Tropical Acacias in East Asia and the Pacific

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edited by
Kamis Awang and David A. Taylor

1992
Winrock International Institute for Agricultural Research

The Forestry/Fuelwood Research and Development (F/FRED) Project, funded by the U.S. Agency for International Development, is designed to help scientists address the needs of small-scale farmers in the developing world for fuelwood and other tree products. It provides a network through which scientists exchange research plans, methods, and results. Research and development activities center on the production and use of multipurpose trees that meet the several household needs of small farmers.

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Correct citation

Awang, Kamis and David 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), held in Phuket, Thailand, June 1-3, 1992. Bangkok, Thailand: Winrock International. 106 + iv pp.

ISBN 0-933595-71-9

Winrock International, Forestry/Fuelwood Research and Development (F/FRED) Project. Financed by the U.S. Agency for International Development.

Cover: *Acacia crassicarpa* growing at Saithong, Thailand (main photo); woods of four-year-old trees of four *Acacia* species, also at Saithong (inset). Photos: Kamis Awang.

Printed by Craftsman Press

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Introduction

Taking up a recommendation made by the MPTS Research Committee in 1991, the first meeting of the Consultative Group on Research and Development of Acacias (COGREDA) was convened June 1-3, 1992 in Phuket, Thailand. Eighteen experts currently working on acacias in the fields of tree biology, breeding and propagation, silviculture, pests, utilization, economics, and marketing attended.

The Group attempted to identify priorities for improving the contribution of acacias in community forestry, commercial use of forest products, and the rehabilitation of degraded lands. The meeting reviewed past work and experience, and recommended priority areas for future research as described in the next section.

Acacia species, many of which are native to Australia and Papua New Guinea, have shown fast growth on a wide range of sites. The genus includes species that thrive in semi-arid environments as well as others widely grown in the humid and sub-humid tropics. This first meeting of COGREDA focussed on experience with acacias in the humid and subhumid areas of East Asia and the Pacific.

In synthesizing these results and charting future research and development, the Group aimed to improve the use of acacias by both communities and industry, and thereby reduce pressure on natural forests. The assignment of priorities was guided by assessment of processing technologies and marketing opportunities as well as the state of Acacia propagation, silviculture, management, and community forestry.

Acacia mangium, the most-studied Acacia in the region, will be the subject of a monograph to be published in 1993.

The meeting organizers and editors would like to acknowledge Mr. Noppadon Prueksawan, Provincial Forest Officer, Phuket, for hospitality shown during the meeting, and Ms. Leela Wuttikraibundit, for administrative and publication assistance.

Recommendations

The following priority assessment for research in three areas resulted from the working groups at the June COGREDA meeting. They are for *Acacia* species in East Asia and the Pacific, primarily the humid/subhumid tropics.

Species Assessment and Improvement

Table 1 shows the research priorities for acacia assessment and improvement in the humid and sub-humid tropics. From the limited field testing conducted in recent years, the following species are considered 'best bets' for development: *A. auriculiformis, A. mangium, A. aulococarpa*, and *A. crassicarpa*. On a second tier, the following merit further study: *A. leptocarpa, A. oraria, A. cincinnata,* and *A. angustissima*.

A. mangium and *A. auriculiformis* provenance trials have been widely conducted; the limitation to wider use of these species now is availability of improved planting materials. Plus tree selection, along with the establishment of seed production areas and seed orchards, are the highest priorities in the region for these two species.

With increasing interest in *A. aulococarpa* and *A. crassicarpa*, there remains the need for provenance trials of these species, as well as greater seed production. Although other species may be faster-growing, *A. leptocarpa* has shown fast growth, particularly in agroforestry systems. Its light branching and tendency toward single-stemmed growth also justify its inclusion here.

Table 2 ranks priorities for studies of acacia hybrids, also for the humid and sub-humid tropics. The best-known hybrid, *A. mangium* x *A. auriculiformis*, is at this stage ready for field testing and clonal tests. Hybrids are very site-sensitive and so require tests for suitability before widespread introduction in any new area. Other crosses listed should be studied for their potential before proceeding to this level of testing.

Although triple crosses can represent even more important gains in some situations (for example, cocoa in Sabah), they are more laborious in slower-growing crops. Generally, also, they are intended to capitalize on gains in fruiting; growth vigor may be lost.

Criteria for hybrid development would generally be: (1) growth, (2) timber quality -- bole length, fewer nodes, side-pruning habit, and (3) wood density. The fact that crosses dilute some desirable qualities at the same time that they

Table 1. Priorities for species assessment and improvement of humid/sub-humid acacias, by species.

	Prov. trials	Seed prod. area	Plus tree selection	Seed orchard	Progeny test	Cutting propagation	Tissue culture
A. auriculiformis	0	2	3	2	2	0	0
A. mangium	0	2	3	3	3	0	0
A. aulacocarpa	3	2	3	1	3	3	3
A. crassicarpa	3	2	3	1	3	3	3
A. leptocarpa	1 (s)	1	1	1	1	1	1
A. oraria	1 (s)	1	1	1	1	1	1
A. cincinnata	1 (s)	1	1	1	1	1	1
A. angustissima	1 (s)	1	1	1	1	1	1

Priority ranking: 0 = done, 1 = low, 2 = medium, 3 = high.
(s) indicates that silvicultural research should assess these species before improvement work begins.

Table 2. Research needed on acacia hybrids.*

Cross	Potential	Field testing	Breeding	Vegetative propagation	Clonal test	Isoenzyme
Am x Aa	0	3	2	0	3	0
Am x Ac	2	2	1	2	2	2
Am x Aal	2	2	1	2	2	2
Alep x Aa	2	2	1	2	2	2
Aal x Aa	2	2	1	2	2	2

Am = *Acacia mangium*; Aa = *A. auriculiformis*; Aal = *A. aulacocarpa*; Ac = *A. crassicarpa*; Alep = *A. leptocarpa*. Priority ranking: 0 = done, 1 = low, 2 = medium, 3 = high.
*Joint evaluation of species and provenance performances across sites should involve several countries.

Table 3. Priorities for species selection and improvement of semi-arid acacias, by species.

	Prov. trials	Seed prod. area	Plus tree selection	Seed orchard	Progeny test	Cutting propagation	Tissue culture
A. ampliceps	2 (s)	2	1	1	1	1	1
A. brassii	2 (s)	2	1	1	1	1	1
A. difficilis	2 (s)	2	1	1	1	1	1
A. holosericea	2 (s)	2	1	1	1	1	1
A. plectocarpa	2 (s)	2	1	1	1	1	1
A. catechu	2 (s)	2	1	1	1	1	1
A. arabica	2 (s)	2	1	1	1	1	1
A. confusa	2 (s)	2	1	1	1	1	1

Priority ranking: 0 = done, 1 = low, 2 = medium, 3 = high. (s) indicates that silvicultural research should assess these species before improvement work begins.

multiply others reinforces the need for care in proceeding. Identification of gains should be informed by a marketing perspective; for example, increases in volume growth may outweigh slight losses in wood density in terms of increased revenues to the producer.

Sabah, Malaysia and Saitong, Thailand appear to be the most promising locations for testing crosses due to the age and flowering of acacia stands at these locations. For new crosses, the research timeframe should generally be two years for developing the crosses and three years for testing.

Natural hybrids already exist in Malaysia, the Philippines, and Thailand. They can be tested faster using tissue culture. Regarding propagation, hybrids must be reproduced by clone, not seed.

Because the experience with acacias in East Asia and the Pacific has been primarily with humid and sub-humid species, the recommended priorities for semi-arid acacias in Table 3 should be regarded as provisional, and reflect only their relative priority in that region. In other regions these or other acacias may receive different priority rankings.

Silviculture

Recognizing that different growing conditions and objectives dictate different research needs, Table 4 describes silvicultural priorities for site rehabilitation, industrial plantation, and agroforestry and community forestry using the humid/subhumid species and selected semi-arid acacias.

Species suitability and species-site suitability remain high priorities for silvicultural research for all these conditions. For rehabilitation planting, grasslands recovery is a regional priority. In industrial plantations, silvicultural practices depend on the product; therefore this portion of the table is divided between pulp, fuelwood, and chemical uses on the one hand, and sawn timber on the other.

In agroforestry, likewise, silvicultural research should differentiate between trees grown in combination with cash crops and those grown with cereal crops.

Regarding pest and disease control, it is difficult to prioritize species because conditions vary from country to country. Attacks of *A. auriculiformis* by the "powder post beetle" might dictate priority for that species. In any case, periodic surveys of pests and diseases, with damage assessments, should identify the significant problems in an area. From this, appropriate integrated pest management (IPM) practices can be developed. These will depend also on the crops grown in association with the trees.

The heart rot affecting *A. mangium* is not addressed in Table 4 for several reasons. First, the expert on acacia diseases was not able to attend the meeting. Second, the heart rot problem is not universal. Third, except by selecting alternative species, there are few means for dealing with the problem.

From an industrial perspective, protection is more interesting in terms of maintaining the investment of a standing crop; for the principal commercial species (*A. mangium*), the other aspects of silviculture, such as pruning and thinning, are already known. From the perspective of multiple use and farm management, however, it must be recognized that *mangium* is not always the most appropriate planting choice; thus the preliminary steps for the other species merit priority.

Again from the point of commercial-scale management, the most important consideration is to reduce weeding costs (which now accounts for up to 70% of establishment costs) and examine soil preparation. Reducing the length of time seedlings spend in the nursery is relatively insignificant in terms of cost.

Silvicultural practices for hybrids is an area considered to be automatically included in the areas identified for other silvicultural research.

Utilization, Economics and Marketing

Table 5 shows a priority ranking for utilization research, by species and product. A priority ranking of general research areas in this field, using the same scale as in the tables, appears below.

Topic	Rank
Development and utilization of non-wood products	2
Utilization of small-size logs (grown in plantation and by farmers)	2
Development of local processing technology (including products for community consumption)	3
Appropriate machinery development (harvesting saw logs, peeling, chipping, defibrating)	3
Basic research on solid wood and fiber/ particle characteristics of recently introduced materials	3

For Economics and Marketing studies, the following topics are of primary importance (not prioritized):

- cost-benefit analysis of products intended for introduction, and under different planting systems
- economics of introducing appropriate machinery for processing small-diameter trees
- processing economics for small-sized trees
- transportation (freight)
- storability of wood materials
- processing incentives
- creation of processing centers (local industry centers)
- exchange rate changes and their effect on marketing produce of large-scale plantations
- assessment of acceptance and market for new products
- supply and demand of acacias in the wood industry
- ergonomic factors in harvesting and processing
- government policy incentives, including tax credits
- cost-effectiveness studies

Table 4. Priorities for silvicultural research for three sets of objectives, by species.*

Site Rehabilitation

	Sp.-Site Suitabl.	Gr & Yld	Plant. Estab. Ds	Sp	T	Pr	Pl	Th	FA	RM	PD
Humid/Subhumid											
A. auriculiformis	1	3	3	2	2	1	1	0	0	1	2
A. mangium	1	3	3	1	1	1	1	1	0	1	2
A. aulacocarpa	3	1	1	2	2	2	2	0	0	2	1
A. crassicarpa	3	1	1	2	2	2	2	0	0	2	1
A. leptocarpa	3	1	1	2	2	2	2	0	0	2	1
A. oraria	3	1	1	2	2	2	2	0	0	2	1
A. cincinnata	3	1	1	2	2	2	2	0	0	2	1
A. angustissima	3	0	0	0	0	0	0	0	0	2	1
Semi-arid											
A. arabica	2	2	1	2	2	2	2	3	2	2	3
A. catechu	3	3	1	2	2	1	2	3	2	2	3
A. confusa	2	3	1	2	2	2	2	3	2	2	3
A. nilotica	3	3	1	2	2	2	2	3	2	2	3
A. pennata	2	3	1	2	2	1	2	3	2	2	3

Industrial Plantation — Pulp, Fuelwood, and Chemical Uses

	Sp.-Site Suitabl.	Gr.& Yld	Plant. Estab. Ds	Sp	T	Pr	FA	RM	PD
Humid/Subhumid									
A. auriculiformis	0	3	3	1	1	0	2	1	2
A. mangium	0	3	3	1	1	0	2	1	2
A. aulacocarpa	3	1	1	1	1	0	2	2	1
A. crassicarpa	3	1	1	1	1	0	2	2	1
A. leptocarpa	3	1	1	1	1	0	2	2	1
A. oraria	3	1	1	1	1	0	2	2	1
A. cincinnata	3	1	1	1	1	0	2	2	1
A. angustissima	3	0	0	0	0	0	0	2	1
Semi-arid									
A. arabica	2	1	2	2	2	3	2	2	3
A. catechu	3	1	2	2	1	3	2	2	3
A. confusa	2	1	2	2	2	3	2	2	3
A. nilotica	2	1	2	2	2	3	2	2	3
A. pennata	2	1	2	2	1	3	2	2	3

Industrial Plantation — Sawn Timber

	Sp.-Site Suitabl.	Gr.& Yld	Plant. Estab. Ds	Sp	T	Pr	Th	FA	RM	PD
Humid/Subhumid										
A. auriculiformis	0	3	3	3	3	3	3	3	2	1
A. mangium	0	3	3	3	3	3	3	3	2	1
A. aulacocarpa	3	3	1	3	3	3	3	3	1	2
A. crassicarpa	3	3	1	3	3	3	3	3	1	2
A. leptocarpa	3	1	1	1	1	1	1	1	1	2
A. oraria	2	1	1	1	1	1	1	1	1	2
A. cincinnata	2	1	1	1	1	1	1	1	1	2
A. angustissima	0	0	0	0	0	0	0	0	1	2
Semi-arid										
A. arabica	1	1	1	1	1	1	1	1	1	1
A. catechu	1	1	1	1	1	1	1	1	1	1
A. confusa	1	1	1	1	1	1	1	1	1	1
A. nilotica	1	1	1	1	1	1	1	1	1	1
A. pennata	1	1	1	1	1	1	1	1	1	1

Agro- and Community Forestry

	Sp.-Site Suitabl.	Gr.& Yld	Plant. Estab. Sp	Pr	Pl	RM	PD
Humid/Subhumid							
A. auriculiformis	0	1	3	2	3	1	2
A. mangium	0	1	3	2	3	1	2
A. aulacocarpa	3	3	3	2	3	2	1
A. crassicarpa	3	3	3	2	3	2	1
A. leptocarpa	3	3	3	2	3	2	1
A. oraria	2	2	3	2	3	2	1
A. cincinnata	2	2	3	2	3	2	1
A. angustissima	3	1	0	0	0	2	1
Semi-arid							
A. arabica	2	3	2	2	3	1	1
A. catechu	3	2	2	2	3	1	1
A. confusa	2	2	2	2	3	1	1
A. nilotica	2	2	2	2	3	1	1
A. pennata	2	2	2	2	3	1	1

Sp.-Site Suitabl. = Species-Site Suitability; Gr.& Yld. = Growth and Yield; Ds = Direct seeding; Sp = Spacing; T = Tending; Pr = Pruning; Pl = Pollarding; Th = Thinning; FA = Fertilizer Application; RM = Rhizobia and Mycorrhizal Relationships; PD = Pests and Diseases. Priority rating: 0 = no work needed; 1 = low priority; 2 = medium priority; 3 = high priority.

*For PD, numbers indicate priority for periodic survey of pests and diseases, excepting heart rot of *A. mangium*, which receives the highest priority (3).

Table 5. Priorities for utilization research, by species and product.

	Timber				Chips				Ven./			Glue,				Envir.				
	C	Sc	Nc	Part.	Fiber	Food	Fuel	Bark	Plwd	Slcg	LVL	Lam.	Hny.	Fod.	Chem.	Plant.	Posts	Crft.	Countries	Comments
Humid/Subhumid																				
A. mangium	2	2	2	3	3	0	2	2	3	3	3	3	3	2	2	3	1	3	All	General utility timber
A. auriculiformis	2	3	3	2	2	0	3	2	2	3	3	3	3	2	2	3	2	3	All	High silica content, poor form
A. aulacocarpa	2	2	2	2	2	0	2	2	2	3	3	3	3	1	1	3	2	3	Recently introduced	Good sawn wood
A. crassicarpa	2	2	2	2	2	0	2	2	2	3	3	3	3	1	2	3	2	3	Recently introduced	Furniture
A. leptocarpa	1	2	2	2	2	0	2	2	2	3	3	3	3	2	3	3	2	1	Recently introduced	Good sawn wood
A. oraria	0	0	0	0	1	0	2	1	0	0	0	0	0	0	0	3	2	2	Recently introduced	
A. cincinnata	0	0	0	0	1	0	2	1	0	0	0	0	0	0	0	3	2	3	Recently introduced	
A. angustissima	0	0	0	0	1	0	2	1	0	0	0	0	0	0	0	3	2	2	Recently introduced	
Semi-arid																				
A. arabica	1	1	2	1	1	1	3	2	1	1	1	2	3	2	3	3	2	1	Pakistan, India, Nepal	Gum, fuel uses
A. catechu	1	1	2	1	1	1	3	3	1	1	1	3	3	2	3	3	2	1	Bn, In, L, My, N, Th, V	Poor form, fire-tolerant
A. confusa	1	1	2	1	1	0	3	2	1	1	1	2	3	1	0	1	2	2	Ph, ROC, Th	Slow growing
A. nilotica	1	1	2	1	1	0	3	2	1	1	1	2	3	2	3	3	2	1	SE Asia, In, Pak	General utility in dry areas
A. pennata	1	0	0	0	0	3	0	0	0	0	0	0	0	2	2	3	0	0	L, Ca, Th	Shrub

C = Construction; Sc = Semi-construction; Nc = Non-construction; Part = Particleboard; Ven/Plwd = Veneer/Plywood; Slcg = Slicing; LVL = Laminated veneer lumber; Lam. = Laminating; Hny = Honey; Fod = Fodder; Chem = Chemical; Envir Plant = Environmental Planting; Crft = Handicrafts.

Countries: Bn = Bangladesh, In = India, L = Laos, My = Myanmar (Burma), N = Nepal, Pak = Pakistan, Ph = Philippines, ROC = Republic of China (Taiwan), Th = Thailand, V = Vietnam.

Priority rating: 0 = done or not needed; 1 = low priority; 2 = medium priority; 3 = high priority.

Australian Collaborative Research on Tropical Acacias

Khongsak Pinyopusarerk

The Australian Centre for International Agricultural Research (ACIAR) has funded collaborative research on tropical acacias since 1984. More than 25 Australian *Acacia* species, mostly lesser-known, (together with species from other genera) have been evaluated for their adaptability and productivity in a range of tropical soils and climates in Australia, China, Indonesia, Kenya, Pakistan, Thailand, and Zimbabwe. Subsequent complementary research (e.g., propagation and silviculture) has been carried out for the promising species. Results of these studies appear in workshop proceedings (ACIAR Proceedings No. 16, 35, and 37), monographs (e.g., ACIAR Monograph No. 10), and scientific journals. This paper highlights some of the ACIAR-funded research with which I have been associated, and also refers to results obtained from other ACIAR projects. ACIAR's current acacia research is summarized in Table 1.

Species Domestication

Many acacia species have shown great potential for forestry. Based on field results in Thailand, China, Indonesia, Pakistan and Zimbabwe, the following species are considered to be best adapted in the range of semi-arid/subhumid to humid/subhumid climates.

Humid/Subhumid	*A. aulacocarpa*
	A. auriculiformis
	A. cincinnata
	A. crassicarpa
	A. mangium
	A. leptocarpa
	A. oraria
Semi-arid/subhumid	*A. ampliceps*
	A. brassii
	A. difficilis
	A. holosericea
	A. plectocarpa

A. aulacocarpa, A. auriculiformis, A. crassicarpa, and *A. mangium* are best adapted to humid/ subhumid regions. These species grow large and are most suited for wood production (pulp, sawn timber). Much of the present plantation development of acacias is based on *A. mangium* and *A. auriculiformis* due to their proven success. Newcomers *A. aulacocarpa* and *A. crassicarpa* are now accepted and will certainly play an increasing role in plantation forestry in the Asia region.

A. cincinnata has shown moderate growth in China and produced many individuals with very straight stems (Yang et al. 1989). In Thailand, the species shows below average growth except at Sakaerat in the central region, where it has grown very well with excellent stem form.

A. leptocarpa is a small to medium-sized tree. It has shown early rapid growth and, on favorable sites, may reach its full potential size within three years. The species attracts attention for agroforestry use because of its light, open crown and its propensity to produce single stems. Though regarded primarily as a species for humid/subhumid areas, it was one of the best adapted species in salt-affected land in northeastern Thailand (long dry season of 6-8 months, annual rainfall about 1000 mm). A suspected hybrid of *A. leptocarpa* x *A. auriculiformis* has been observed nearby an ACIAR trial in that area.

Little is known of *A. oraria*, a species native to Australia and Indonesia. It is a small, freely-branched shrub, but also can be a tree 10-15 m tall. Provenances from north Queensland (Cairns and Lakeland Downs) have survived and grown well on sites heavily infested by *Imperata cylindrica* (imperata grass). Planted at 2 x 2 m spacing in Thailand, its dense foliage and enormous leaf litter totally suppressed imperata grass within 1-2 years. *A. oraria* also tolerates highly alkaline sites.

A. holosericea has shown early rapid growth and adaptability to semi-arid/subhumid

Table 1. Summary of current research on acacias sponsored by ACIAR.

