 72, 77, 78, 81, 102, 105, 113, 205, 220
Thai Plywood Company 52
Thailand 13, 14, 16, 25, 39, 44, 50, 51, 52, 101, 104, 139, 143, 157, 163, 168-171, 173, 175, 179, 183, 184, 186, 187, 189, 190, 191, 192, 195, 206, 219, 244
thinning 51, 76, 125, 129, 133-140, 143, 152, 154, 235, 246, 248, 256
Thosea 191
Thosea asigna 190
timber 1, 16, 78, 113, 119, 149, 214, 243, 250, 252, 253, 256

utilization 40, 138, 143, 225, 228-239, 254

Valanga nigricornis 192
veneer 138, 231-232, 254-256
Vietnam 13, 16, 44, 48, 237, 244
volume 118, 132, 137, 154-159, 250

weeding 93-95, 115, 118-120, 129, 136, 145
wind 15
wind damage 117

Xystrocera globosa 194

yield 35, 50, 105, 114, 123, 125, 132, 136, 137, 149-151, 154-159, 203, 246, 250, 251

Zeuzera coffeae 196

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