Research topic	Key species
Genetic improvement	*A. auriculiformis* *A. mangium* *A. aulacocarpa* *A. crassicarpa*
Floral biology/hybridization	*A. mangium* *A. auriculiformis*
Vegetative propagation	*A. mangium* *A. auriculiformis*
Silviculture (e.g., yield, spacing, fertilizing, coppice)	*A. auriculiformis* *A. aulacocarpa* *A. crassicarpa* *A. leptocarpa*
Use (pulp, paper)	*A. mangium* *A. auriculiformis* *A. aulacocarpa* *A. crassicarpa* *A. cincinnata*
Reforestation of imperata grassland	*A. oraria* *A. auriculiformis* *A. mangium* *A. aulacocarpa* *A. crassicarpa*
Screening species for specific sites	
salt-affected land	*A. ampliceps* *A. saligna* *A. stenophylla* *A. auriculiformis* *A. holosericea*
alkaline soils	*A. ampliceps* *A. auriculiformis*
semi-arid/subhumid	*A. holosericea*
Rhizobium symbiosis	*A. mangium* *A. auriculiformis*
Physiology	*A. auriculiformis*
Acacia/eucalypt mixture	*A. auriculiformis*

sites. *A. ampliceps* has performed well on alkaline soils and tends to be sensitive to acid soils. *A. difficilis*, *A. plectocarpa*, and *A. brassii* perform equally well in the same climatic zones. *A. holosericea* is widely planted in West Africa, and is being evaluated in provenance trials in Asia and Africa. Research on the other species has not progressed beyond species trials.

Provenance Trials

ACIAR-sponsored provenance trials have been established for *A. auriculiformis* in China, Thailand, and Zimbabwe, and for *A. crassicarpa* in Thailand. The *A. auriculiformis* trials are part of an international series involving some cooperators in the Multipurpose Tree Species (MPTS) Research Network. At just over two years of age, these trials have already shown marked differences among provenances in growth and form.

Genetic Improvement

The species receiving most attention are the large and now widely accepted *A. auriculiformis*, *A. mangium*, *A. aulacocarpa*, and *A. crassicarpa*. Provenances from Papua New Guinea have frequently been found to be more vigorous than Australian provenances. However, the situation for stem straightness is less clear. Some straight trees of *a. auriculiformis* are found in Queensland provenances. *A. auriculiformis*, widely planted in China, India, and Thailand, is receiving much emphasis in part due to the availability of planting material.

Progeny Trials

More than 150 families of *A. auriculiformis* from phenotypically superior trees in Australia, Papua New Guinea, and Thailand have been planted in replicated locations in Thailand. These trials are now at least four years old and are being converted to first-generation improved seed stands. Another trial comprising 100 selected families of *A. aulacocarpa* has been established recently at Sakaerat, Thailand.

Vegetative Propagation

Studies conducted at Sakaerat have shown that *A. auriculiformis* can be successfully propagated by air-layering and cuttings (Simsiri 1991). Air-layering showed better results when performed in the rainy season. Younger trees (4-8 years old) rooted more readily than older trees (15 years and older). Cuttings of epicormic shoots gave far better results than those of branches. As with air-layering, cuttings from younger trees rooted better than those from older trees.

Studies in Sabah, Malaysia show that single-node cuttings from young seedlings of *A. mangium* and *A. auriculiformis* can be rooted throughout the year at operationally acceptable levels using simple techniques (Wong and Haines 1992). Multiplication by cuttings for producing planting stock of both species is feasible (annual multiplication rate for *A. mangium* of 53.3, and for *A. auriculiformis*, 232.4). The higher multiplication rate for *A. auriculiformis* is believed to be related to higher rooting rates and faster shoot growth.

Plantation Management

Proving trials

Provenances of *A. auriculiformis*, *A. crassicarpa*, *A. aulacocarpa*, and *A. leptocarpa* known to grow well on several sites have been planted in Thailand in large plots for growth and yield monitoring. These will provide current annual increment (CAI) and mean annual increment (MAI) data and allow biomass assessment.

Coppice ability

Most fast-growing acacias coppice well when cut during the wet season and at a relatively young age (coppice rates for *A. auriculiformis* can approach 100%). Coppicing ability, however, varies considerably among species and provenances. Provenances from Papua New Guinea (PNG) of *A. auriculiformis*, *A. crassicarpa*, *A. aulacocarpa*, and *A. leptocarpa* show lower coppicing survival rates than Queensland provenances, and since these are among the best provenances this is a concern.

Further study should determine the best season of coppicing for each of the prominent provenances.

Fertilizing — macro level

Marked response (observed on *A. auriculiformis* and *A. crassicarpa*) was noted to NPK 15:15:15 applied at 3 and 6 months after planting: up to 500% increase in above-ground biomass at a sandy-soil site in Thailand. No comparable information is available for *A. aulacocarpa* and *A. leptocarpa*.

Mixed plantings of eucalypts and acacias

Eucalypt plantations are under criticism for a variety of reasons, including possible deterioration of soils and resulting long-term decline in tree productivity. Mixed plantings of eucalypts with nitrogen-fixing acacias may help sustain site productivity. Combinations of *Eucalyptus camaldulensis* and *A. auriculiformis* will be planted in Thailand to determine the long-term impact on soil fertility. Such mixtures may provide more acceptable and sustainable systems than eucalypts alone.

Physiology

Field results from many countries show that PNG provenances of *A. auriculiformis* are best for biomass production, and Queensland provenances are best for form; Northern Territory provenances were inferior in both growth and form.

Photosynthetic capacity of different provenances growing in progeny trials/seed orchards on Melville Island, Northern Australia were determined during the dry season. Contrary to expectation, Northern Territory provenances had five times greater activity than both Papua New Guinea and Queensland provenances (Woo 1991, personal communication). The stomata in leaves of Northern Territory provenances remained wide open throughout the day, allowing photosynthesis to proceed. By contrast, stomata in the Queensland and Papua New Guinea provenances were relatively closed. Evidently, the Northern Territory — not Queensland or PNG — provenances are well adapted to the conditions of high water deficit and low relative humidity found during the dry season in the Northern Territory. The results suggest that physiological parameters may be useful in analyzing growth performance and adaptation of *A. auriculiformis*. Physiological studies could be extended to include other field material, especially that planted in the international provenance trials. Great potential exists for producing improved genotypes in genetic improvement programs to suit specific planting needs and conditions.

Other ACIAR-Funded Research

Biological nitrogen fixation

Responses to inoculation with *Rhizobium* strains vary between *A. auriculiformis* and *A. mangium*. Laboratory and field studies in the Philippines showed that *A. mangium* was more specific in its strain requirements than *A. auriculiformis*, and that none of the strains obtained from a range of Philippine sites was truly effective. A strain (PMA 311/1) isolated from soils in Cape York, Queensland was very effective on both species and is now used as an inoculant in commercial and experimental acacia plantings in several countries (Dart et al. 1991).

Acacias for salt-affected lands

One ACIAR project has concentrated on evaluating a suite of Australian woody species for performance on saline, sodic and waterlogged land in Australia, Pakistan, and Thailand. *A. ampliceps*, *A. saligna*, *A. machonochieana*, and *A. stenophylla* have performed very well on highly saline land (EC_e > 25 dS m^{-1}), often with high pH and sodic but little associated waterlogging. *A. ampliceps* has been particularly productive under these conditions. At lower salinity levels (EC_e 10-15 dS m^{-1}), *A. auriculiformis* and *A. holosericea* have performed well. Further investigation of the following issues is proposed:

- o rigorous evaluation of family and provenance of *A. ampliceps*
- o screening for salt x waterlogging

- evaluation of the effect of inoculating acacias with salt-tolerant rhizobia and ectomycorrhiza on saline sites

- water use by *A. ampliceps* on saline and waterlogged sites

Use for pulp

Studies have shown that *A. aulacocarpa*, *A. crassicarpa*, and *A. cincinnata* can be included with the already-accepted *A. mangium* and *A. auriculiformis* as suitable pulpwood species. An ACIAR project with the Chinese Academy of Forestry and CSIRO Division of Forest Products found that *A. aulacocarpa* had excellent potential as a source of fiber for pulping and paper making, and the kraft pulp could be readily bleached to a high brightness. *A. cincinnata* also had acceptable pulp yield, but the kraft pulp was harder to bleach. *A. crassicarpa* pulp would also be acceptable for a wide range of end products, but bleaching results were poorer than those of other acacias (Clark et al. 1991).

Future Directions

As far as ACIAR priorities are concerned, the present research objectives are still valid and will be continued to cover other promising species. Still, the following activities are considered to be of equal, if not greater, importance.

Nutrition

Multi-stemmed trees of *A. mangium* appear to be common on more fertile sites; this may be linked to nutritional factors. In an earlier provenance trial on Melville Island, all provenances of *A. mangium* showed a propensity to develop a multiple-stemmed habit. This may have been induced by the addition of nitrogen in the standard fertilizer formulation used on the island. Research using different levels on N-fertilizer on selected *A. auriculiformis* provenances having the genetic potential to produce straight stems will help determine the influence of N-nutrition on stem characteristics.

Pests and diseases

There is a need to document existing information on insect pests and diseases and management systems. Some acacias are vulnerable to attack by insect or disease. This can cause economic loss. A branch and twig borer, *Sinoxylon* sp., has been found to attack small stems and branches of *A. auriculiformis* in the dry season. The insect girdles and breaks stems or branches at the point of attack. Young trees up to two years old, when stem diameter is small (1-2 cm), are most susceptible. This is a major concern because the broken stemmed-tree develops multiple leaders, lowering its commercial value. There is no definitive solution at this stage, although chemical spraying during the dry season reduces the damage. There is every possibility that the same beetle will attack species such as *A. aulacocarpa* and *A. crassicarpa*.

A provenance trial of *A. crassicarpa* planted in 1985 at Sipitang, Sabah, was found attacked by a stem borer, ambrosia beetle (*Platypus* sp.) (Thapa 1992). Up to 86% of the trees, most of them 11-23 cm dbh, were infested. Trees smaller than 11 cm in diameter were less susceptible. Black-stained sap exuded from the borer holes; as many as 50 holes were spotted on a single tree. In heavily attacked trees, black stain from the tunnels spreads out considerably in the sapwood region, but was absent in heartwood. The black staining of the sapwood is caused by bacterial infection transmitted by the borer. Plantation-grown trees of *A. auriculiformis*, *A. mangium*, *A. mearnsii*, and *A. aulacocarpa* in Sabah were also found to be lightly attacked by this borer. No mortality has yet been reported.

Heartrot in *A. mangium* is widespread in plantations in Malaysia and elsewhere. Though not a major threat where pulpwood is the prime planting objective, it is a serious problem in plantations grown for sawn logs.

Seed supply

Dependence on external seed supplies should be reduced. Self-sufficiency in seed supply helps in planning planting programs, and in developing countries can save valuable foreign exchange. The simplest way to establish seed production areas is by heavy thinning of existing stands of appropriate provenances and adequate genetic base. With support from ACIAR, seed stands of *A. crassicarpa* and *A. mangium* have been established in China.

Promoting Use of Acacias

ACIAR's mandate does not include extension *per se*. This is seen as the responsibility of national research institutions and extension services. Nevertheless, the established ACIAR field trials have been a focus of attention for local and international forestry organizations. ACIAR and its collaborators will continue to encourage visits to trial sites by foresters, extension workers, and especially farmers. Research results have been made available through newsletters, workshops, and books.

Industrial plantation development groups are always quick to know what species to plant. It is the rural dwellers—the majority in the tropics—who need promotional information. Arguably, extension is one of the most important options for promoting acacia planting, since most tropical countries already have some form of extension program.

Extension programs should be developed in close collaboration with local communities so as to meet their perceived needs. Very often an extension program fails due to a lack of communication between the extension agent and the community. Extension can only succeed when the community are offered what they perceive they need, not what the agent views as most suitable. In areas where firewood shortage is severe, desired species are often those with high calorific value, capacity to burn evenly without smoke or sparking, and ability to coppice.

The Royal Thai Forest Department (RFD) has established more than 50 forest nurseries in all major provinces of the country as part of its extension scheme to promote country-wide tree planting. Seedlings are provided free of charge to local schools and farmers. RFD nurseries are in a very good position to help promote planting of acacias.

Seed availability is a very important factor in the success or failure of promotion efforts. Once suitable species have been identified, procurement of seed should be planned in conjunction with the development of an extension program.

Discussion Notes

In coppicing, there appear to be differences between Australian and PNG seedlots of *A. aulococarpa*. In China, *A. aulococarpa* has performed well for pulp and paper.

ACIAR is also interested in physiology studies of the question: Why are NT provenances of *A. auriculiformis* most variable in growth and form?

Question: From the ACIAR experience, what is *A. crassicarpa*'s potential?

Answer: It is still a new species, even to ACIAR. In lower rainfall areas, it does not perform well — *A. aulococarpa* does better. (See also Sim's paper — pulping quality not as good as *A. mangium*.) CSIRO research shows *A. auriculiformis* having the best pulping quality, although SFI experience now shows *A. aulococarpa* slightly better.

Q: What about problems with heart rot in *A. mangium*? In Malaysia now there is a moratorium on mangium planting pending FRIM studies of recovery of trees intended for sawn timber from heartrot.

A: ACIAR research has not explored this area in depth, as its mandate is not for commercial uses but subsistence uses such as fuelwood.

Comment: Sabah Softwood reports that the *A. mangium* heartrot problem can be avoided by harvesting after only 5-7 years for pulping. For this purpose they plant at dense spacing (1-1.6 m).

Comment: FIO research in Thailand shows that 80-90% of 10-year-old *A. mangium* was infected by heartrot, with infection starting as early as 4 years. FRIM studies in Malaysia show heartrot appearing in seedlings only two years after outplanting. The narrow genetic base is probably a factor in the scale of this problem.

Comment: Trial results may be contradictory; site conditions and seed source may be critical to this problem. For example, despite some research on boron deficiencies in New Zealand and Australia, Boron deficiency doesn't appear to be a problem in other countries. For this reason guidelines for good experiment designs are needed.

In PNG, where boron deficiencies do occur, affecting height growth, one matchbox of boron applied at planting has given good results with *Pinus* species.

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Potential for Growing Acacias in Thailand

Suree Bhumibhamon

Background

Problems of wood shortage for household and industrial uses are increasing. For its wood supply, Thailand relies mainly on imports from Burma (Myanmar), Cambodia, Malaysia, Papua New Guinea, and other countries. Policy makers are concerned by the uncertainty of this external supply; tree planting in all forms has thus been actively promoted. It is quite clear that the Thai Royal Forest Department will continue to concentrate on enrichment planting in degraded forest reserve areas and tree planting in community forestry programs to increase the use of trees in roadside plantings, agroforestry systems, homesteads, and shelterbelts.

When considering growing acacias to meet national needs for wood products, we must remember that 80% of wood consumption in Thailand is by the rural poor, mainly for fuelwood (83% of wood used in Thailand is fuel). While rural people are generally not familiar with exotic acacias, the dwindling quality of natural forest stands and competing land uses of agriculture and aquaculture (in the case of mangrove forests) make it worthwhile to explore the role of acacias in meeting the demand for forest products.

Where afforestation is promoted, pilot studies to test and screen species are important. The private sector tends to establish small and large tree farms of industrially viable species, while NGOs tend to focus on biodiversity. Thai state agencies are promoting native and exotic multipurpose tree species (MPTS) in close collaboration with the USAID-funded F/FRED Project and the MPTS Research Network's Secretariat. Linkage is provided by the National Research Council of Thailand. The Royal Forest Department, cooperating with other agencies, is also active in giving information to planters, and in some cases providing seedlings.

Native Acacia Species

Thirteen *Acacia* species are native to Thailand: *A. caesia oxyphylla, A. catechu catechoides, A. comosa, A. craibii, A. harmandiana, A. leucophloea, A. macrocephala siamensis, A. megaladena, A. oxyphylla sulonuda, A. pennata, A. podalyriaefolia, A. rugada, and A. tomentosa. A. catechu catechoides* and *A. pennata* are among the more promising native acacias planted by the rural poor.

A. catechu is useful as a shelterbelt due to its spines, and produces very good charcoal. *A. pennata*'s edible shoots, which smell like *Parkia speciosa*, are saleable in rural markets in the country. *A. craibii* is valued for medicinal uses, as is *A. tomentosa*.

Acacia catechu

A. catechu catechoides is a moderate-sized, deciduous tree that grows in most dry areas of the country. The tree has a light feathery crown that looks vivid green in the summer. It occurs on poor soils and well-drained sites. Its spikes are white, about 5-10 cm long. Flowers are axillary on the young shoot. The pods are also 5-10 cm long and 1-2 cm wide. At maturity, seeds contain about 12.9% moisture content, which drops to 6% a month later. Amata-archachai and Hellum (1984) reported that seed germination is highly variable, with immature seeds germinating better than mature ones. Seed drying has a strong influence on seed hardening. Physical or chemical pretreatment is required for germination. Seeds are often infested by *Bruchus bilineatopygus* (Eungwijarnpanya and Hedlin 1984).

The species is a strong light demander. It coppices well, and natural regeneration is possible. Propagation is possible by direct seeding or by nursery-grown seedlings. The seed and bark have medicinal uses—the seed is good for curing skin diseases, while bark is good for stomach problems. The bark is also distilled for tannin production. Farmers in Northeastern Thailand chew the bark as a substitute for areca nut. Tannin production is not common at present—due to the poor market, farmers can gain more benefit from other products. Still, this is an excellent colonizing species in rehabilitating degraded sites. It can improve soil fertility and grow well in fire-sensitive areas.

Acacia pennata

A. pennata (or *A. insuavis*) is grown in many rural homesteads. It is a bushy tree with spines located on the stem. The young tip is generally cooked or boiled and eaten with hot spices. Propagation is usually by grafting and cutting.

Species Trials

With the cooperation of ACIAR, species and provenance trials started in Thailand for 12 acacias. *A. crassicarpa, A. auriculiformis*, and *A. aulococarpa* were found to be superior on most sites; *A. mangium* shows excellent performance only on suitable sites. In agroforestry, *A. auriculiformis* proved much better than *A. leptocarpa, A. aulacocarpa*, and *A. cincinnata.* More research is needed on acacias on problem soils (i.e., saline and acid soils, drought areas, waterlogged sites, and areas unsuitable for agriculture) and along canals and rivers.

Other papers in this report highlight research on these species by the Thai Royal Forest Department and the Thailand Institute of Scientific and Technological Research (see papers by K. Pinyopusarerk and K. Yantasath). Research by the Faculty of Forestry, Kasetsart University (KUFF), has included species and provenance trials, and stem form and physiology studies of *A. mangium*.

MPTS Research Network Trials

With the close collaboration of Winrock International-F/FRED, six sites in Thailand were established as part of the international 1987 Humid and Subhumid Network Trials. Three of these sites were used in 18- and 36-month intersite analyses. These experiments tested: *A. mangium* (Papua New Guinea and Queensland provenances), *A. auriculiformis* (also from PNG and Queensland), *Leucaena* hybrid (K743), and *Leucaena diversifolia*. In Lad Krating (eastern) and Uthai Thani (northeastern), *A. mangium* and *A. auriculiformis* from PNG show excellent health and performance. Seed production areas should be established using both seedlots.

Provenance Trials

At Lad Krating Plantation, KUFF established provenance trials of *A. mangium* based on seedlots from Queensland (13 seedlots), PNG (2 seedlots), and Indonesia (1 seedlot). Survival ranged between 94-100%. Growth characteristics are presented in Table 1.

These provenance trials have served as an excellent basis for genetic studies. Later, 163 trees were selected and 76 families were tested, and the 10 best families were selected for general planting programs.

Table 1. Growth of *A. mangium* at Lad Krating, eastern Thailand.

Age (yrs)	Survival (%)	Height (m)	D_0 (cm)	DBH (cm)	CD (m)
2	99-100	5.5-07.2	14.1-17.1	8.8-11.6	3.9-4.8
4	96-100	24.8-30.5	24.8-30.5	16.8-20.8	6.1-7.4
7	94-100	26.9-35.5	26.9-35.5	20.9-28.7	6.3-7.8

Provenance trials of *A. auriculiformis*, supported by F/FRED and ACIAR, were established using 28 provenances. Generally, tree form is not good due to the wide spacing used (3 x 3 m) and the fact that the planting faces the wind direction. For most plantations, a spacing of 1 x 2 m is recommended for better form, with removal of inferior trees at two and four years.

At 24 months, the trial at Lad Krating showed an average survival rate of 99.5%. The average height was 6.13 m, D_0 averaged 9.56 cm, and average diameter at breast height (DBH) was 7.21 cm. The Papua New Guinea provenance has shown better height, D_0, and DBH growth at the later stages of development, and the highest stomatal frequency. The average number of stomata of *A. auriculiformis* were 407.81, with 388.1 stomata/mm^2. Research on stem form and progeny trials are planned.

The Royal Forest Department has also participated in this set of trials with sites at Sai Thong, Kanchanaburi, and Sakaerat. Performances has varied greatly from site to site (Luangviriyasaeng et al. 1991).

Tree Planting

Acacia planting programs have been generally accepted by the Thai public, in part as an alternative to the controversial eucalypts. *A. auriculiformis* was introduced relatively long ago and is planted mainly as a decorative tree, both in urban and rural areas. In recent years, this species has been planted in industrial plantations but the stem quality remains poor.

More *A. mangium* plantations have been established. The species performs better where annual rainfall is greater than 1300 mm and the site has deep soil and good drainage. Heartrot is regarded as the major factor in selecting this species for planting.

Farmers in Buriram, in eastern Thailand, are growing *A. mangium* and harvesting the trees at four years of age. The Thai Plywood Corporation purchases the logs for export to Japan, where it is used in veneer for plywood. Trees harvested at this stage show very little heart rot problem.

Whereas *A. mangium* has shown benefits to farmers there, *A. auriculiformis* appears better for production in open areas, for farmers' home consumption, and for sale to the parquet industry.

Other superior acacia genetic materials will be used in industrial plantations, in the future. The National Sub-Committee on Research and Development of Multipurpose Trees, National Research Council of Thailand, has considered the importance of these species and encouraged establishment of on-farm trials using them.

Discussion Notes

Comment: Heartwood extractive of *A. catechu* is used like areca nut. Three varieties exist in Thailand, with varying uses.

Question: Is *A. mangium* used for chipping in Thailand?

Answer: Yes, but *Eucalyptus* species are preferred for this purpose now.

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Acacia mangium: A Review on Reproductive Biology, Tree Improvement and Hybridization

Zakaria Ibrahim

Introduction

Acacia mangium Willd. is the most widely planted Australian acacia in Southeast Asia (Pinyopusarerk and Puriyakorn, 1987; Udarbe and Hepburn, 1987; Bell and Evo, 1983; Darmono and Dayanto, 1981). It is planted for pulp, chips, sawlogs, soil stabilization, wastelands reclamation, fodder, and fuelwood. Since its introduction in Southeast Asia (probably first in Sabah in 1966), this species has been researched extensively and undergone various levels of improvement.

This paper reviews the existing research on *A. mangium* with reference to reproductive biology, tree improvement and hybridization and identifies research gaps.

Reproductive Biology

A number of papers document the occurrence of *A. mangium* in its natural habitat, including quantitative and qualitative descriptions of its reproductive biology in terms of inflorescence and flower morphology, and flowering and fruiting phenology (Turnbull 1987; Turnbull et al. 1986; Turnbull 1986; Turnbull et al. 1983; Pedley 1987; 1978; 1975). Bowen (1981) noted the number of flowers per branch of *A. mangium* and compared the figure with that of *A. auriculiformis* and suspected hybrid of *A. mangium x auriculiformis*.

Recent research includes a comprehensive study on the reproductive biology of *A. mangium*, covering the inflorescence and flower morphology, flowering and fruiting sequence, flowering and fruiting phenology and breeding system (Zakaria 1991; Zakaria and Kamis 1991, 1992; Sedgley et al. 1992a).

Tree Improvement

The major concern when *A. mangium* became a major plantation species, especially in Malaysia, was its narrow genetic base. Efforts have been made to widen the genetic base with imported seedlots from Australia and Papua New Guinea and provenance trials conducted in collaboration with the Commonwealth Scientific and Industrial Research Organization (CSIRO).

The International Provenance Trial of *A. mangium* initiated in 1983 tested 21 provenances (17 provenances from Queensland, Australia, 2 from Papua New Guinea, and 2 from Indonesia)(Doran and Skelton 1982). Malaysia participated in this trial with sites in Peninsular Malaysia and Sabah.

Preliminary results of these trials have been reported (Chung et al. 1990; Johari and Chew 1987; Zashimuddin et al. 1986; and Hagedon and Nixon 1982). Selection of superior individual trees in these trials has begun in various countries, with the aim of establishing clonal seed orchards.

Hybridization

Since the occurrence of natural hybrids between *A. mangium* and *A. auriculiformis* was noted by Tham (1976) and Turnbull et al. (1986), general interest in using the hybrids as planting materials has risen. Phenotypic characteristics of the hybrids were reported by Bowen (1981) and Rufelds and Jaffirin (1986). Rufelds (1988) studied seedling morphology of *A. mangium*, *A. auriculiformis*, and *A. mangium x auriculiformis* hybrid in order to distinguish them at the nursery stage. Gan and Sim (1992) formulated a nursery guideline to identify hybrid seedlings.

Wickneswari (1989) and Kiang et al. (1989) worked with isozymes to identify the hybrid seedlings from the parent species seedlings.

In producing hybrid seedlings artificially, Zakaria (1991) obtained a considerable number of true hybrid seedlings of *A. mangium x auriculiformis* and hybrid seedlings of reciprocal crosses by control pollination using the anther method without emasculation. Sedgley et al. (1992b) obtained 100% hybrid seedlings *A. mangium x auriculiformis* through control pollination with emasculation.

Darus and Rasip (1989) and Rufelds (1987) have compared the growth of the hybrids with *A. mangium* and *A. auriculiformis*. Though Rufelds saw no significant difference in diameter and height growth (in contrast with the findings of Darus and Rasip), he did find that stem form of the natural hybrid was less fluted.

Comparing the height growth of 7-month old seedlings of *A. mangium, A. auriculiformis, A. mangium x auriculiformis*, and *A. auriculiformis x mangium*, Zakaria (1991) found that height growth of *A. mangium x auriculiformis* was far superior to the others.

Wickneswari and Norwati (1992) made a pod production and seed yield study of *A. mangium* and *A. auriculiformis*. Temporal variation in hybrid seed yield was significant in both species. Average spontaneous hybridization rate was lower in *A. mangium* (6.9%) than in *A. auriculiformis* (9.3%).

An ongoing study is observing flowering phenology and seed production in a seedling hybridizing orchard of *A. mangium* and *A. auriculiformis* (Josue 1992).

Recommendations

From this review emerges recommendations for further research in the areas of reproductive biology, tree improvement, and hybridization.

Reproductive biology

Most of the basic information in this area for *A. mangium* is well documented. There is no need for further study of the flower and inflorescence morphology of this species.

Phenology observations on flowering and fruiting at specific sites would usefully supplement and complement the observations made elsewhere.

Tree improvement

It is timely for a compilation of the results of the International Provenance Trials of *A. mangium* to determine the trend of provenance performance at different trial sites in order to capitalise on between and within provenance superiority. Channels and means of exchange of genetic materials should be made available.

Depending on a country's goals for planting *A. mangium*, plus trees should be selected for desired traits, and production and breeding orchards should be established. Progeny testing and reselection of genotypes should be in progress or planned in the very near future.

Hybridization

Hybrids are very sensitive to the effect of environment. Before hybrid seedlings are released for plantation, they should be tested for site adaptability.

Countries intending to use hybrids of *A. mangium x auriculiformis* should conduct provenance trials of both *A. mangium* and *A. auriculiformis*. This is to ensure that there are enough materials to select as parent trees and to maintain a wider genetic base for future hybridization program.

To obtain optimal crossing combinations, research should determine breeding values of the species in terms of specific combining ability and general combining ability. With about 850 *Acacia* species native to Australia and Papua New Guinea, the hybrids between *A. mangium* and *A. auriculiformis* may not be the best hybrid combination. Therefore determination of crossability patterns of *Acacia* spp. would enable us to tap the potential of the whole range of interspecific hybrid combinations for particular purposes and sites.

Discussion Notes

So far, a higher hybrid yield has been found when *A. auriculiformis* is the mother tree and *A. mangium* is the father.

The most effective time for controlled pollination is early morning.

Question: Are there constraints to sharing of information in these areas, particularly between private companies and government sources?

Answer: In Malaysia there is generally no problem with this exchange, as evidenced by the presence of three industry representatives here together with academics from government organizations.

Comment: Related to the topic of this paper, an international symposium on seed storage and treatment is planned for mid-1993 and sponsored by the ASEAN-Canada Tree Seed Centre in Thailand and F/FRED, among others.

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Vegetative Propagation of Acacias by Stem Cuttings and Tissue Culture Techniques

Darus Haji Ahmad

Introduction

Of the approximately 1,100 species in the genus *Acacia*, over 850 occur naturally in Australia and neighboring Papua New Guinea and Indonesia. Most of the remainder are endemic to Africa and tropical America (Boland et al. 1984). *A. mangium, A. auriculiformis, A. crassicarpa*, and *A. aulacocarpa* are planted in Bangladesh, Costa Rica, India, Indonesia, Malaysia, Nepal, Pakistan, the Philippines, Sri Lanka, Thailand, and Hawaii in the United States, as well as a few African countries.

Although they are widely planted, continuous supply of good quality seeds for large-scale reforestation programs can be a major problem. Successful vegetative propagation of these species by conventional stem cuttings and tissue culture techniques can be very important to ensure that planting stock production satisfies future demand.

Nine *Acacia* species can be easily propagated by vegetative means: *A. mangium, A. koa, A. mollisima, A. catechu, A. decurrens, A. auriculiformis, A. albida, A. nilotica*, and *A. melanoxylon*. However, for a higher rooting percentage in stem cuttings and greater multiple-shoot formation in tissue culture, important factors to consider are: age of stock plants, rooting medium, presence of phyllodes, basal medium, and type and concentration levels of rooting hormones and growth hormones used.

Propagation by Stem Cuttings

Vegetative propagation of tree species by stem cuttings has been practiced by horticulturalists over many centuries. It offers many advantages over growing stock from seedlings: reduced time and labour in seed collection, uniform growth performance, and maintenance of the genetic make-up of the superior mother trees. *Acacia mollisima, A. catechu, A. decurrens* (Nanda et al. 1970), *A. auriculiformis* (Simsiri 1991; Hu and Shen 1986), and *A. mangium* (Darus et al. 1989; Darus 1989a and Wong 1989) have been successfully propagated and mass produced from stem cuttings.

Hu and Shen (1986) reported that *A. auriculiformis* leafy cuttings were rooted when treated with either indole-3-butyric acid (IBA) or alphanaphtalene acetic acid (NAA) at 250 ppm concentration levels. Simsiri (1991) reported that stem cuttings of epicormic shoots of *A. auriculiformis* gave a higher rooting percentage (90.0%) than branch cuttings (70.0%). He found that a commercial rooting powder, Seradix 3, was the best hormone for rooting *A. auriculiformis* stem cuttings.

Darus (1988) reported that stem cuttings of young *A. mangium* seedlings were also easily rooted when they were treated with hormones and planted in a suitable rooting medium. The best rooting medium for *A. mangium* stem cuttings was a 1:1 mixture of sand and sphagnum peat. Rooting hormones such as IBA, NAA, and a hormone rooting powder (Seradix 3) greatly improved rooting percentage and speed of rooting of *A. mangium*. Both Darus (1988) and Wong (1989) reported that cuttings treated with Seradix 3 produced more roots and hastened faster adventitious roots formation compared to other rooting hormones.

However, the rooting percentage of *A. mangium* stem cuttings decreased significantly with older stock plants. Cuttings taken from 6- and 12-month-old stock plants rooted faster than stem cuttings of old stock plants and produced higher rooting percentages of 71.3 and 65.0%, respectively. The presence of phyllodes was also important for rooting success of *A. mangium* cuttings. Those with one phyllode or a half-cut phyllode produced better rooting percentages (66-76%), faster rooting, and with very low mortality compared to leafless cuttings or cuttings with two phyllodes (Darus et al. 1989).

Root formation in one-year-old *A. mangium* stem cuttings was first detected in the phloem region, very near to the cambial layer and in between the actively elongated medullary rays (Darus 1989b). The cortical cells were the first to divide and the medullary rays broadened. Subsequently groups of smaller cells which had merismatic capability appeared in the phloem region. These smaller cells then developed into root initials. After further cell division, the root initial together with the newly developed vascular elements, formed the compact spherical root primordium, which grew outward through outer layers to become adventitious roots.

Tissue Culture

Tissue culture techniques are becoming increasingly popular as an alternative means to propagate woody plants. A few timber species have been successfully propagated this way, including *Eucalyptus citriodora* (Gupta et al. 1981), *Tectona grandis* (Gupta et al. 1980), *Ficus* sp. (Anon. 1986), and *Albizia* spp. (Crizaldo 1980 and Phukan and Mitra 1983). Six *Acacia* species have been propagated using *in vitro* techniques with success: *A. koa* (Skolmen and Mapes 1976), *A. nilotica* (Mathur and Chandra 1983), *A. albida* (Dohoux and Davies 1985), *A. melanoxylon* (Mayer and Staden 1987), *A. auriculiformis* (Yang et. al 1989; Semsuntud and Nitiwattanachai 1991; and Darus 1990) and *A. mangium* (Darus 1988).

Dohoux and Davies (1985) achieved shoot formation of *A. albida* by placing explants (cotyledonary buds) into Murashige and Skoog (1962) (MS) basal medium supplemented with 0.5 mg^{-1} benzylamino purine (BAP) and vitamins. The excised shoots were then rooted on Lin Staba medium with 50 g^{-1} sucrose and vitamins. The roots plantlets were reported very healthy and suitable for field planting.

Darus (1988) reported on a successful micropropagation technique for *A. mangium*. The optimum cytokinin concentration for inducing multiple shoots was found to be 0.5 mg^{-1} of BAP for nodal explants from aseptically germinated seedlings (giving an average of 25.6 shoots per explant) and 1.0 mg^{-1} of BAP for nodal explants of eight-month-old greenhouse-grown seedlings (giving an average of 16.9 shoots per explant).

Mayer and Staden (1987) reported the success of the *A. melanoxylon* callus cultures using both mature and juvenile explants. The healthy adventitious shoots were obtained whenever the explants put on MS medium and supplemented with benzyladenin (1.0 uM) and indole-3-acetic acid. Indole-3-butyric acid at 10uM was the best treatment for *in vitro* root formation.

Skolmen and Mapes (1976) reported that callus cultures of *A. koa* shoot tips were developed and subsequently differentiated into shoot primodia on a MS basal medium supplemented with coconut water followed by a MS medium with 5 mg^{-1} benzyladenin. It rooted when placed on a medium containing 0.2 mg^{-1} indolebutyric acid (IBA).

Semsuntud (1988) and Semsuntud and Nitiwattanachai (1991) reported that multiple-shoot formation of *A. auriculiformis* was induced by using the buds from branch cuttings of mature trees as well as from aseptically germinated seedlings. However, the number of shoots that developed varied with the type of explants used. The best results were obtained in MS basal medium supplemented with either indole-acetic acid (IAA) or NAA at 10-5 M concentration levels. On the other hand, Yang et al. (1989) reported that the optimum medium for *A. auriculiformis* for shoot multiplication was MS basal medium supplemented with 1.0 ppm IBA, applying an average of 2.5 shoots per explant.

Mittal et al. (1989) reported on multiple-shoot formation from different explants (seedling leaves, cotyledon, hypocotyl segment and axillary buds) excised from one-month-old *A. auriculiformis* seedlings. Multiple shoots could be obtained only from axillary buds in a MS basal medium supplemented with coconut water (5-10%) and BAP. The shoots produced roots at their base whenever they were transferred to basal medium supplemented with IBA or NAA.

Mathur and Chandra (1983) reported that nodal explants taken from young twigs of *A. nilotica* and placed in MS basal medium, supplemented with 0.5 mg^{-1} IAA, formed shoots and roots after two weeks of incubation. However, other types of explants, including leaves and cotyledons, did not show differentiation on any of the combination of hormones tried.

Discussion

Clearly, acacias can be vegetatively propagated by both stem cuttings and tissue culture methods. However, to get a higher shoot multiplication for tissue culture and a higher rooting percentage for stem cuttings and excised shoots derived from tissue cultures, some important environmental and physiological factors need to be considered.

For stem cuttings, the environmental and physiological factors such as juvenility or age of stock plants, phyllode number per cutting, rooting medium and growth substances are very important (Darus 1988 and 1989b; Hu and Shen 1986; and Wong 1989). Rooting is reported to be greatest for stem cuttings taken from young materials, treated with rooting hormones, and then planted in a suitable rooting medium.

Tissue culture techniques have been developed to propagate both aseptically germinated seedlings as well as mature plants of some *Acacia* species. Although many factors influence the success of tissue culture techniques, the most important factors for *in vitro* culture of *Acacia* species are:

(1) the concentration levels of cytokinins auxins used

(2) the choice of explants

For example, Darus (1988) reported that with the right explant any cytokinin level used, *A. mangium* nodal cultures yielded more shoots per explant than the results given by Yang et al. (1989).

An important aspect to highlight is the genetic stability of micropropagated regenerants derived from tissue culture. Darus (1989a) reported that all rooted plantlets of *A. mangium* are normal diploid (2n=26) similar to normal germinated seedlings. However, growth of tissue culture plantlets was somewhat slower than that of germinated seedlings. The average height of the micropropagated plantlets at 12 months after potting was 46.5 cm; the germinated seedlings at the same age averaged 81.6 cm.

Priority Areas for Future Research

Based on this review, priority areas for further studies on propagation by stem cuttings and tissue culture are:

1. Effect of environmental factors, such as air and medium temperatures, photoperiod, light intensity and air humidity on rooting performance of acacia stem cuttings.

2. Effect of carbohydrate content on rooting performance of stem cuttings and the cause of mortality of stem cuttings in the rooting beds.

3. Coppicing habits of *Acacia* species and rooting performance of stem cuttings taken from coppiced shoots.

4. Number of rooted cuttings or the number of rooted plantlets that can be produced from a single seedling or explant in one year.

5. Callus and cell cultures of *Acacia* species. Both are important techniques for easier mass production of genetically improved planting materials.

Discussion Notes

For tissue culture propagation of *A. mangium*, cover with plastic for higher humidity. Inoculation is easy. Don't transfer cuttings too quickly after root development. Each explant produces more than 20 shoots.

The medium for tissue culture of the *A. auriculiformis x A. mangium* hybrid is the same as that used for *A. mangium*.

The genes that determine form have not yet been identified, but at FRIM current studies are examining the genes controlling growth performance of *A. mangium*; these require isoenzyme studies first, in order to identify which can hybridize.

Question: What material is best used for propagation by cuttings?

Answer: Both young and mature cuttings can be used, but cuttings from mature plants must be from coppice growth in order to develop roots.

The process is: marcot the mother tree; once established, prune the marcot for root development of the plantlet — this will appear to be a tap root first.

For *A. mangium*, however, heartrot problems dictate against propagation by cuttings, as wounds offer entry to the heartrot fungus.

Q: What about the economics of large-scale tissue culture propagation?

A: It is feasible to train technicians in the techniques in 2-3 weeks. In field performance, plantlets show less multiple shoot development, and growth is equivalent to acacias grown from seed. Fertilizer application must be adjusted, however; for plantlets of the hybrid, fertilizer application at planting led young seedlings to form multiple leaders.

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Overview of Acacia Research in Sabah

Sim Boon Liang

Domestication of *A. mangium*

Acacia mangium is a robust, fast-growing leguminous tree capable of colonizing problem sites. Its site amelioration ability has attracted much attention for use in rehabilitating degraded land and reducing erosion.

Acacia mangium was unknown as an exotic until 1966, when it was introduced into Sabah, Malaysia by an Australian forester, D.I. Nicholson. The genetic base was only a small quantity of seed collected from a single tree standing beside a bridge over Lacey's Creek, on the road between Mission Beach and El Arish in Queensland, Australia. The first seedlings were planted in firebreaks around pine trial plots in Ulu Kukut (300 trees) in Jalan Madu and as trial plots in Gum Gum (100 trees) and Sibuga (70 trees) in Sabah.

Seed from the Ulu Kukut planting was subsequently harvested and a pilot plantation was established by Sabah Softwoods Sdn. Bhd. (SSSB) in 1976. Since then the species has been intensively domesticated and the Sabah Forest Department and various forest plantation agencies in Sabah have devoted much research to study of the species.

The discovery of the *A. mangium* x *A. auriculiformis* hybrid in Sabah has generated great enthusiasm for using the higher- yielding hybrid for commercial planting. This stimulated ACIAR-Malaysia collaborative research on the hybrid's phenology, controlled pollination, vegetative propagation, and development of isozyme technology.

In 1989, the first successful commercial production of printing and writing paper using *Acacia mangium* paper was reported by Sabah Forest Industries Sdn. Bhd. (SFI). The paper quality was found to be good. There is also great potential for blending *A. mangium* wood with mixed tropical residual wood for production of quality printing and writing paper. This was an important breakthrough, and removed all doubts about the suitability of mangium wood for making quality paper. The commercial test results has given many planters confidence and provided a major boost to tree-planting industries locally and abroad.

A. mangium has also become a popular plantation tree species for afforestation, erosion control, and agroforestry. The number of countries planting *A. mangium* is increasing. Currently over 100,000 ha of this species has been planted worldwide, Malaysia, Indonesia, and Vietnam having the greatest proportion. Rapid expansion of *A. mangium* plantings is anticipated; a further 200,000 ha of plantations are already committed. Seed is currently selling for over US$1,000 per kg on the international market (SFI working plan 1990).

From a notorious weed in Australia, mangium has become an important weapon in the battle against the rampant deforestation of tropical areas. The successful domestication of *A. mangium* has also generated keen interest into exploration and testing of other related tropical acacias.

Species-Site Matching Trials

The productivity of a tree plantation depends to a great extent on correctly matching the right species to the right site. Recognizing the importance of the correct choice of species and seed source, a series of species-site matching trials have begun in Sabah. SFI has tested over 300 provenances of 40 hardwood and softwood species in replicated trials across 6 distinctive site conditions (ranging in altitude from 100-1,000 m, in mean annual rainfall from 2500-3100 mm, and in pH from 4.1-5.6), representing the range of site variation within the 289,000 ha of SFI concession.

The results of these trials show clearly that no single species is best for all sites. The tropical acacias are preferable for tropical lowland areas (below 800 m asl). *A. crassicarpa, A. aulacocarpa,* and *A. mangium* perform better than other tested species in terms of fiber production per unit area (Sim and Gan 1987).

A. mangium

A. mangium already has a good track record as a plantation species and is the most widely planted species in Sabah. On deep, clayey soil it tends to produce multiple leaders. Growth is fast but not as productive as *Gmelina arborea* on these prime sites.

On sandy and shallow soil, *A. mangium* tends to be stunted after the first eight months of growth. It is slower growing than *A. crassicarpa* on this type of extreme site (Sim 1986).

A. crassicarpa

In the lowlands with deep and clayey soil and clean ground conditions, *A. crassicarpa*'s growth is comparable to *A. mangium*. It is outstanding on poor shallow and sandy soils. On poor sites it has been recorded growing twice as fast as *A. mangium*.

A. aulacocarpa

On good sites, *A. aulacocarpa* grows more slowly than *A. mangium*, although the two are comparable on shallow and sandy site. Due to its higher wood density and better pulping quality, *A. aulococarpa* offers good potential for pulp.

Tree Improvement

A. mangium has been commercially planted in Sabah since 1976. The total area planted to *A. mangium* in the state exceeds 20,000 ha. Commercial plantations are mainly large, identified block plantings of various seed sources, with boundaries clearly marked in the field and accurately mapped. Planting and seed origin are well-documented. In addition to this well-documented population of known genetic base, replicated, range-wide provenance trials and half-sib progeny trials were begun in several locations in 1977. Initially, populations tested were all Queensland provenances. Papua New Guinea and Indonesian provenances were brought in after 1981.

The breeding of *Acacia mangium* in Sabah commenced 12 years ago. Initial aims of the genetic improvement program were to (1) obtain marked improvement of stem straightness and branching habit, and (2) reduce the frequency of multiple leaders and forking trees, while retaining the species' rapid growth rate.

Simple mass selection was applied to the extensive plantations of good provenances available. More effective was a progressive program of selecting superior trees and establishing clone banks, clonal seed orchards, and seedling seed orchards. This strategy proved to be fruitful, as evidenced by the early availability of improved seed from seed stands and seed orchards that have routinely produced plantations of visibly superior quality compared to stands grown from imported seed, and seed from unselected stands. These seed production areas also generate a handsome economic return to the research work through seed sales.

Impressive efforts have been made to broaden the base of genetic material. The extensive genetic resources which have been established have laid an important foundation for the breeding of improved strains of acacias over a large area of Sabah in the future.

The extensive series of replicated species, provenance, and progeny trials established in several locations in Sabah serve:

- to study genotype x environment interaction
- as partial selection bases locally
- as local seed production areas

The great number of plus trees selected (over 500 *A. mangium*, 100 *A. crassicarpa*, 30 *A. auriculiformis*, 10 *A. aulacocarpa*) offer an opportunity for establishment of a breeding population (Sim 1989, 1991).

Breeding and associated work on mass propagation of acacias, especially *A. mangium*, has advanced considerably in recent years. Basic knowledge and techniques required for vegetative propagation and control pollination have been acquired.

Hybridization

The first occurrence of a possible hybrid between *A. mangium* and *A. auriculiformis* was reported in 1972 by Hepburn and Shim in a roadside planting in Sook, Sabah. Later Tham (1976) stated that the two species hybridize and that the hybrid tends to be taller than its parents. The existence of the hybrid was confirmed in July 1978 by Pedley after studying the herbarium specimen (81530) sent to him in January 1977.

The discovery of *A. mangium x A. auriculiformis* hybrid in Sabah has generated great enthusiasm to use the higher yielding hybrid for commercial planting. This has subsequently stimulated a series of studies into phenology, controlled pollination, vegetative propagation, and development of isozyme technology, under an ACIAR-Malaysia collaborative research Project (No. 8630), entitled Hybridization and Vegetative Propagation of Tropical Acacias.

The following important aspects of controlled pollination and hybridization were reported at the workshop related to that project, held in July 1991 in Tawau Sabah:

- The floral biology of *A. mangium* and *A. auriculiformis* was described (Zakaria and Kamis 1992; Chittachumnonk and Sirilak 1991).
- The phenology of flowering of the two species in a number of places has been defined (Sedgley et al. 1991).
- The insect pollinator species (mainly bees) have been determined.
- Techniques for controlled pollination have been developed.
- Isozyme technology was developed for identification of hybrids and determining outcrossing rates (Wickneswari and Norwati 1992; Wickneswari 1989).
- Outcrossing was found to predominate in the breeding system.
- A methodology was developed for identifying hybrids using young seedlings (Rufelds 1988; Gan and Sim 1992).
- Methods for rooting cuttings from young seedlings were developed, and promising results were obtained in studies on rejuvenating and propagating selection-age trees (Wong 1989; Darus 1988; Simsiri 1991; Visaratana 1991).
- Marcotting techniques for mature trees were developed (Sim 1986).
- Micropropagation techniques for juvenile material have been developed (Darus 1988, 1991; Semsuntud 1991).

Growth and Yield

The growth and health of the commercial plantations in Sabah have been systematically monitored by an established network of random, permanent sample plots. Growth rate, health, and soil and foliar nutrients of each sample plot are monitored annually.

Regional volume regressions and volume tables has been developed for *A. mangium* by the three major plantation agencies in Sabah (SFI, SSSB, and the Sabah Forest Development Authority, or SAFODA).

Silviculture

Spacing trials, pruning trials, thinning trials, weeding trials, fertilizer trials and various nursery systems and potting medium have been tested repeatedly by the various plantation agencies and the Forestry Department in Sabah.

Future Research

The following topics in the areas of site tolerance and stability, tree improvement, and wood utilization should be further studied:

Site tolerance and stability

- Site stability of the species, especially for poorer sites such as mine tailings, podzolic sand, and grassland.
- Nitrogen fixation rate of the various acacias and their contribution to intercropping systems.

Tree improvement

- Evaluate the advantage of inter-provenance hybrid and inter-species hybrid against pure species across several site conditions.
- Develop simpler controlled pollination methods, including

  uses of chemicals for flower sterilization

  techniques for pollen storage

  determination of outcrossing and selfing rates

  identification of the biochemical factors that determine the expression of various important characters, including the role of GA7

  gene conservation for future breeding

Wood utilization

A major research and promotion effort must focus on the utilization and preservation of acacia wood. These are fairly new plantation species, and information on their wood properties and marketability is scarce.

Discussion Notes

SFI's mill requires 800,000 cubic meters of wood annually; the nursery produces 5 million seedlings annually.

A. mangium is not commercially viable on poor sites. *A. crassicarpa* is far better on poorer sites, although it suffers crown die-back.

SFI has used mangium for making paper since 1989. Its preferred status depends on site quality. For this reason, SFI conducts soil surveys at each site before planting; this includes its contracts with smallholders as well.

Question: What is *A. crassicarpa's* wood density and potential for development?

Answer: SFI reports that it is better than *A. mangium*, although pulping qualities are not as good.

Pinhole borer has been a problem in some *A. crassicarpa* stands, but this does not significantly affect pulping quality. *A. crassicarpa* is more vulnerable to wind than *A. mangium* or other acacias.

Other uses for *A. aulococarpa* and *A. crassicarpa* include saw wood (Australia).

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Afforestation of *Imperata cylindrica* Grasslands Using Acacia Species

Risto Vuokko, Goran Adjers and Markku Temmes

Introduction

This paper highlights the objectives, activities, and results of the tree improvement work done by the Indonesia-Finland Forestry Project, emphasizing the role of *Acacia* species.

The project started with a pilot phase in South Sumatra in 1981. Since 1983 it has worked in Banjarbaru, South Kalimantan, with the main objective of developing an efficient, large-scale afforestation system for highly competitive *Imperata cylindrica* (alang-alang) grasslands. Tree improvement activities, such as selection of proper species and provenances and development of a supply of improved seeds, are essential parts of a functional afforestation system.

In most tree improvement programs, the largest, cheapest, and fastest gains can be made by assuring the use of the proper species and provenances within species (Zobel and Talbert 1984). A land race should be developed to produce the best adapted individuals with desirable growth and form. A land race is a population of individuals that has become adapted to the specific environment in which it has been planted. After a land race is formed, a breeding program can be considered (Luukkanen and Rousi 1992).

In the early years of the project, relevant information for species and provenance selection for alang-alang areas in South Kalimantan was very limited. Thus a rather large-scale program of species and provenance trials was initiated in 1986. At the same time, several pilot plantations were established using different species and provenances. Pilot plantation establishment has continued, with seed sources selected based on the results of the species and provenance trials. Thus the genetic base has been widened, land races developed and possibilities for breeding programs created.

As *Acacia mangium* was noted to be one of the most important afforestation species in Indonesia, and because it also performed well in the project's trials, the project prepared and initiated a model tree improvement program for the species. The program's objective is to establish and develop clonal seed orchards using vegetatively propagated, carefully selected plus trees.

Field work has been carried out in the project's field station, located in the basin of the Riam Kiwa river in South Kalimantan, about 50 km east of Banjarbaru (3° 30'S, 115° 00'E). The topography is undulating and the altitude is 100-200 m asl. Annual rainfall is over 2000 mm, with a pronounced dry season from May to September. The soils are heavy textured, acid (pH 4.8-5.4), and well drained. Soil fertility is moderate for forestry purposes (Simpson 1992).

Species Trials

During 1982-1985, the project carried out pilot plantings in South Sumatra (Subanjeriji) and South Kalimantan (Rantau). The species in these trials were *Pinus merkusii, Eucalyptus alba, E. urophylla, Acacia auriculiformis,* and *A. mangium.*

More intensive and long-term species testing started in 1986 with establishment of the special trial area in Riam Kiwa. So far, some 100 tree species have been planted in trials. The main interest has been in fast-growing species, as they are expected to be able to compete with alang-alang grass. However, several slow-growing species have also been tested, some of them under shade of the fast-growing species.

The initial selection of trial species was based on discussions and correspondence with some experienced researchers, and observations from other trials in Indonesia. No computer programs to assist in species selection for trials were available at the time. The critical factor was the availability of desired seeds. The project obtained seeds from commercial seed suppliers

(Inhutani, Dendros Seed, Future Forest, Queensland (QLD) Forestry Service, Australian Tropical Plant Supplies), government-sponsored laboratories (CSIRO, the Danish International Development Agency, the Bandung Institute of Technology, the Forestry Research Development Centre), universities (Gadjah Mada University, Oxford), concession holders (Astra, ITCI) and from other projects (the ASEAN-New Zealand Afforestation Project, F/FRED). In addition, the project's own collections were arranged in limited scale in Kalimantan, Java, Sulawesi, Moluccas, and Irian Jaya. Today, seed acquirement for trial activities is greatly improved.

Testing has followed the guidelines described by Burley and Wood (1976). They divide the species testing to three phases: species elimination, species testing, and species proving.

The trials were arranged using a Randomized Complete Block (RCB) design. Species elimination trials were carried out using line plots of five trees, with 6-8 replications. Species that performed well in those trials were studied in more detailed trials (species testing phase). In these, square plots of 16-64 trees and buffer rows have been used. The species proving phase has been initiated with several species by establishing pilot plantations (1-5 ha).

Recently some small trials have been established using the Nelder wheel design, which allows testing of species/provenance and spacing in the same trial. This design limits the use of some statistical analysis, but is considered a very effective demonstration block design (Briscoe 1990).

Results from the Species Trials

Burley and Wood (1976) consider the final results from species trials to be available at half of the rotation age. Based on our experience in Kalimantan, this means 3-5 years for fast-growing species, and 10-20 years for others. The use of line plots (or any other small plots) shortens the life of the trial due to interactions between adjacent plots. Some conclusions from the species trials in Riam Kiwa have been prepared (Hadi, Vuokko and Adjers 1990a, Nikles 1990, Vuokko 1991).

Several acacias have performed well, with particularly impressive survival in the field (90-100%). Among all the trial species, the acacias seem to have the best potential considering both survival and growth.

Acacia mangium has grown well, as expected. *A. crassicarpa* has grown even better than *A. mangium* in the species elimination trials, and generally very well in other trials too. Especially on dry and poor sites, *A. crassicarpa* seems to be superior. *A. aulacocarpa, A. auriculiformis, A. cincinnata, A. leptocarpa*, and *A. oraria* have shown good early survival and height growth. However, *A. oraria* remained a small bush and the growth rates of *A. cincinnata* and *A. leptocarpa* have clearly slowed down after 3-4 years. *A. hylonoma* was planted in a species trial in 1988. It has high survival but relatively slow growth compared to the promising acacias.

Acacia auriculiformis, A. aulacocarpa, A. crassicarpa, and *A. mangium* are all very promising afforestation species and are now in more detailed tests. *A. polystachya* has recently been included in species elimination trials, and its early growth and survival have been quite good.

Provenance Trials

Once promising species are found, the next logical step in an improvement program is to continue with provenance trials of those species. The Indonesia-Finland project has established provenance trials of 12 species, of which the most comprehensive and successful are those with tropical acacias. The trials with other species have suffered from a limited range of provenances, silvicultural difficulties, and fire destruction.

Burley and Wood (1976) divide provenance testing into three phases: range-wide provenance sampling, restricted provenance sampling, and provenance proving. The trials of acacias in Riam Kiwa represent mainly the two first steps, but also extend somewhat into the third phase (pilot plantations/base populations using different provenances).

The provenance trials have employed an RCB, using plots of 16-49 trees with 4-6 replications. The plots have been measured annually for height, DBH, number of stems, and crown diameter. Some trials have been analyzed in greater detail for M.Sc. and Ph.D. theses.

Recently more attention has been paid to the representative sampling within a provenance. The desired number of parent trees has been set at 20 or more (Nikles 1990).

Acacia mangium

The project has established a total of four provenance trials of *A. mangium*. The first trial, begun in the rainy season of 1986-87, consisted of 25 provenances or land races. Although this trial represented quite well the species' natural distribution, it did not include any provenances from Merauke (Irian Jaya) or Papua New Guinea (PNG).

The second trial, established one year later (1987-88), consisted of three PNG provenances and the Subanjeriji land race. It was thus an extension of the first trial, the Subanjeriji origin connecting the two trials.

The next two trials were planned based on the results of the earlier trials. The search for provenances for testing in these trials focused on those that performed well in the earlier trials and on other provenances not tested in those trials.

As there were many seedlots available in various seed laboratories, the geographical area covered was divided among 9 provenance regions, 0-8 (Nikles 1990). Seeds of 1-4 provenances from all 9 regions were acquired, and the two trials were planted in 1990-91 and 1991-92. The most recent trial, in particular, is expected to give valuable information, as it includes all the generally high-performance provenances (Table 1). The approximate locations of the provenance regions are marked on the map in Figure 1, which also shows the locations of Indonesian and Malaysian provenances/land races tested in 1986-87 trial.

Acacia auriculiformis

During the rainy season of 1989-90 a provenance trial of *A. auriculiformis* was established as part of the multilocation, international provenance trial of the species, organized jointly by the F/FRED project and CSIRO. There are 25 provenances in the trial, representing a wide range of distribution of the species (QLD and Northern Territories in Australia, and PNG).

Acacia aulacocarpa

A. aulacocarpa has grown rather well in species elimination trials, but has been remarkably multi-stemmed. In 1991-92 the project established a small provenance trial of the species with five provenances from PNG and one from Irian Jaya (Table 2).

Acacia crassicarpa

This species was introduced to Riam Kiwa in 1986, and the authors are aware of no previous trials with this species in Indonesia. From the beginning, the species has shown good growth, and in species trials has performed even better than *A. mangium*.

Difficulties with seed supply have limited further testing of this species, however. Thus, only a small provenance trial with three provenances was established in 1989.

In 1991, the project acquired seeds of 13 different provenances. These seed enabled the establishment of a good provenance trial of the species representing both PNG and QLD origins (Table 3). The old trial will be converted into a temporary seed stand.

Results from the Provenance Trials

Acacia mangium

The 1986/87 provenance trial has been analyzed at age 30 months (Hadi, Vuokko and Adjers 1990b) and 61 months (5.1 years). These results can be considered final, having well

Table 1. *Acacia mangium* provenances in the provenance trial* established 1991-1992.

No	Region	Seed supplier	Origin	No. of parent trees	Approximate number of seedlings
1	0	s17866	PNG 06°51'S 141°29'E	34	1440
2	1	ff1996	PNG 08°31'S 142°41'E	24	1080
3	1	s16971	PNG 08°47'S 142°52'E	120	5175
4	1	s17872	PNG 08°49'S 142°54'E	140	14400
5	2	ff2011	PNG 08°01'S 142°58'E	35	675
6	2	s16938	PNG 08°05'S 142°58'E	70	3285
7	2	ff2013	PNG 08°19'S 143°02'E	50	630
8	3	s16997	PNG 08°37'S 141°58'E	30	4320
9	3	ff1981	PNG 08°40'S 142°00'E	20	1980
10	3	s16990	PNG 08°42'S 141°52'E	25	3285
11	4	ff1998	PNG 08°31'S 141°13'E	25	720
12	4	MOF	Erambo, Merauke, Irian Jaya	30	900
13	5	s17701	QLD 12°45'S 143°17'E	57	2700
14	5	s17946	QLD 12°48'S 143°18'E	60	1350
15	6	a538	QLD 15°53'S 145°20'E	50	6750
16	6	d590	QLD 16°16'S 145°21'E	227	3375
17	6	s15367	QLD 16°31'S 145°24'E	120	1845
18	8	s15238	QLD 18°00'S 145°50'E	170	810
19	-	Inhutani	Subanjeriji,S. Sumatra	?	2340
20	4	SRW	Pulup, Irian Jaya	2	540

s = CSIRO, Australia; ff = Future Forests, Australia; a = Australian Tropical Plant Supplies; d = Dendros seed, Australia; SRW = Surya Raya Wahana, Indonesian forestry company, MOF = Ministry of Forestry
*4 replications, 7 x 7 tree plots, 3 m x 3 m spacing, 20 x 4 x 49 trees = 3920 trees, plus buffer rows.

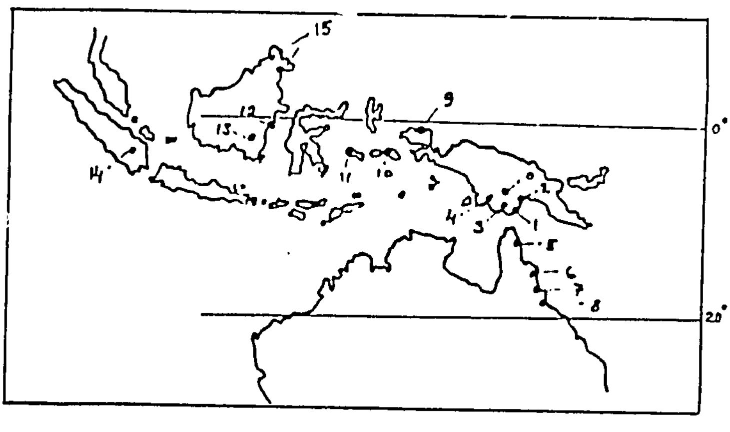

Figure 1. Map showing the provenance regions and other seed sources tested in the provenance trials in Riam Kiwa. Regions under detailed testing are numbers 0-8. Other numbers refer to: 9 = Sidei, 10 = Ceram, 11 = Pulau Taliabu, 12 = Sanga-Sanga, 13 = Barabai, 14 = Subanjerji, and 15 = Sabah.

exceeded half of rotation age (Hadi, in preparation). The trial was also sampled for a study on wood properties (Laurila, in preparation).

The 1988/89 trial, consisting of PNG provenances, will be converted into a temporary seed stand as the 1991-92 trial will completely replace it. A report of this trial is in preparation (Vuokko and Azis, in preparation). The following paragraphs describe results from these two trials.

Survival of all provenances has been good, varying between 90 and 100%. Height growth development of selected provenances from the oldest trial (1986-87) is presented in Figure 2. The tallest provenance in the trial is Claudie River, QLD. The widely used Indonesian land race Subanjeriji, South Sumatra and Sidei from Irian Jaya show slower growth. The poorest performer in the trial is the Sanga-Sanga land race from East Kalimantan. The growth curves show very large provenance differences.

The provenance with best height growth also shows the best diameter growth. If stem volumes are compared, the differences between provenances become huge. The best provenances reached mean annual increment (MAI) of 50-60 m^3/ha/year, whereas the Subanjeriji did not exceed 30 m^3/ha/year. The Sanga-Sanga origin produced less than 20 m^3/ha/year, and the amount of usable wood is even smaller due to its forking stem (Schildt 1992).

In general, provenances from the northernmost tip of Queensland and southern PNG have performed better than those from Irian Jaya or land races from elsewhere in Indonesia or Sabah. Similar results have been obtained in several other trials (Harwood and Williams 1991). There seem to be big differences in stem quality properties between provenances (Hadi, Vuokko and Adjers 1990b). Such differences in stem quality can be clear even between provenances that are geographically rather close (Vuokko and Azis, in preparation).

The Merauke provenances were not present in the older trials. They are included in the younger trials of 1990-1992, and are of great interest as they may have some of the good characteristics found in nearby PNG provenances.

Acacia auriculiformis

Some preliminary results from the *A. auriculiformis* trial at two years (Table 4) indicate that provenances from PNG are very vigorous, whereas the provenances from QLD have the best stem form (highest percentage of single stems, 74-97%) and a survival exceeding 95% for all provenances. The provenances of NT are poor both in vigor and quality, although there appear to

Table 2. *Acacia aulacocarpa* provenances in the provenance trial* established 1991-1992.

No	Seed supplier	Origin	No. of parents	Approximate number of seedlings
1	ff1983	PNG 08°05'S 142°58'E	50	810
2	s16996	PNG 08°38'S 142°03'E	150	900
3	s17628	PNG 08°33'S 141°45'E	50	540
4	ff1986	PNG 08°01'S 142°41'E	40	945
5	ff1987	PNG 08°31'S 141°13'E	70	1080
6	SRW	Bade, Irian Jaya	5	1035

s = CSIRO, Australia; ff = Future Forests, Australia; SRW = Surya Raya Wahana, Indonesian forestry company. *4 replications, 7 x 7 tree plots, 3 m x 3 m spacing, 6 x 4 x 49 trees = 1176 trees, plus buffer rows.

Table 3. Provenances of *Acacia crassicarpa* planted in the provenance trial* established 1991-1992 in Riam Kiwa, South Kalimantan, Indonesia.

No	Seed supplier	Location	No. of parents	Approximate number of seedlings
1	ff2000	PNG 08°31'S 141°13'E	9	13957
2	s16598	PNG 08°37'S 141°55'E	230	6075
3	s16602	PNG 08°31'S 141°13'E	41	855
4	s13680	PNG 08°51'S 141°26'E	21	675
5	s16993	PNG 08°40'S 141°50'E	20	900
6	s17552	PNG 08°53'S 141°17'E	35	900
7	s17561	PNG 08°40'S 142°43'E	30	630
8	s17869	PNG 08°45'S 141°37'E	34	675
9	s16977	PNG 08°49'S 142°48'E	20	1800
10	s16128	QLD 11°02'S 142°22'E	15	540
11	s17948*	QLD 12°38'S 143°23'E	10	
	s17943*	QLD 12°19'S 142°50'E	5	585
	s17944*	QLD 12°48'S 143°18'E	4	
12	s16755*	QLD 15°36'S 145°19'E	3	405
	s15950*	QLD 15°36'S 145°20'E	10	
13	s16598	PNG 08°37'S 141°55'E	230	

*4 replications, 7 x 7 tree plots, 3 m x 3 m spacing, 13 x 4 x 49 trees = 2548 trees, plus buffer rows.
**Mixed seedlots

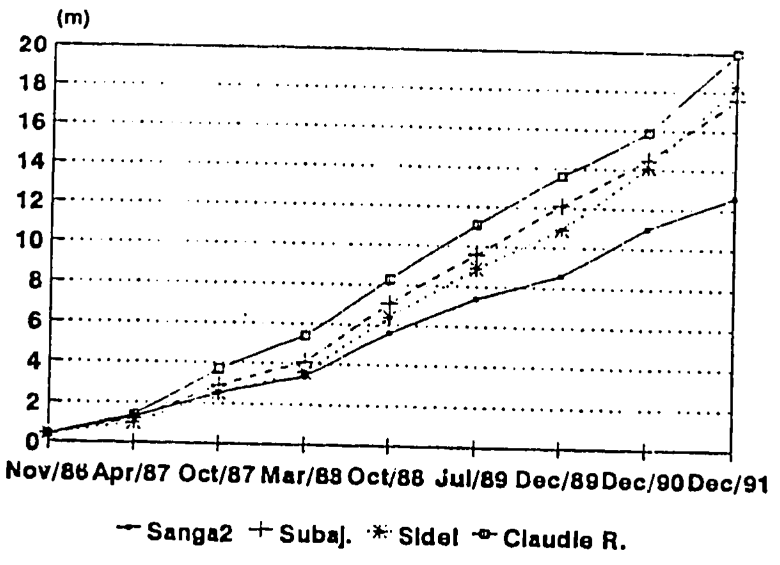

Figure 2. Height growth (m) of four provenances of *Acacia mangium* in the 1986-87 provenance trial in Riam Kiwa, at 61 months (5.1 years).

Table 4. Height growth and percentage of single stem trees at the age of 24 months of various *Acacia auriculiformis* provenances in Riam Kiwa, South Kalimantan, Indonesia.

No.	CSIRO Seedlot No.	State	No. of Parent trees	Height (m)	% Single Stem
1	15483	QLD	5	7.8	90
2	15697	QLD	10	7.2	90
3	15985	QLD	10	6.7	94
4	16142	QLD	7	7.4	74
5	16145	QLD	20	7.5	93
6	16484	QLD	6	8.0	97
7	16485	QLD	7	7.6	90
8	16147	NT	5	8.6	74
9	16148	NT	10	6.7	57
10	16149	NT	10	5.7	77
11	16151	NT	8	5.9	64
12	16152	NT	10	7.1	60
13	16153	NT	5	6.4	79
14	16154	NT	9	7.2	83
15	16155	NT	4	8.0	84
16	16156	NT	6	7.4	78
17	16160	NT	10	6 1	71
18	16163	NT	9	8.0	88
19	16187	NT	7	6.9	74
20	16101	PNG	16	8.2	81
21	16103	PNG	7	8.0	57
22	16105	PNG	12	7.1	54
23	16106	PNG	35	8.4	63
24	10107	PNG	19	8.8	74
25	16108	PNG	8	7.7	64

be exceptions (Table 4). In general there seems to be greater variation within provenances than in *A. mangium* provenances, which produce very uniform stands. A trial report will be prepared in cooperation with Winrock.

Future Activities

General

Future project activities will depend in part on the results of the established trials, especially those planted in 1991/92. The emphasis will be more centered on the whole management system when *I. cylindrica* grasslands are afforested. Information gaps remain in several fields and need to be addressed.

Nutrition

Nutrition is an area for which information is lacking. Additional fertilizing trials were established in 1991/92. Priority species are *A. mangium* and *A. crassicarpa* (Simpson 1992).

Thinning, spacing, and growth and yield trials

Volume and yield assessment, as well as thinning trials of *A. mangium* were laid out in 1991 in a 4-year old stand. This work is done in cooperation with Gadjah Mada University in Yogyakarta.

The first volume tables are expected to be ready during 1992. The yield study and the thinning trials will take three to four more years to be completed.

Spacing trials with *A. mangium* and *A. crassicarpa* were established but unfortunately lost to wild fire in October 1991. New trials of *A. mangium* and *A. aulacocarpa* were planted in the first half of 1992.

Forty-five semi-permanent yield plots in South Kalimantan and South Sumatra have also been laid out and are now being monitored.

Model tree improvement program for *Acacia mangium*

Acacia mangium is a well tested, reliable afforestation species that also has potential as raw material for industry. The species has been widely used in planting programs in Indonesia, mostly using seed from collections in plantations of Subanjeriji, South Sumatra. The genetic base of those plantations is very narrow, and the use of these plantations as the major seed source of *A. mangium* should be avoided (Nikles 1990 and 1991). Furthermore, the provenance trials carried out in Riam Kiwa have shown that several seed sources in QLD and PNG are superior to the Subanjeriji land race. Better seed production areas can and should be developed in Indonesia. This has been addressed by the project.

The species and provenance trials, as well as the pilot plantations with different provenances of *A. mangium*, have made it possible to initiate tree improvement work with this species. The model tree improvement program for this species was designed by Dr. Garth Nikles.

For the improvement program, several base populations of best provenances (provenance regions 0-8) of *A. mangium* have been or will be established. Seed collected from at least 100 parent trees per provenance region will be used to establish these plantations, which will be at least 10 ha and preferably larger. From these plantations, phenotypically good parent trees (plus trees) will be selected. Their genetic value will be tested, vegetative propagation of plus trees developed, and finally seed orchard(s) for production of genetically improved seed will be established.

The main undertakings of the tree improvement program are listed below.

1982	*Acacia mangium* compared with other species, potential confirmed in species trials and pilot plantations (first in Subanjeriji, South Sumatra and later in Rantau/Riam Kiwa, South Kalimantan)
1986-1992	provenance tests established
1987-1996	provenance tests analyzed
1988	genetic base populations established using best provenances in the provenance trials
1991	plus trees selected in selection-aged (3-4 years) stands (approximately 10-20 trees can be found annually)
1992	temporary seed stands tended and thinned
1992	vegetative propagation of acacias tested
1993	plantlets from plus trees produced
1993	seeds from plus trees harvested, progeny tests carried out
1994	first clonal seed orchard established
1996	seeds from the seed orchard one harvested, progeny tests, roguing

Later, the seed orchard(s) and the other created seed stands (base populations) will be used to supply seed to government reforestation programs. Again, though, large-scale seed collection, storage, and distribution is not the work of the project, but should be taken up by an appropriate national organization.

If this model tree improvement program for *A. mangium* is successful, it can be relatively easily repeated in other locations or with another acacia species.

Vegetative propagation

In order to find appropriate techniques for production of plantlets with superior genotypes for use in seed orchards, the project initiated studies on vegetative propagation methods. This work is still going on, focussed on the project priority species of *A. mangium, A. crassicarpa* and *A. auriculiformis*.

Selection of plus trees of *A. mangium* started in 1991. The other species have not yet reached the selection age. Until they do, it is possible to develop vegetative propagation methods.

Rooting and grafting

Rooting frequency of *A. mangium* has been satisfactory only with stock younger than two years. There has been little success in rooting or grafting of cuttings from trees of selection age (3 years or older).

The highest rooting has been obtained with *A. crassicarpa*. In a trial comparing the effect of rooting hormones IAA and IBA, 80% of the cuttings treated with 6,000 ppm IBA rooted. In another trial 20% of bud grafted plants survived at the nursery. New trials have been established to study the field performance of such plants.

It is not known why the success of vegetative propagation of tropical acacias declines with increasing age. By rejuvenating the stock through severe pruning and decapitation, this problem may be overcome.

Marcotting

So far marcotting, although tedious, is the best known successful method. In a marcotting trial, 17 out of 50 marcottes of *A. mangium* rooted. During the acclimatization phase in the nursery, seven of them died. In this ongoing trial the marcottes vigorously produce juvenile shoots, which can be used for further rooting trials.

Proposed topics for future research

The present Phase IV of the Reforestation and Natural Forest Management project expires at the end of December 1992. For the next four-year phase, proposed activities include:

- continued species and provenance trials
- continued trial and development work with vegetative propagation
- tree improvement with acacias
- soil studies and fertilization
- thinning and spacing trials
- growth and yield
- a management system for large-scale plantations in *I. cylindrica* grasslands using satellite images and geographic information systems
- species for the second rotation after one generation of acacia

If the project continues into its next phase, activities will focus on the promising *Acacia* species.

Discussion Notes

The nursery in South Kalimantan, producing 7 million seedlings per year, was turned over to the Indonesian government several years ago.

A. crassicarpa and *A. mangium* have proven very good; *A. aulococarpa* has been less successful, showing poor, multi-stemmed growth. Another set of trials on this latter species is underway, as are wood-processing studies of *A. mangium*.

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Acacias in Papua New Guinea: Current and Future Research

P.B.L. Srivastava and W. Yelu

Introduction

Acacias in the humid tropics have proven to be truly multipurpose trees. Besides their commercial use for pulping and as sawn timber, they have been successfully integrated in some farming systems as important agroforestry trees for providing firewood, charcoal, wood, shade, and shelter. Their fast growth and capacity to stabilize and improve degraded soils have made *Acacia* the most popular genus of afforestation and reforestation species in many countries outside their natural distribution. This paper reviews current research on acacias in Papua New Guinea (PNG) and proposes future course of work for better understanding their silvicultural requirements.

Distribution

The ecology and distribution of *Acacia* species in PNG has been described by Skelton (1986). In all, 14 *Acacia* species have been recorded on the Papua New Guinea mainland. Nine of these are indigenous, two are naturalized, and three have been cultivated (Verdcourt 1979). The species with their approximate recorded maximum heights are shown in Table 1.

In PNG, acacias are mostly confined to a small area between the Digul and Fly rivers in southern New Guinea, on a low plateau known as the Oriomo Plateau in Western Province, and to the Merauke Ridge in Irian Jaya, Indonesia. There the shrub *A. simsii* and five of the large and medium tree species are common. *A. aulacocarpa, A. crassicarpa, A. leptocarpa* and *A. pubirhachis* have been observed only in this region of PNG.

The Oriomo Plateau is a slightly undulating, featureless plain through which a number of shallow-gradient, deep rivers have incised open valleys. In contrast, the Fly-Digul

Table 1. Acacia species found in Papua New Guinea mainland.

Species	Type L	Type M	Type S	Type C	Approximate max ht. (m)	Condition
Acacia aulacocarpa	*				35	indigenous
A. auriculiformis	*				30	indigenous
A. crassicarpa	*				30	indigenous
A. mangium	*				30	indigenous
A. mearnsii	*				25	naturalized
A. leptocarpa		*			10	indigenous
A. solandri		*			12	indigenous
A. deanei			*		6	cultivated
A. farnesiana			*		4	naturalized
A. flavescens			*		7	cultivated
A. holosericea			*		6	cultivated
A. simsii			*		6	indigenous
A. concinna				*	18	indigenous
A. pluriglandulosa				*	tall shrub	indigenous

L = large tree; M = medium-sized tree; S = small tree/shrub; C = climber.

Shelf consists of closely spaced narrow ridges and valleys with an intricately dendritic pattern (Blake in Paijmans et al. 1971). This is probably due to the higher rainfall: in Oriomo Plateau, mean annual rainfall varies between 1500 and 2100 mm, with most rain falling between January and May. The boundary between moist high forest to the north and dry evergreen forest and savannas to the south approximately coincides with the 2200 mm isohyet, just north of the lower Fly River.

Seed Collection

The Brown River provenances of *A. auriculiformis* have been planted extensively in small woodlots since 1960s and seed of an unknown Queensland provenance of *A. mangium* was introduced at Bulolo Research Station in 1978. Still, no research was initiated on acacias in PNG, in part because it was not considered a priority genus for afforestation or reforestation. At that time, and to some extent even now, most research concentrated on tropical pines, *Eucalyptus robusta*, and *E. grandis* in the highlands; Araucarias in mid-montane areas; and almost exclusively *E. deglupta* in the lowlands. Initial interest in acacias was for seed collection from natural stands, especially *A. mangium* probably due to its excellent performance in Sabah, Malaysia. A large demand for seeds of this species was foreseen. Seed collections in 1980, 1982, and 1983 are described by Doran and Skelton (1982), Turnbull (1982), Skelton (1983), and Turnbull et al. (1983). Seed collections from natural stands of Western Province of PNG are still being carried out as a collaborative project between the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) and the Papua New Guinea Forest Research Institute (PNGFRI). The latest expedition was mounted in 1991 by a CSIRO team.

Establishment of Seed Production Stands

Seed collection from natural stands in Western Province was found to be very expensive, in addition to posing a number of other logistic problems. The Forest Management Research Branch therefore decided to establish a number of seed production stands. To date, four 4-ha seed production stands of Balamuk, Toko, Iokwa and Oriomo provenances of *A. mangium* were established in Madang in 1984-85. Individual half-sib offspring from natural mother trees are equally distributed on the site. The trees were planted at 8 x 8 m spacing so that they would develop bigger and wider crowns which would produce greater quantities of seed pods. Three trees are now 30 cm in diameter at breast height (DBH) and about 15-20 m in height. The first viable seeds were collected in 1987 (about 8 kg pure seed). During 1988-89, the quantity increased to 10 kg per stand. However, from the natural trees in Western Province, as much as 1 kg pure seed could be obtained from one tree (Skelton 1983). In 1984, three 2-ha seed stands of *A. auriculiformis* were established in Bulolo (altitude 700 m). In 1985, another two 2-ha seed stands of *A. mangium* were established, one on formerly forested land and the other two on grassland sites in the same locality. The *A. mangium* stands on grassland did not perform well due to poor site conditions, dry weather, and chewing damage on stems inflicted by grasshoppers or rats (the actual cause could not be identified although a rat killer chemical was applied). In all these stands, a 7 x 7 m spacing was adopted. Seed collection from these stands began in 1987-88.

From general observations, seed stands established in logged-over rain forests are producing trees with better growth and form and larger crowns; a few have reasonably straight boles, good crown form, and small branches. We at PNGFRI are planning to establish second generation seed orchards from seeds collected from these trees. Seed trees in grasslands are poorer in growth and form. We are also planning to establish more provenance seedling seed orchards of *A. mangium*, *A. auriculiformis*, *A. crassicarpa*, and *A. aulacocarpa* in order to get genetic material suitable for an improvement program.

Seed Germination and Nursery Practices

After a number of trials, following procedure has been adopted as a standard:

1. Put seeds in small round containers made of flywire.

2. Soak the container of seeds in boiling water for 30 seconds.

3. After 30 seconds, remove the seed container from the boiling water and soak in cold water for 24 hours.

4. Broadcast seeds in germination trays and leave them under sarlon shade (50-70%).

Germination begins between 7-14 days using this procedure. Average germination for all *Acacia* species is 60%. Two weeks after germination, seedlings are tubed and left under sarlon shade (50%) for six weeks. They are then transferred to stand-out beds and left for three months before planting out in the field. Total time from sowing to planting out is between five and six months, when seedlings are 20-30 cm in height. No improved fertilizer application techniques have yet been tested. However, JANT found that application of 3 granules of NPK fertilizer per pot improved leaf color from yellow to normal dark green and reduced nursery period by at least a month. Another major problem in the nursery is high mortality caused by damping off fungus disease. The chemical Thiram has been found very effective in controlling this disease.

Species and Provenance Trials

Acacia mangium Provenance trial

This trial, established in 1982 in the lowland forest areas of Gogol Valley, Madang Province, tested nine provenances: four from PNG, five from Australia, and control of two other species — *Eucalyptus deglupta* and *A. auriculiformis*. Three types of sites were selected for this trial:

- ex-forest, hill imperfectly drained
- ex-forest flat, poorly drained
- *Imperata cylindrica*-dominated grasslands hill, imperfectly drained

Preliminary results at age 2.5 years (1985 measurements), reported by Skelton and Howcroft (1986), showed that Balamuk provenance had the best height growth, although the differences among provenances was not statistically significant at $P < 0.05$. The trial was terminated in 1987 at age 5 years, but the data have yet to be analyzed.

Acacia auriculiformis Trial

Most PNG research on this species was confined to the trials established in anthropogenic grasslands in East Sepik Province. From continuous gardening for subsistence agriculture, these plains have deteriorated to fragile, poorly drained soils. Lamb (1975) described widespread mortality of this species, possibly due to waterlogged soils for lack of pathological evidence. Ineffective mycorrhizae could also be responsible. A spacing trial to study the species' form was abandoned in 1979 after pigs repeatedly uprooted seedlings. Growth plots of this species were established on three sites in Bulolo, representing the same types of sites as in the *A. mangium* provenance trial described above (grassland hill, imperfectly drained; ex-forest hill, imperfectly drained; and ex-forest flat, poorly drained). Observations indicate best performance on ex-forest hill site.

Acacia Species cum Provenance Trial

In 1986, a species *cum* provenance trial of PNG acacias was established in a randomized block factorial, replicated at two (ex-forest hill, well drained, and *I. cylindrica* hill imperfectly drained) sites. The details of the species and provenances are given in Table 2. Total trial area was 1.1 ha on each site with 18 m x 18 m plot (0.0324 ha). There were 33 plots on each site with one plot per treatment.

At age 1.5 years, *A. mangium*, B 1622, Toko provenance showed the best height growth (1.70 m) on the grassland site ($P<0.01$), but not significantly different from *A. auriculiformis*, B 1612 Bula, *A. auriculiformis*, B 1608 Balamuk and *A. auriculiformis*, B 1610, Iokwa provenances. At $P<0.05$, *A. mangium*, B 1622, Toko was greater than all treatments but not significantly greater than *A. auriculiformis*, B 1612, Bula. In terms of survival, treatments 4 and 11 were the best.

Table 2. *Acacia* species and provenances tested.

Treat-ment No.	Batch No.	Gm Sowed	Species	Provenance
1.	1602	10	*A. aulacocarpa*	Iokwa
2.	1604	10	*A. aulacocarpa*	Oriomo River
3.	1606	10	*A. aulacocarpa*	Keru
4.	1608	10	*A. auriculiformis*	Balamuk
5.	1610	10	*A. auriculiformis*	Iokwa
6.	1612	10	*A. auriculiformis*	Bula
7.	1614	20	*A. crassicarpa*	Wemenever
8.	1616	20	*A. crassicarpa*	Mata
9.	1618	20	*A. crassicarpa*	Oriomo River
10.	1920	20	*A. crassicarpa*	Woroi/Wipim
11.	1622	10	*A. mangium*	Toko

On the well-drained, ex-forest site, *A. auriculiformis*, B 1602, Balamuk showed greater height than other treatments (max height = 6.81 m), at $P<0.01$, but not significantly different from *A. auriculiformis*, B 1612, Bula, *A. mangium*, B 1622 Toko and *A. auriculiformis*, B 1610 Iokwa provenances. At 5% level, *A. auriculiformis*, B 1602 Balamuk and B 1612 Bula were greater than the rest of the treatments but significantly not different from *A. auriculiformis* B 1610 Iokwa provenance. In terms of survival, *A. auriculiformis*, B 1608 Balamuk again showed the best performance. The trial was terminated in 1990, but the data have not been analyzed.

Other Trials

To determine which multipurpose tree species are suitable for different sites and altitudinal zones, the Department of Agriculture and Livestock established a series of growth/observation plots of a number of legume species, including *Acacia* species. In almost all characteristics (height, number of branches, biomass, volume) in both lowlands and highlands, *A. angustissima*, introduced from South America, performed the best in two years of observations. This species withstands drought and waterlogging and has a deep tap root system suitable for rehabilitating degraded and marginal sites. Though its greatest potential lies in alleycropping and fallow management in the highlands, its prolific seeding could also make it a weed species (Kanua and Sitapai 1992).

In another trial, *A. auriculiformis* and *A. crassicarpa* were planted at 4 x 4 m and 4 x 1 m, with intercrops (using alley cropping system) of lettuce, chinese cabbage, zucchini, cucumber, eggplant, snake bean, radish, celery, carrot, tomato, turnip, watermelon, sweet potato, and maize. At age two years, *A. auriculiformis* and *A. crassicarpa* showed a mean height of 5.8 m and 7.0 m, respectively, and mean diameter of 5.9 cm. *A. auriculiformis* yielded more total biomass than *A. crassicarpa*, mainly due to its more dense branching (Gessesse 1992).

Research Priorities and Future Program

This brief review reveals that research on *Acacia* species in PNG has been limited mainly to establishment of seed production stands and a few species and provenance trials. This has been due to two reasons:

1. Neither timber companies nor the Department of Forests considered acacias

priority species for reforestation. To date, more than 80% of reforestation land (about 42,000 ha) is covered by *Eucalyptus* and *Pinus* species. *Acacia mangium* covers only 1.1%. Only in the last few years have some timber companies started large-scale planting of *A. mangium*, once it was proven beyond doubt that this species grows faster than *E. deglupta* on the same site in Gogol Valley.

2. Lack of trained personnel and funding.

Since acacias are now attracting attention from large timber companies for planting programs and their potential for integration with subsistence farming systems, PNGFRI's research program includes the following investigations, subject to availability of funds:

1. *Species suitability*

   Acacia species trials on a range of climato-edaphic conditions

2. *Nursery techniques*

   Shorten nursery period and tube size (through application of fertilizers)

   Production of planting stock by vegetative propagation

   Rhizobia inoculation trials

3. *Plantations*

   Site suitability -- species trials

   Direct sowing vs. transplanting

   Spacing -- closer for pulp and paper

   Tending and thinning

   Fertilizer trials

   Growth and yield

4. *Tree improvement*

   Selection of plus trees

   Establishment of clonal seed orchards

   Progeny testing

5. *Others*

   Testing acacias in agroforestry trials

Strategically, we have decided to implement the program through three means:

- o Establish research trials with our own staff and funding resources
- o Collaborate with timber companies in their ongoing plantation programs
- o Through the MPTS Research Network, collaborate with other organizations, especially the Department of Agriculture and Livestock

Discussion Notes

Germination and nursery work has not been studied as it is generally standardized by now. There is a need to find a species as acceptable to the farmer as *Casuarina oligodon*.

Regarding fertilizer studies:

PNG soils generally do not require fertilizer. *A. mangium* has suffered large-scale mortality in waterlogged conditions.

SFI finds that there have been few in-depth studies of fertilizer application. Its effectiveness often depends on site quality. Often, N interferes with rhizobium activity of *A. mangium*. Phosphorus (P) and potassium (K) leach quickly. A cost-benefit review of compound fertilizers is needed.

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Research on Acacias and Their Potential

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Introduction

The rapid depletion of tropical forests has led to critical shortages of fuelwood in rural areas of many tropical countries. One way to tackle this problem is to develop sustainable agro-forest farms and communities, in which fast-growing, multipurpose tree species (MPTS) play an important role, providing fuelwood, animal feed, green manure, food, soil and environmental conservation, and other wood uses.

Many species used in tree-planting programs, especially in industrial plantations, are generally regarded as single purpose, and not adapted for the multiple needs of farm communities. The Thailand Institute of Scientific and Technological Research (TISTR) is one of many institutions undertaking research on MPTS and recently on acacias and other species considered to have potential as MPTS.

Among potential MPTS, the genus *Acacia*, widely distributed in South America, Africa, Australia, and Asia, is becoming more popular among researchers. So far, this popularity in humid and subhumid areas is limited to a few species, particularly *Acacia auriculiformis* and *A. mangium*. This paper reports on TISTR's research on acacias and recent results from TISTR species and provenance trials, highlighting promising, lesser known species and provenances.

TISTR Research on Acacias

Recent acacia research has been reported in Turnbull (1987, 1991), Boland (1989), in the annotated bibliography on *A. auriculiformis* prepared by Pinyopusarerk (1990), and in Lantican and Taylor (1991). TISTR's contributions to these have included a research project undertaken 1982-1986, with support from the U.S. Board on Science and Technology for International Development (BOSTID), testing *A. auriculiformis* and *A. mangium* along with other fast-growing, nitrogen-fixing tree species. In these, both species showed outstanding adaptability to acid-sandy soil. Other results include: biomass yields related to plant spacings; coppicing and regrowth characteristics; fertilizer responses; feed and digestibility properties, physical and heating properties and pulp qualities (Yantasath et al. 1985, 1986, 1987, 1992) as well as the relationships between tree species and several genera of vesicular-arbuscular mycorrhizae (VAM) associated with the tree's roots (Yantasath 1989; Poonsawad and Yantasath 1991).

During 1986-1990, TISTR received follow-on support from BOSTID to conduct research on acacias in a project entitled Management and Production of Selected Nitrogen-Fixing Trees. Field trials were established to:

- evaluate the site adaptabilities of several *Acacia* species and provenances, along with other species
- identify significant genetic variability in tree forms and yields
- identify breeding systems and pollination biology of *A. auriculiformis* and *A. mangium*
- develop regression relationships of the tree performances to different climatic and soil variables

The experiments were conducted under four different sets of soil and climatic conditions in the provinces of Chiang Mai (northern), Chonburi (eastern), Chumphon (upper southern), and Surat Thani (southern). Site descriptions are given in Table 1. The experiments were established as yield trials, species elimination trials, half-sib progeny selection trials, and phenology studies.

Table 1. The TISTR sites of Acacia trials.

Location	Latitude, Longitude	Altitude (m)	Soil: Classification	Soil: Characterization 0-20	Soil: Characterization 21-50	Soil: Characterization 51-100	Soil: Physiography	Soil: Slope	Soil: Permeability	Soil: Drainage	Natural Vegetation	Annual Rainfall mm	Annual Rainfall dist.	Mean No. of Rainy Days	Temperature (°C)	Humidity (%)
Maejo Agri. Techology College, San Sai, Chiang Mai	18° 56' N 99° 03' E	390	Kanhaplic Haplustults, Isohyperthermic, Clayer-skeletal, Kaolinitic	Sandy loam pH 5.4 OM 0.59	Sandy loam pH 5.2 OM 0.26	Sandy clay loam pH 5.1 OM 0.19	Inter-mountain basin	1%, facing Southeast	Moderate	Well drained	Dipterocarp forest 10% gravel on surface	1,108	5 months May to September	116	Mean: 27 Max: 32 Min: 21	Mean: 69 Max: 86 Min: 47
Wat Yansangwararam, Royal Temple, Ban Lamung, Chon Buri	12° 47' N 100° 58' E	50	Ustoxic Dystropepts, Coarse loamy, Siliceous	Sandy loam pH 5.6 OM 0.59	Sandy laom pH 5.8 OM 0.07	Sandy loam pH 5.6 OM 0.05	Nearby hills	2%, facing West	Rapid	Moderately well drained	Cleared to upland crops, including cassava	1,159	7 months May to November	106	Mean: 28 Max: 32 Min: 21	Mean: 77 Max: 87 Min: 65
Kancharadit Forest Plantation, Surat Thani	9° 07' N 99° 39' E	40	Typic Paleudults, Fine loamy, mixed	Sandy loam pH 5.0 OM 0.61	Loam pH 5.1 OM 0.37	Sandy clay loam pH 4.9 OM 0.19	Plain	Flat	Rapid to moderate	Well drained	<u>Imperata cylindrica</u>	1,168	8 months May to December	64	Mean: 27 Max: 32 Min: 22	Mean: 81 Max: 95 Min: 60
Pathiu District, Chumphon	10° 59' N 99° 22' E	7	Uncoated Ustic Quartzipsament, Isohyperthermic	Sand pH 4.3 OM 0.78	Sand pH 4.8 OM 0.[illegible]	Sand pH 5.0 OM 0.11	Coastal plain	Complex	Very rapid	Excessively drained	Beach forest	1,710	7 months May to November	169	Mean: 27 Max: 32 Min: 23	Mean: 82 Max: 94 Min: 63

Yield Trials

In these, three provenances each of *A. auriculiformis* and *A. mangium* were compared with *Leucaena leucocephala, L. diversifolia* and *Cassia siamea* (Table 2). The trials employed a randomized complete block design, with 4 replicates, 36 trees per plot. Acacias were planted at 2 x 2 m spacing, the other species were planted at 1 x 2 m.

Three years after planting, *A. auriculiformis* and *A. mangium* had adapted very well at the wetter Surat Thani site; its high rainfall was one significant correlation factor. Yields declined at Chonburi, Chumphon, and Chiang Mai, in that order. Performances of both acacias were highly correlated to humidity.

Table 2. Species and provenances tested in TISTR yield trials at all four sites.

Code	Species	Provenance
1. Aur 1	*A. auriculiformis*	Chumphon
2. Aur 3	*A. auriculiformis*	Queensland
3. Aur 7	*A. auriculiformis*	Ratchaburi
4. Man 1	*A. mangium*	Chumphon
5. Man 2	*A. mangium*	Lad Krating
6. Man 3-1	*A. mangium*	PNG
7. Leu K28	*L. leucocephala*	Hawaii
8. Leu K156	*L. diversifolia*	Hawaii
9. Sia 1	*Cassia siamea*	Chumphon

Species Elimination Trials

To eliminate and select outstanding species and provenances, 20 species, represented by 65 provenances (Table 3), were planted at the four sites. Trials were planted in an unreplicated plot of 36 trees per plot, with 6 rows 2 m apart and 6 trees per row, 1 m between trees.

Outstanding tree provenances at each site were evaluated based on growth characteristics and yield performance, as well as genetic uniformity, survival rate, stem form, and pest and disease damage.

At Chiang Mai, where most trees did not perform well due to poor soil and long drought conditions, the best performing provenances 18 months after planting were Lep 1, Lep 2, Aur 5, and Hol 1 (Table 4). Average heights were over 2 m and diameter at breast height (DBH) averaged over 1 cm. Survival for these ranged between 70-100%, even though these would elsewhere be considered very low.

At Chonburi, the best performing tree provenances were of *A. mangium*, *A. auriculiformis*, *A. holosericea*, and *A. aulacocarpa* (Table 4), with over 3 m average heights and over 2 m DBH, and survival of 70-100%.

Performances at Chumphon were better than at the other two sites, with 70-97% survival percentages, 5-6 m average heights and 4-5 cm DBH for the outstanding provenances (Table 4). At Surat Thani, the best performing species and provenances also had survival rates of 70-100%, with average heights of 4-5 m and average DBH of 2-4 cm.

Among these species, the best provenances with outstanding characters from each site were: Man 3-2-SR; Man 13459-CP; Man 13238-CB; Aur 2-CP; Cra 1-SR; Cra 2-CP; Aur 3-CP and Aur 6-CP. These showed faster growth, good form, good survival, and fewer problems with pests and disease. Other provenances that also grew well and possessed relatively good form and straight stems were: Lep 1-CP; Lep 2-CP; Lep 2-SR and Cam 1-SR. *Leucaena* species (K156-SR; Leu 1-SR; Leu 1-CM and KX_3-SR) did not perform so well, due to attacks and damage caused by the psyllid (*Heteropsylla cubana*), particularly in the dry season. Other provenances possessed good stem straightness (Man 13646-CM; Plec 1-CM and Man 3-1-CB) but were slower growing. On the other hand, some provenances grew faster, but the trees produced more branching and crooked stems.

Table 3. Species and provenances in elimination trials at the four TISTR sites.

Species/ Prov. No.	Code	Scientific name	Seed source	Seedlot No.	Site CM	CB	CP	SR
1	Amp 1	*Acacia ampliceps*	CSIRO, WA	14668	x	-	-	x
2	Aul 1	*Acacia aulacocarpa*	CSIRO, QLD.	13865	x	x	x	x
3	Aul 2	*Acacia aulacocarpa*	CSIRO, Cooktown	14969	-	-	x	x
4	Aul 3	*Acacia aulacocarpa*	CSIRO, QLD.	13866	x	-	-	-
5	Aul 4	*Acacia aulacocarpa*	CSIRO, Yeppoom.	14591	x	x	x	x
6	Aur 1	*Acacia auriculiformis*	TISTR, Chumphon		x	x	x	-
7	Aur 2	*Acacia auriculiformis*	CSIRO, PNG	15648	x	x	x	x
8	Aur 3	*Acacia auriculiformis*	CSIRO, QLD	15477	-	-	x	-
9	Aur 4	*Acacia auriculiformis*	Malaysia	1404	x	x	-	x
10	Aur 5	*Acacia auriculiformis*	Philippines		x	-	x	x
11	Aur 6	*Acacia auriculiformis*	PNG, Belamuk		-	-	x	-
12	Aur 7	*Acacia auriculiformis*	RFD, Ratchaburi		-	x	x	x
13	Aur 8	*Acacia auriculiformis*	RFD, Rayong		-	-	-	x
14	Aur 9	*Acacia auriculiformis*	TISTR, Chan Thuk		-	-	x	-
15	Cin 1	*Acacia cincinnata*	CSIRO, QLD	13878	x	x	x	x
16	Cin 2	*Acacia cincinnata*	CSIRO, QLD	13864	x	x	x	x
17	Cra 1	*Acacia crassicarpa*	CSIRO, PNG	13680	x	-	x	x
18	Cra 2	*Acacia crassicarpa*	CSIRO, PNG	13681	x	-	x	-
19	Dif 1	*Acacia difficillis*	CSIRO, NT	14623	-	-	x	x
20	Har 1	*Acacia harpophylla*	CSIRO, QLD	15100	x	-	x	-
21	Hol 1	*Acacia holosericea*	CSIRO, QLD	13879	x	x	x	x
22	Lep 1	*Acacia leptocarpa*	CSIRO, QLD	14139	x	-	x	x
23	Lep 2	*Acacia leptocarpa*	CSIRO, QLD	14966	x	-	x	x
24	Man 1	*Acacia mangium*	TISTR, Chumphon		x	-	-	x
25	Man 2-1	*Acacia mangium*	TPC, Lad Krating	(survey)	-	-	x	x
26	Man 2-2	*Acacia mangium*	TPC, Lad Krating	(buy)	-	-	-	-
27	Man 3-1	*Acacia mangium*	Malaysia	2154	x	-	-	-
28	Man 3-2	*Acacia mangium*	Malaysia	2332	x	-	x	x
29	Man 3-3	*Acacia mangium*	Malaysia	2333	x	-	x	x
30	Man 3-4	*Acacia mangium*	Malaysia	2520	x	-	x	x
31	Man 3-5	*Acacia mangium*	Malaysia	0002	x	x	x	-
32	Man 4	*Acacia mangium*	CSIRO	13261	x	-	-	-
33	Man 6	*Acacia mangium*	AUST, Kuranda.	27I	x	-	-	x
34	Man 7	*Acacia mangium*	AUST, Hawkins.	28I	x	-	-	x
35	Man 8	*Acacia mangium*	AUST, Wallaman.	29I	x	-	-	x
36	Man 9	*Acacia mangium*	AUST, Ingham.	30I	x	-	-	x
37	Man 10	*Acacia mangium*	AUST, QLD.	13534	x	-	-	x
38	Man 14	*Acacia mangium*	AUST, QLD.	15063	x	-	x	x
39	Man 19	*Acacia mangium*	Philippines		x	-	x	x

CM = Chiang Mai (dry); CB = Chonburi (dry to medium); CP = Chumphon (medium to wet); SR = Surat Thani (wet).
x = included in the test at that site; - = not included.

Table 3 (continued).

Species/ Prov. No.	Code	Scientific name	Seed source	Seedlot No.	Site			
					CM	CB	CP	SR
40	Man 21	*Acacia mangium*	AUST, QLD	15677	-	-	-	x
41	Man 13232	*Acacia mangium*	TPC, Lad Krating		x	-	-	-
42	Man 13234	*Acacia mangium*	TPC, Lad Krating		-	-	x	-
43	Man 13235	*Acacia mangium*	TPC, Lad Krating		x	-	-	-
44	13236	*Acacia mangium*	TPC, Lad Krating		-	-	x	-
45	13237	*Acacia mangium*	TPC, Lad Krating		-	-	x	-
46	13238	*Acacia mangium*	TPC, Lad Krating		-	x	x	-
47	13239	*Acacia mangium*	TPC, Lad Krating		x	-	-	-
48	13240	*Acacia mangium*	TPC, Lad Krating		-	-	x	-
49	13241	*Acacia mangium*	TPC, Lad Krating		-	-	x	-
50	13242	*Acacia mangium*	TPC, Lad Krating		x	-	x	-
51	13459	*Acacia mangium*	TPC, Lad Krating		x	x	x	x
52	13621	*Acacia mangium*	TPC, Lad Krating		-	x	x	-
53	13646	*Acacia mangium*	TPC, Lad Krating		x	-	-	-
54	MEL 1	*Acacia melanoxylon*	CSIRO, QLD	14176	x	x	x	x
55	MEL 2	*Acacia melanoxylon*	CSIRO, QLD	14585	x	x	x	x
56	PLE 1	*Acacia plectocarpa*	CSIRO, WA	14696	x	x	x	x
57	POL 1	*Acacia polystachya*	CSIRO, QLD	13871	x	-	x	x
58	TOR 1	*Acacia torulosa*	CSIRO, QLD	14141	x	-	-	-
59	FAL 1	*Paraserianthes falcataria*	TISTR, Chumphon		-	-	-	x
60	SIA 1	*Cassia siamea*	TISTR, Tubsakae		x	-	x	x
61	CAM 1	*Eucalyptus camaldulensis*	FIO, Surat Thani		-	-	-	x
62	K 156	*Leucaena diversifolia*	Hawaii, U.S.A.		-	-	x	x
63	DIV 1	*Leucaena diversifolia*	TISTR, Phuluang		-	x	x	-
64	LEU 1	*L. leucocephala* (K28)	TISTR, Chan Thuk		x	-	x	x
65	KX 3	*Leucaena* K 156 x K8	Hawaii, U.S.A.		-	-	x	x
66	K hyb	*Leucaena* hybrid	TISTR, Chan Thuk		-	-	x	-

CM = Chiang Mai (dry); CB = Chonburi (dry to medium); CP = Chumphon (medium to wet); SR = Surat Thani (wet). x = included in the test at that site; - = not included.

Table 4. Best-performing provenances at each site after 18 months.

Site	Species	Provenance
Chiang Mai	*Acacia leptocarpa*	Lep 2, Lep 1
	A. auriculiformis	Aur 5
	Leucaena leucocephala	Leu 1
	A. holosericea	Hol 1
Chonburi	*Acacia mangium*	Man 238, Man 459
	A. auriculiformis	Aur 4, Aur 2, Aur 1
	A. holosericea	Hol 1
	A. aulacocarpa	Aul 4
Surat Thani	*Leucaena diversifolia*	K 156
	A. crassicarpa	Cra 1
	A. auriculiformis	Aur 5, Aur 4
	A. mangium	Man 3-2
	A. leptocarpa	Lep 2
	L. leucocephala	Leu 1
	E. camaldulensis	Cam 1
Chumphon	*A. auriculiformis*	Aur 2, Aur 3
	A. crassicarpa	Cra 2, Cra 1
	A. difficilis	Dif 1
	A. mangium	Man 459

Observations at 36 months revealed that the trees at all four sites were following the same growth trends as they had at 18 months. Among these, *A. mangium* and *A. crassicarpa* (particularly Man 3-2; Man 13459; Man 19; Man 13241; and Cra 1 and Cra 2 at Chumphon and Surat Thani sites) performed very well.

Half-Sib Selection Trials

To select superior progenies and individual plus trees and to produce genetic advanced of open pollinated seeds from the selected progenies, half-sib, open-pollinated seeds of *A. auriculiformis* (8 provenances) and *A. mangium* (37 provenances) were planted at the Chumphon and Chonburi sites (Table 5). Each plot consisted of two 10-tree rows, with 2 m between rows and 1 m between trees.

At one year after planting, the trees were evaluated for their drought tolerance. All *A. auriculiformis* provenances thrived well at Chonburi, with over 60% survival; Aur 2, Aur 3, Aur 4, and Aur 5 showed survival rates over 80%. The low survival rates for *A. mangium* might have been caused by a long drought season. Drought-tolerant provenances of *A. mangium* at this site were Man 2-2, Man 15, Man 13232, and Man 13459. Again, survival rates for both species at the Chumphon site were better than in Chonburi. All the *A. auriculiformis* provenances showed over 80% survival. Survival rates for *A. mangium* were lower. At this site, the more drought-tolerant *A. mangium* provenances were Man 132229, Man 13240, Man 15, Man 13232, and Man 13239.

Tree form was recorded after 2 years, with priorities of stem form and branching habit. Among the *A. auriculiformis* group, Aur 2 showed the straightest stems and less branching. Due to the close spacing, most *A. mangium* provenances showed good performance, also with straight stems and low branching. Man 1 and Man 15 had excellent forms among *A. mangium* group. The trees at Chonburi were more crooked than at Chumphon, due to the stronger wind at Chonburi.

Comparison of performances at the two sites showed that the provenances of both species grew better at Chumphon than at Chonburi. Growth rates of *A. mangium* showed significant differences among provenances at each site. The fastest-growing provenances at Chonburi were Man 15, Man 19, Man 13238, Man 13240, and Man 13459. The fast-growing provenances at Chumphon were Man 1, Man 13232, Man 13234, Man 13237, and Man 13242.

Interspecific hybrids of *A. auriculiformis* x *A. mangium* were found at both sites. The hybrids resembled *A. auriculiformis*, but possessed less branching and greater stem straightness. They also seemed to be faster-growing and more drought tolerant than the parent trees. At the Chumphon site, about 50% of the hybrids possessed more than 2 stems per plant, and showed an average height 15-40% greater than the outstanding parents. The average DBH was also nearly twice as large as for the parents. This could mean that the interspecific hybrids could produce up to 3-4 times more stem

Table 5. Outstanding provenances in the half-sib selection trials.

Chon Buri	*A. auriculiformis* *A. mangium*	Aur 2, Aur 5 Man 15, Man 19, Man 13238, Man 13240, Man 13459
Chumphon	*A. auriculiformis* *A. mangium*	Aur 2, Aur 5 Man 1, Man 13232, Man 13234, Man 13237, Man 13242

volume than the parent trees at two years of age.

In concluding the experiment, five outstanding trees were selected from each of the best provenances at both sites (Table 5). These trees will serve as parent trees in establishing a seed orchard.

The *A. mangium* x *A. auriculiformis* hybrids from each site were propagated through grafting and planted in 1990 at TISTR's experimental site at Chan Thuk, in the northeastern province of Nakhon Ratchasima, for further genetic improvement.

Phenology Studies

TISTR's phenology studies examined reproductive growth, vegetative growth, and yield components of *A. auriculiformis* and *A. mangium*.

Reproductive Growth

Floral phenology and reproductive phenophase

Quantitative and qualitative characteristics and flower compositions of *A. auriculiformis* (Aur 1) and *A. mangium* (Man 1) were studied on six-year-old trees at Chumphon. *A. auriculiformis* flowered intermittently throughout the year, but the period of maximum flowering (greatest number of trees flowering at one time) occurred from May to July. Pod maturation occurred five months after flower initiation; pods could be harvested year-round, except during the peak flowering period. The greatest number of maturing pods were found in September and October.

Flowering and fruiting behavior of the two species differed. *A. mangium* had two flowering seasons: once in March-April and another from August to December. The floral buds of the former period usually aborted, while the ones in the latter period were greater in number and developed through the blooming and podding stages. Mature pods could be harvested about seven months after blooming, in March-April.

Reproductive phenophase

In the main season, the floral buds of both species flowered in 22-24 days. However, the times between flowering and seed maturity of the species varied: 120 days for *A. auriculiformis* and 206 days for *A. mangium*. Estimations of the time of antheses (flowering period) within inflorescences showed that the mean period between antheses of the first and last flowers were 5 days for *A. auriculiformis* and 6 days for *A. mangium*. In the newly established trials at the four locations, *A. auriculiformis* first flowered earlier than *A. mangium*. *A. auriculiformis* flowered 17 months after planting at Surat Thani and 18 months at the other three sites. *A. mangium*, on the other hand, showed a tendency for trees near the equator to flower earlier than those further from the equator.

Vegetative Growth

Growth rates

By its nature *A. auriculiformis* thrives well on difficult sites. In these experiments, trees from the yield trials at the four infertile sites exhibited favorable growth rates at all except the site at Chiang Mai, which produced unsatisfactory yield

Table 6. Mean growth for *A. auriculiformis* and *A. mangium* at the four TISTR sites, at three years.

Species	Height (cm)				DBH (mm)			
	CM	CB	ST	CP	CM	CB	ST	CP
A. auriculiformis	418	784	803	545	38	65	72	50
A. mangium	130	85	107	69	6	85	107	69

CM = Chiang Mai; CB = Chonburi; ST = Surat Thani; CP = Chumpon

(Table 6). The slow growth and poor yield at Chiang Mai appeared to be due to low rainfall and a long drought season. *A. mangium* appears to need more fertile soils than *A. auriculiformis*. Furthermore, it is a tree for wet sites and long drought period retards its growth severely (NAS 1983). Thus at Chiang Mai, *A. mangium* performed poorly, while in higher precipitation areas it grew more quickly.

Yield components

Of the two species, *A. auriculiformis* produced more seeds per pod (10.57), greater hundred seed weight (1.63 g), and greater seed length (4.71 mm) and width (3.69 mm). However, *A. mangium* produced more pods per inflorescence (19.44) and longer pods (16.87 cm) than *A. auriculiformis*.

Conclusion

Based on results from TISTR multisite trials, drought tolerance species and provenances include: *A. leptocarpa* (Lep 1, Leo 2), *A. auriculiformis* (Aur 5, Aur 2, Aur 1), *A. crassicarpa* (Cra 2), *A. plectocarpa* (Plc 1), *A. holosericea* (Hol 1), and a few provenances of *A. mangium* (Man 3-1, Man 646). At the driest site, *A. leptocarpa, A. auriculiformis*, and *A. holosericea* performed best.

Under wet conditions, *A. mangium* (Man 3-2, Man 13459, Man 13242), *A. crassicarpa* (Cra 1, Cra 2), *A. auriculiformis*, *A. leptocarpa* (Lep 1, Lep 2), and *A. difficillis* (Dif 1) performed better.

Outstanding hybrid trees of *A. auriculiformis* x *A. mangium* were selected and observed. Studies have also examined the relationships between tree species and soil microorganisms, particularly vesicular-arbuscular mycorrhiza and nitrogen-fixing root nodules. Further studies in this area should focus on the use of natural sources of soil microorganisms to promote plant growth.

Discussion Notes

Mangium and auriculiformis performed best on the acid soil sites (pH 4.5). Under *A. auriculiformis* at pH 4.5, VAM activity (*Glomus coloratus*) was very high. As noted elsewhere, mangium has not performed so well on poor soils, or in the drought conditions of northeastern Thailand.

Question: In its experiments, Kasetsart University's Faculty of Forestry has noted no significant different between inoculated and uninoculated trees in the field. What might explain this?

Answer: Response to rhizobium inoculation is greatest in the first year of growth; after that, native strains of rhizobium take over. Response to VA mycorrhizae can last for just over two years; for ecto-mycorrhizae, up to three years.

Slerocistus species are [illegible] used so much anymore, due to poor spore germination. Now, *Glomus* species are preferred.

The site specificity of rhizobium and mycorrhizal effectiveness means that documentation of the planting site conditions is required in order to assess the response. Soil pH, available phosphorus, and other climatic conditions must be characterized. Soils with higher P levels show less response to inoculation.

Under normal field conditions, dependence on mycorrhizal associations is low; it is on more extreme sites where inoculation is most effective.

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Nitrogen Fixation and Mycorrhizae in Acacias on Degraded Grasslands

Reynaldo E. dela Cruz and Mercedes U. Garcia

Introduction

Leguminous and other fast-growing multipurpose trees have frequently been recommended for use in reforesting denuded and degraded grasslands. In the Philippines, initial success with *Leucaena leucocephala* highlighted the potential for introduction of leguminous trees in adverse sites. Unfortunately, that species was severely defoliated by an infestation of psyllid (*Heteropsylla cubana*) in 1985-87 which set back the extensive use of *Leucaena* species in reforestation.

Leguminous trees can compete with native grasses such as *Imperata cylindrica*, and adapt to adverse conditions, including acid soils, drought, fires, and high phosphorus-fixing soils. One reason why leguminous trees can grow in adverse sites is their association with symbiotic organisms such as *Rhizobium* and mycorrhizae. *Rhizobium* is the nitrogen-fixing bacteria which forms root nodules in which nitrogen gas is converted into organic forms of nitrogen that the plant can tap for its use. Leguminous trees that can fix atmospheric nitrogen can therefore improve the nitrogen status of grassland soils even without application of chemical forms of nitrogen.

Most leguminous trees introduced in grasslands also form mycorrhiza, the symbiotic association between the roots and a fungus. Mycorrhiza is known to increase absorption of nutrients (e.g., phosphorus) and water, and provide biological control of harmful pests (e.g., nematodes) and fungi (e.g., root rot fungi).

Acacia species, particularly *A. auriculiformis* and *A. mangium*, have been successfully introduced in Southeast Asia. These are leguminous, fast-growing trees that can tolerate acidic pH and compete well with *I. cylindrica* and other grasses. Both these species form natural associations with *Rhizobium* and mycorrhiza. This paper focuses on nitrogen fixation and mycorrhizal symbiosis found with acacias.

Nitrogen Fixation

Annual rates of nitrogen fixation for cultivated legumes range from 10-40 kg/ha/year (Nutman 1976); for pasture legumes, annual rates are 100-200 kg/ha/year (Date 1973). Woody legumes can fix an average of 2.8-18.8 kg/ha/year (Langkamp 1979). Acacias have been reported to fix between 10-32 kg of N per ha/year (Adams et al. 1981).

Chang et al. (1986) reported that *A. auriculiformis* seedlings inoculated with *Rhizobium* had greater root and shoot dry weight and N uptake than uninoculated plants. Significant increases in shoot dry-matter yield, nodule weight, and nitrogen and phosphorus uptake have also been observed for inoculated *A. mangium*. In *A. mearnsii*, inoculation with local *Rhizobium* isolate B_3 significantly increased tree height and diameter, and nodule number and weight (Dar 1990).

Roughley (1987) reported host specificity in the genus *Acacia*. Root nodule bacteria that nodulate acacias can belong either to the genus *Rhizobium* (fast-growing) or *Bradyrhizobium* (slow-growing). There are now three effective groups of *Acacia* species (Dreyfus and Dommergues 1981):

- those that exhibit effective nodulation with fast-growing strains
- those that exhibit effective nodulation with slow-growing strains
- those that do not effectively nodulate

Cross-inoculation studies showed that *Leucaena* rhizobia can nodulate *Acacia farnesiana* (Trinick and Galbraith 1980).

Balaji and Rangarajan (1989) inoculated seeds of *Acacia nilotica* with three strains of rhizobia: ADC 2 isolated from *A. dealbata*, ANM.111 isolated from *A. nilotica*, and ECM.1 isolated from *Albizia saman*. The trials took place at Coimbatore (430 m msl) and Sandyanallah (2240 m msl) in India. *Acacia nilotica* inoculated with strain ADC.2 produced a maximum biomass of 1.14 g/plant at Coimbatore and 1.01 g/plant at Sandynallah. By contrast, those inoculated with ECM.1 strain produced the lowest biomass at both locations. Similarly, the number of nodules per plant and nodule dry weight were highest for plants inoculated with ADC.2 strain at both locations. These results indicate that growth, nodulation, and nitrogen fixation of *A. nilotica* were influenced by different rhizobia strains.

Dart et al. (1991) tested 12 strains isolated from *A. auriculiformis* in the Philippines and found that they varied from ineffective, fixing no nitrogen (3 strains), to moderately effective (7 strains producing 30-75% of the plant growth of the best strain) to effective (2 strains). They also found that none of the 12 strains isolated from *A. mangium* grown in Philippines soils nodulated *A. auriculiformis* effectively. For both species, the strains that fixed the greatest amounts of nitrogen came from plants grown in Northern Australia and Papua New Guinea. *Acacia mangium* was more specific in its *Rhizobium* affinities than *A. auriculiformis*. Only 2 of 48 strains tested were effective (>75% of the growth with PMA 311/1) and most were quite ineffective.

The studies by Dart et al. (1991) suggest that many strains naturally present in soils are only partially effective for many *Acacia* species, and that inoculation can produce responses in young seedlings. After outplanting, competition between inoculant strains and native rhizobia population changes because the inoculant strains need to colonize new roots formed.

Factors Influencing Successful Inoculation

Factors that can affect the success of inoculation with *Rhizobium* include:

- soil pH
- soil temperature
- soil moisture
- rhizobial strain(s)
- inorganic nutrition, particularly nitrogen

Soil pH

Nodulation in *Acacia* species has been found to be best at pH 6.5-7.0, less effective at pH 8.5-9.0, and absent at 3.5-5.5 (Habish 1970).

Soil Temperature

Nodulation generally takes place at all soil temperatures tolerated by most free-living bacteria, but nodule abundance decreases at cooler and warmer extremes. Root temperatures higher than 30°C are known to affect nodulation in most tropical legumes, although some species appear to be adapted to higher temperatures. *Acacia mellifera* could still produce effective nodules at 30-35°C, a fact that Habish (1970) attributed to resistance of rhizobia to high temperatures.

Soil temperature can profoundly affect plant growth and nodulation. Habish (1970) reported that growth, nodulation, and nitrogen accumulation of acacia seedlings were generally greater at 35°C than at 30°C and 40°C. Sixty-five percent more nodules formed at 35°C than at 30°C, and no nodulation occurred at 40°C.

Soil Moisture

Soil moisture of 7.5% can also reduce nodulation, dry matter yield, and N content by 60%, 55%, and 73%, respectively (Habish 1970). Both waterlogging and drought were shown to drastically reduce nitrogenase activity of *A. cyanophylla* (Nakos 1977).

Rhizobial Strains

Inoculation of *A. auriculiformis* with UPLB (the University of the Philippines at Los Banos) *Rhizobium* isolates Aa_2 and Aa_3 significantly improved seedling height, dry matter yield, and nodulation, and caused appreciable increases in N, P, K, Ca, and Mg uptake by inoculated plants (Garma 1992).

Bahry (1988) compared the response of *A. albida* to 12 rhizobial strains. All 12 strains were infective, but differed in their effectivity in promoting growth of *A. albida*. Seedlings inoculated with Aa_2 (isolated from *A. mangium*) showed superior growth compared to those inoculated with other strains. The response to inoculation was more pronounced in less fertile soil.

Inorganic Nutrition

Generally, significantly taller and heavier plants are obtained at 30-300 kg N/ha application, but nodule development has been suppressed or reduced at higher levels of N (Garma 1992). The interaction between inoculation and N-fertilization has given no significant results in any parameters except for macronutrient content, in which N was found to increase with N fertilization alone at 100-300 kg/ha. But this did not differ significantly from those that were inoculated alone with Aa_2 and Aa_3. The concentration of other macroelements in the host were generally increased by inoculation in the presence of modest amount of fertilization.

Cali (1991) reported on a nursery experiment on the effect of liming and inoculation of *A. mangium* in the presence or absence of NPK fertilizer, using Annam clay (pH 5.9 and 0.74% OM) and Adtuyon clay loam (pH 6.2 and 5.31% OM). Liming the soil did not improve growth and nodule development of *A. mangium*. The seedlings fertilized with 200 kg N/ha 100 kg PK/ha grew best in both soils, followed by those that were inoculated with *Rhizobium* in the presence of only PK. Height, diameter, and nodule weight were significantly affected by the interaction of lime, inoculation, and fertilizer treatments.

Cali (1991) also reported that inoculation of *A. mangium* independently improved height, shoot biomass, nodule weight, and nitrogen content and uptake. The relationship between shoot biomass and nodule number, nodule weight, and N-uptake was highly significant. The local *Rhizobium* isolate Am_2 could replace about 91% of the N requirement of *A. mangium* in Adtuyon clay loam. Calculations for actual N-replacement capacity suggested a savings of US$15 per 100 seedlings grown in the nursery.

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

Garcia et al. (1988) reported that liming the soil to pH 6.5, regardless of N fertilizer, improved the performance of *Rhizobium* in *A. mangium*.

Mycorrhizae

Mycorrhizal research at UPLB has concentrated on:

1. collection, isolation, and identification of fungi
2. screening for effectiveness among isolated fungi
3. mass inoculant production
4. inoculation technologies
5. nursery and field testing

Collection, Isolation and Identification of Fungi

Introduction of many *Acacia* species for reforestation in the tropics was not accompanied by similar inoculations of mycorrhizal fungi. It is reasonable to assume that the introduced *Acacias* formed mycorrhizal associations with the native fungi, some of which effectively promote acacia growth.

Table 1. Reported mycorrhizal status of *Acacia* species. Source: Reddell and Warren 1986.

Type of mycorrhiza	Acacia species
Ecto	*aneura, dealbata, decurrens, melanoxylon, mitchellii, pycanatha, platycarpa, retinodes, rubida, salcina, sophorae, sparciflora, verticillata*
VAM	*albida, arabica, aulacocarpa, auriculiformis, concurrens, constricta, cyanophylla, farnesiana, floribunda, goetzsii, greggii, holosericea, lutescens, mangium, mellifera, nigrescens, nilotica, nubica, polyacantha, pulchella, pyrifolia, raddiana, richi, saligna, senegal, seyal, suaveolens, torulosa, yirrkallensis*
Both VAM and Ecto	*myrtifolia, redoxylon, rothii, simsii*

The exact nature of the mycorrhizal fungi associated with *Acacia* species is still not clear. Reddell and Warren (1986) reported that 13 acacias form ectomycorrhizal associations, 29 form vasicular arbiscular mycorrhizae (VAM) associations, and 4 form both VAM and ectomycorrhizal associations (Table 1).

Regarding the formation of ectomycorrhizal associations: to date, the only basidiomycetous fungus we found associated with *A. mangium* and *A. auriculiformis* is a *Thelephora* species which we have not yet identified, but which is similar to *T. ramariodes* (Gibson 1981). It is doubtful, however, whether this fungus forms an ectomycorrhizal association because it does not exhibit the typical symptoms such as fungal sheath and Hartig net. Furthermore, inoculation with this fungus produced no evident growth increases.

VAM association appears to be the more common among *Acacia* species. Six genera of VAM had been observed: *Acaulospora, Entrophosphora, Gigaspora, Glomus, Sclerocystis,* and *Scutellispora*. Each genus is represented by a number of species, although the exact number has not yet been determined.

The taxonomy of VAM associated with *Acacia* species needs further study. Many isolated VAM fungi cannot be identified despite the use of present keys and monographs. It is possible that many new VAM species are appearing.

Screening for Effectiveness among Isolated Fungi

Some VAM fungi are more effective than others in promoting growth of the host plants. Screening for effectiveness among mycorrhizal fungi can be done in a number of ways. The most common method is to test the effectiveness of different VAM fungi in promoting the survival and growth of a plant in adverse conditions such as infertile soils, acid soils, high phosphorus fixing soils, or in aluminum toxic soils.

Dela Cruz et al. (1988) studied the effectiveness among VAM fungi and *Rhizobium* (R) in promoting growth of *A. auriculiformis* and *A. mangium* in a degraded, P-deficient grassland soil. *Glomus fasciculatus* + R and *Gigaspora margarita* + R were most effective for *A. mangium*. *Scutellispora persica* + R, *G. margarita* + R, and *Glomus fasciculatus* + R were most effective for *A. auriculifonnis*. Consistently poor growth was shown by seedlings inoculated with *Sclerocystis clavispora* + R, *Rhizobium* alone, and by uninoculated seedlings. The effective VAM promoted nitrogen concentration and N content of seedlings, P concentration and total P content, nodule weight, and nitrogen fixation determined by acetylene reduction assay.

In another study, different species of *Glomus, Scutellispora,* and *Acaulospora* were inoculated separately to *A. auriculifonnis* seedlings by blanket application of *Rhizobium* (Dela Cruz et al. 1991). Among four species of *Acaulospora*, three (*A. appendicula, A. morrowae* and *A. spinosa*) were equally effective in promoting better growth than *A. delicata, Rhizobium* alone, or the uninoculated control. Among the seven *Glomus* species, five (*Glomus sp., Gl. claroideum, Gl. etunicatum, Gl. intraradices*, and *Gl. macrocarpum*) gave significantly better height and diameter growth of *A. auriculiformis* than the *Rhizobium* and uninoculated treatments. Nodule dry weights of VAM-inoculated plants were significantly higher than the latter two treatments. Among the four *Scutellispora* species, *S. callospora* consistently promoted better height and diameter growth of *A. auriculiformis*.

This study showed that effective VAM species consistently increased P uptake of seedlings and improved nodule weight, and that consequently seedlings produced better height, diameter and total biomass.

Screening for mycorrhizal fungi that are effective in promoting tree growth on adverse sites is an important step in using these fungi for reforestation. Inoculation of effective mycorrhizal species may improve the survival and growth of plants introduced to adverse sites.

Mass Production of Inoculant

Mass inoculant production of VAM fungi employs the pot culture technique. Pure spores of effective VAM are aseptically inoculated to the roots of a suitable trap plant and grown in sterile soil-sand (3:1 by volume) mixtures in a greenhouse. The fungi infect the roots of the host plant, proliferate within the roots, and form numerous external (internal for some fungi) spores after 4-5 months. The soil-sand mixture containing infective propagules in the form of infected roots and spores can be used to inoculate host plants.

Other mass inoculant production procedures still in the testing stage are: the nutrient film technique, developed in Rothamstead, U.K.; aerophonics developed in Florida, USA; and the root tissue culture technique.

Inoculation Technologies

A major constraint to large-scale inoculation of VAM in nurseries and the field is the limited production of cheap but effective inoculants. The pot-culture technique cannot provide an adequate supply of inoculant for large-scale trials. The traditional inoculation technology is to add about 1 teaspoonful of the inoculant at the base of seedlings at transplanting. This works best for container-grown species, such as *A. auriculiformis* and *A. mangium*.

In the Philippines, the National Institutes of Biotechnology and Applied Microbiology (BIOTECH) produce two commercial VAM inoculants: MYKOVAM 1 and MYKOVAM 2 (Dela Cruz et al. 1992). The former is a powdered form of soil inoculant produced from the soil-sand mixture. MYKOVAM 2 is a granulated form of soil inoculant and appears somewhat like chemical fertilizers.

Results of MYKOVAM 1 testing are presented below. MYKOVAM 2 has been tried with *A. mangium* in the nursery. Seedlings inoculated with MYKOVAM 2 containing the VAM fungus *Gigaspora margarita* attained a height of 17.5 cm after 4 months, compared to 6.9 cm attained by the uninoculated control (Dela Cruz et al. 1992). The granular nature of MYKOVAM 2 is attractive to nurserymen accustomed to handling chemical fertilizers.

Nursery and Field Testing

The real test of mycorrhizal efficacy is the ability to increase growth of the host plant both in the nursery and in the field.

Cornet and Diem (1982) found that in a pot experiment with a phosphorus-deficient soil that had been sterilized to kill the native population of mycorrhizal fungi, inoculation of *Acacia raddiana* and *A. holosericea* with the VAM fungus *Gl. mosseae* increased shoot weights by 170% and 850%, respectively, and nodule weights by ten- to twelvefold. Similar growth response in these two *Acacia* species occurred when phosphate fertilizer was applied instead of mycorrhizal inoculation. In a treatment in which the soil was not sterilized, the effects of the introduced VAM fungus were masked by the native VA fungal population. This study also indicated a beneficial effect of mycorrhizae in enhancing the drought tolerance of *A. raddiana*.

In studying nursery and field responses to inoculation of *A. holosericea* with both a VAM fungus and *Rhizobium*, Cornet et al. (1982) found that dual inoculation (both *Rhizobium* and VAM fungus) increased seedling growth in the sterilized nursery soil by almost 50% more than plants inoculated with *Rhizobium* only. After outplanting, also, the dual-inoculated plants performed better than those inoculated with *Rhizobium* only. However, the relative effect of mycorrhizal inoculation diminished with time; seven months after outplanting, dual-inoculated plants were only 8% larger than those inoculated with *Rhizobium* only. This diminishing mycorrhizal effect was probably due to infection of inoculated plants by the natural population of VAM fungi found at the planting site.

Gardezi et al. (1988) studied the effect of double inoculation of *Acacia cyanophylla* in Mexico using *Rhizobium* and VAM in the presence of phosphate fertilizers. They reported a strong effect of mycorrhizal symbiosis on the height of the plant, averaging 44.8 cm compared to the control of 4.9 cm. At the same time, P absorption increased slightly under fertilization regimes of 50 and 100 ppm P_2O_5. Dry weight increased from an average of 0.4 g for the control to 6.2 g with mycorrhiza. Height growth increased by 814% due to the presence of mycorrhiza, and aerial dry weight increased by 1405%. Dual inoculation with *Rhizobium* and mycorrhiza did not significantly increase growth compared to single inoculation by each organism.

Aggangan and Dela Cruz (1991) inoculated *A. auriculiformis* in the nursery separately with *G. margarita*, *S. persica*, and *S. clavispora*, using P-deficient, degraded grassland soil. *Gigaspora margarita* and *S. persica* were equally effective in promoting tree growth. *Gigaspora margarita* significantly increased height by 169%, diameter by 123%, and dry-matter yield by 574% compared to uninoculated seedlings. *Scutellispora persica* increased height by 134%, diameter by 97% and dry matter by 508% over control. *Selerocystis clavispora* did not promote seedling growth. The improved growth of seedlings inoculated with *G. margarita* and *S. persica* can be partly attributed to improved phosphorus nutrition.

In another study, *A. auriculiformis* was inoculated with two VAM fungi (*Glomus etunicatum* and *Gigaspora margarita*) and with *Rhizobium* in the nursery (Dela Cruz et al. 1991). After three months, seedlings were outplanted in a degraded grassland. Height growth was measured over a two-year period (Table 2).

From 6-10 months, seedlings inoculated with *Gl. etunicatum* were the tallest (Figure 1). Uninoculated seedlings exhibited stunted growth with pale yellow leaves, indicating severe nutrient deficiency. Seedlings in the treatments *Gl. etunicatum* + R, *Gl. etunicatum*, *G. margarita* + R, and *G. margarita* were taller than the uninoculated ones. After two years, seedlings inoculated with *Gl. etunicatum* + R were tallest, 67% taller than uninoculated seedlings (Table 2). *Rhizobium* in combination with any VAM species contributed to higher increases in height, but *Rhizobium* alone was not enough to promote good growth in the field.

In another study, *A. mangium* was inoculated in the nursery with *Gl. etunicatum*, *Gl. macrocarpum*, and *G. margarita* (Dela Cruz et. al. 1991), then outplanted in a degraded grassland after three months in the nursery (Table 3 and Figure 2).

Inoculation with any of the three VAM species resulted in highly significant increases in both height and diameter (Table 3). After 10 months in the field, *Gl. etunicatum* and *Gl. macrocarpum* were equally effective in causing significantly greater height and diameter than *G. margarita*. The uninoculated seedlings were the shortest and exhibited symptoms of nutrient deficiency. After 24 months in the field, all uninoculated seedlings were dead. The most effective VAM fungi for *A. mangium* was *Gl. etunicatum*, followed by *Gl. macrocarpum* and *G. margarita*.

Lorilla et al. (1992) inoculated *A. auriculiformis* and *A. mangium* in the nursery with *Glomus etunicatum*, *Gigaspora margarita*, or *Scutellispora calospora*. After five months, seedlings were outplanted in a degraded grassland. Five levels of chemical fertilizer (4-14-14) were applied (0, 5, 10, 25, and 50 grams per plant (gpp)

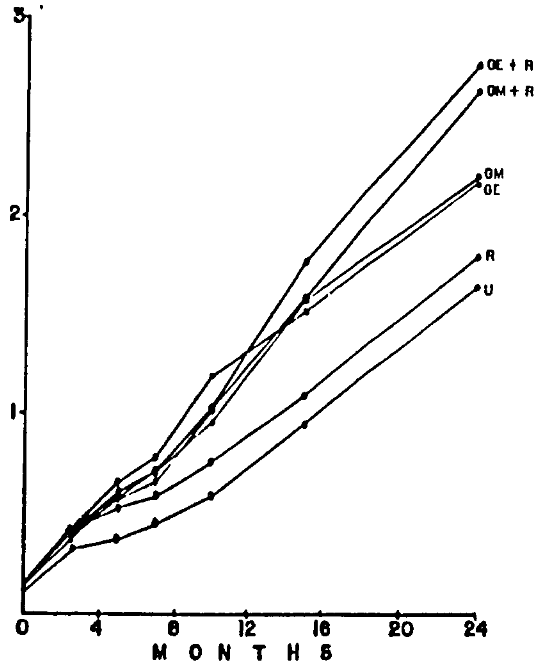

Figure 1. Height growth (m) of *Acacia auriculiformis* in a marginal grassland area in response to inoculation with *Glomus etunicatum* (GE), *Gigaspora margarita* (GM) and/or *Rhizobium* (R). U = uninoculated.

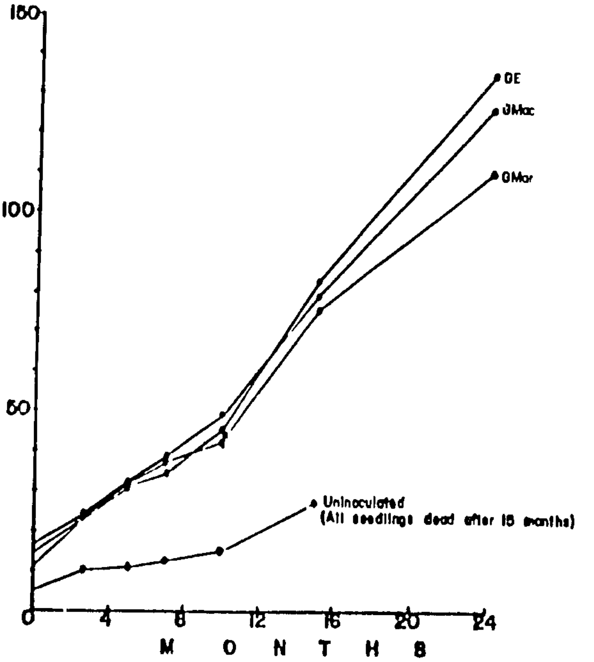

Figure 2. Height growth (cm) of *Acacia mangium* in a marginal grassland area in response to inoculation with *Glomus etunicatum* (GE), *Glomus macrocarpum* (GMac), or *Gigaspora margarita* (GMar) during the nursery phase.

Table 2. Height growth (cm) of *A. auriculiformis* inoculated with VAM species with or without *Rhizobium* (R), grown in the nursery for 3 months and then outplanted in the field. Source: Dela Cruz et al. 1991.

Treatments	Nursery 3	Field (months after planting) 2.5	5	7	10	15	24	Increase (%)
Uninoculated	10.01	32.78	36.76	43.56	57.50	96.10	165.09	--
Rhizobium (R)	11.66	41.11	52.23	59.30	74.50	104.60	179.61	9
Glomus etunicatum	11.42	41.66	64.26	78.14	119.00	150.00	217.98	32
Gigaspora margarita	11.88	37.54	59.59	70.14	95.00	157.10	218.55	32
Gl. etunicatum + R	12.83	41.56	57.09	70.80	102.00	176.90	275.35	67
G. margarita + R	12.61	39.96	56.55	66.10	102.00	155.10	263.85	60

Table 3. Height growth (cm) of *Acacia mangium* inoculated with three VAM species in the nursery and outplanted in a degraded grassland. Source: Dela Cruz et al. 1991.

Treatments	Nursery 2 mo	Nursery Increase (%)	Field (months after planting) 2.5	5	7	10	15	24
Uninoculated	5.0	---	10.73 b	11.10 b	11.89 b	15.40 b	26.73 b	all died b
Gl. etunicatum	4.0	180	23.17 a	30.51 a	33.69 a	45.40 a	82.90 a	136.30 a
Gl. macrocarpum	13.5	170	23.52 a	31.96 a	37.73 a	49.20 a	78.59 a	126.78 a
G. margarita	11.1	122	22.93 a	31.46 a	37.50 a	42.20 a	75.[illegible]	111.70 a

at planting. In the nursery, seedlings inoculated with *S. calospora* performed better than those inoculated with *G. margarita* or *Gl. etunicatum*, or the uninoculated control (Table 4). Seedlings inoculated with *S. calospora* were significantly taller than uninoculated seedlings.

In the field, also, mycorrhizal treatments significantly increased height and diameter growth of seedlings. The most efficient VAM fungus was *Gl. etunicatum* for *A. auriculiformis* and *S. calospora* for *A. mangium* (Table 5). Table 6 shows to what extent these fungi replaced chemical fertilizer requirements.

Current work in the Philippines is trying to incorporate VAM into traditional silvicultural technologies for growing *Acacia* species, such as direct seeding (Dela Cruz et al. 1992). In that experiment, *A. mangium* seeds were placed into fabricated direct-seeding blocks (DSB) and inoculated with either *Gl. macrocarpum*, *G. margarita*, or combinations of the two VAM fungi. The seeds received various pre-soaking treatments to overcome seed dormancy. The DSB were directly seeded into pots containing soils collected from a marginal grassland. Best height and diameter growth were observed for seeds inoculated with *G. margarita* alone (Table 7).

Table 4. Height growth of *A. auriculiformis* and *A. mangium* inoculated with VAM after 5 months in the nursery. Source: Lorilla et al. 1992.

Mycorrhizal treatments	*A. auriculiformis*		*A. mangium*	
	Height (cm)	Increase (%)	Height (cm)	Increase (%)
Uninoculated	27.1 b	--	19.9 b	--
Gl. etunicatum	27.6 a	2	16.3 b	-18
G. margarita	25.9 b	-4	13.6 c	-32
S. calospora	33.5 a	24	30.7 a	54

Numbers in the same column followed by the same letter are not significantly different at $p = 0.05$.

Table 5. Height growth (cm) of *A. auriculiformis* and *A. mangium* inoculated with VAM in the nursery and fertilized with different levels of chemical fertilizers in the field. Source: Lorilla et al. 1992.

VA Mycorrhizal Treatment	Fertilizer levels (gpp)					Mycorrhizal Treatment Means
	0	5	10	25	50	
			Acacia auriculiformis			
Uninoculated	94.6 i	169.4 fg	188.2 ef	216.2 d	249.6 bc	183.6 b
Gl. etunicatum	166.8 g	193.6 e	201.1 de	238.2 c	287.4 a	217.4 a
G. margarita	147.0 h	170.1 fg	194.6 e	196.6 de	257.9 b	193.2 ab
S. calospora	135.3 h	199.1 de	201.1 de	235.5 c	260.2 ab	206.2 ab
Fertilizer Means	135.9 d	183.1 c	196.2 c	221.6 b	263.8 a	
			Acacia mangium			
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 $p = 0.05$.

Table 6. Approximate percentage of post-nursery chemical fertilizer requirements replaced by inoculation with VAM fungi. Source: Lorilla et al. 1992.

	A. auriculiformis	*A. mangium*
G. margarita	24	54
S. calcspora	46	88
Gl. etunicatum	100	100

Table 7. Height and diameter of *A. mangium* in response to seed pre-soaking treatments and DSB-VAM treatments. Source: Dela Cruz et al. 1992.

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 b	
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	

Numbers in the same column followed by the same letter are not significantly different at p = 0.05.

Summary and Conclusions

Rhizobium and mycorrhiza have strong potentials for promoting growth of *Acacia* species, particularly in reforestation of adverse sites such as degraded grasslands. Isolation of native strains and species from the roots of host plants is the initial step in harnessing these beneficial organisms. After isolation, they should be screened for their effectiveness in promoting tree growth in adverse sites. Where possible, *Rhizobium* and mycorrhiza should be incorporated into the traditional silvicultural practices used for growing these trees. The extent to which chemical fertilizers can be replaced by *Rhizobium* and/or mycorrhiza should also be quantified. Technologies to grow inoculants of *Rhizobium* and VAM on a wide-scale are now available.

Discussion Notes

There is not much cross-inoculation potential for rhizobium on *A. auriculiformis*.

For *A. mangium* on acid soils, most *Rhizobium* strains prefer pH of 6.0-6.5, soil temperature of 28-30°C, and soil moisture of 7.5%.

Fertilizer, especially N applied at the seedling stage, depresses *Rhizobium* nodulation. Like mycorrhizal activity, *Rhizobium* inoculation is determined by the plant; if the soil is fertile, the plant conserves carbohydrates that would go into nodulation.

Inoculant production remains a primary obstacle to mycorrhizae use. Strains are not isolated. Thus, soil under existing stands remains a good source of inoculant.

Question: What is the cost for commercial application of MYKOVAM-1?

Answer: US$0.90 per kg of MYKOVAM-1, which is enough to inoculate 700 seedlings.

Q: Do you then recommend doing away with fertilization at the nursery stage?

A: Not complete substitution; fertilizer applied in the nursery can be reduced by 30%. Mycorrhizae cannot totally replace chemical fertilizer but it can replace 60% of fertilizer requirements up to 3 years.

Q: What is the cause of the slow growth shown in the slides?

A: The native mycorrhizae and *Rhizobium* found in Philippine soils are very poor.

Q: Do legumes require both mycorrhizae and *Rhizobium*?

A: Both work together synergistically.

Q: What about requirements on good sites?

A: The plant response is less dramatic on good sites. PICOP has used inoculated plants on logged over areas and found the response diminished.

Q: In Thailand, *A. auriculiformis* shows good growth on any site; mangium does not. Is *A. mangium* more site-specific for inoculation?

A: *A. mangium* is more dependent on mycorrhizal association for growth. N-fixation is greater in the presence of mycorrizhae (both in number of nodules and in nodule weight). For other acacias, mycorrhizal requirements are not known.

The effectiveness of provenance on mycorrhizal formation (at two years old) is being studied. After that point, it becomes difficult to study.

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Research on Growth and Yield, Litter Production, and Nutrient Cycling in Acacias

Lim Meng Tsai

Growth and Yield Studies

Growth and yield studies are important as they provide the basis and justification for selecting species for planting. "Growth and yield" often refers to the amount of wood produced by the tree. This has traditionally been expressed in terms of trees' diameter at breast height (DBH) or girth at breast height (GBH), height, and volume, and is usually calculated on a stand basis (i.e., per ha).

While foresters are used to these measures, there are good reasons to include measurement of biomass in estimates of growth and yield. Biomass is a more universal basis for comparison of natural productivity, particularly in agroforestry and planting of multipurpose tree species (MPTS), in which the main product is not necessarily wood. Biomass allows comparisons between wood and plant products that are not wood. In other words, it allows comparisons between tree products and non-tree products (for examp[illegible]elds vs. yields of corn or vegetable crops). To account for the yield of different plant parts—determined depending on the end use of the tree—we must use a unit of measurement applicable to all plant parts and to all types of plants and even animal crops. This basis is biomass.

There have been a number of studies on the growth of different acacias, but few on their yields. Among the early results on *Acacia mangium* was that often quoted from Tham (1978) of 23 m height and 23 cm DBH at 9 years. Several others have been reported since (Lim 1985, 1988; Halenda 1987; Racz and Zakaria 1986), giving annual growth rates as high as 5 m height and 5 cm DBH. Recently, FRIM produced volume tables for *A. mangium*. Other acacias have been relatively less studied, but growth rates of DBH and height have been reported (Applegate and Nicholson 1987; Kessy 1987).

Litter Production

"Litter" refers to the dead parts of plants that are released back to the forest floor. These consist of dead leaves, branches, parts of flowers and fruits, and parts of the stem, including the bark. Leaves are usually the major component as they are regularly shed and replaced through growth of new foliage. Litter production has been relatively unstudied in acacias, partly because until recently there were few acacia plantations, and also because information on it has been considered of academic interest only. However, litter production is an important aspect of the biomass production of trees, making up one component of the annual productivity of the trees as shown in the following relationship:

Total annual production = Total annual increment + annual litter production + total amount respired

Litter is composed of:

fine litter - dead leaves, flowers and fruits and small branches $\leq$ 2 cm in diameter

coarse litter - branches and stem parts > 2 cm in diameter and roots that die

Fine litter production in *A. mangium* from about age 3 to 6 years averages about 10 tons/ha/year. About 75% of this is leaf litter; branches make up 15%. Litter studies can provide useful information on other aspects of the plants, including patterns of flowering, fruiting, and leaf phenology. The interesting finding from studies of litter production in *A. mangium* is that the ratio of leaf biomass to leaf litter production is about 0.6, suggesting that a very high leaf turnover rate and rapid nutrient cycling. The mean life of a leaf in the *A. mangium* crown is about 7 months.

There are two other types of litter studies that should be conducted to complement litter production studies:

Determination of litter accumulation on the forest floor (also referred to as standing litter). Assuming a steady state of litter production and decomposition, the litter accumulation coupled with litter production can give an idea of overall rates of litter turnover. In studies of four-year-old *A. mangium*, litter accumulation was found to be a fairly high 6 tons/ha.

Experiments on leaf decomposition. While this may not be absolute, changes in organic matter, nutrient contents, and fauna and flora involved can be studied simultaneously.

These two supplementary studies are relevant to nutrient cycling (see below), as the decomposition process represents the way that nutrients are recycled in the system.

Biomass

Biomass studies often entail much physical labor, and are relatively few. The use of allometric equations have helped, but development of such equations still requires destructive sampling. There have been studies on biomass of *A. mangium* in Malaysia and Indonesia, and of *A. auriculiformis* elsewhere, including Hawaii, U.S.A. Most of these have examined small and/or young trees, usually less than 5 or 6 years old, and have given us the kind of information that most of us know today — that *A. auriculiformis* grows rapidly and produces high quantities of biomass in a short time. Some of the results obtained give values of biomass increments of up to 25-30 tons per ha per year. The biomass values reported for these stands are of a biological nature and often do not present the information in the form of commercial volume (m^3) that foresters are more familiar with. Yield estimates are often in that measure, and there may be a case for developing some volume yield/biomass relationships to facilitate the conversion between the two forms of measure.

Biomass studies are in some ways limited as they are often restricted to the above-ground components of the plants. Roots are often left out mainly because they are very difficult to unearth for sampling. Initial studies of stands between 2 and 6 years old show that the fine roots (>5 cm diameter) of *A. mangium* stands average about 4 tons/ha. The most important aspect of biomass studies is that one can estimate a tree's mean annual increment (MAI) in biomass of the different components, as well as the total gross primary productivity.

Nutrients and Nutrient Cycling

This involves the determination of the nutrient concentrations of various components of the tree and the stand, including litter fall, litter on the forest floor, and soil nutrients. The importance of nutrient analysis and the understanding of nutrient-cycling processes in plants are often not very well appreciated. This information is important for determining the amounts removed by harvesting and the natural processes of replenishment. In agroforestry systems, trees are often expected to yield wood for fuel and leaves for fodder or mulch/organic matter/litter for soil improvement. The often unappreciated role of the trees in these situations is that trees are actually pumping out nutrients and water from the deeper soil horizons for the other components of the agroforestry system. Thus, if the amount removed exceeds the natural replenishment rates through weathering and input from rain and dust, the system could be a net drain from the soil and may become degraded over time.

The determination of the nutrient status of acacias and the transfers between various components have not been widely studied. Some preliminary studies on the nutrient contents of *A. mangium* have been made. I have some preliminary and gross estimates of the patterns of nutrient cycling in young *A. mangium* stand. I do not know of others that have attempted such a diagram, although I think it is very important in determining silvicultural treatments for a stand. For instance, the diagram shows an excess of N but a shortage of P; any amelioration should take this into consideration. Otherwise, the action would not be beneficial.

The removal of plant parts through harvest is a part of the use of trees as MPTS in agroforestry, and even in plantations. This is coupled with removal of nutrients from the system and information on the different parts removed will assist in maintaining the productivity of the stand and so make the system sustainable. Clear understanding of the nutrient cycles and organic matter production processes is thus an essential part of the resource use in order that the system is not unduly stressed and degraded over time.

Discussion Notes

All uses must be considered in tracking nutrient cycling.

Question: You indicate negative values for internal cycling of *A. mangium*. Is soil absorption adequate?

Answer: Actually, the negative value implies accumulation of nutrients. Whether or not these nutrients are being absorbed by the soil is hard to tell.

Where these studies took place, soil pH is about 5.5 and topsoil depth > 1 m.

Q: Is there difference in nutrient cycling patterns among different spacings?

A: After canopy closure, there is not much difference.

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The State of Growth and Yield Study of *Acacia mangium* in Indonesia

Agus Setyarso

Introduction

Acacia mangium Wild. is now one of the primary species planted for reforestation, both for forest rehabilitation and large-scale timber plantation. It is known as a pioneer species, able to grow on infertile soils where many other species cannot survive. Where it is planted to supply the growing wood fiber industry, its contribution to local and national economies is quite promising.

Unlike progress in establishment, there is little that can be said about stand improvement or growth and yield performance of *A. mangium* in Indonesia. Most silvicultural and management strategies used in establishing plantations are based on formal guidelines provided by the government, without sufficient modification to existing local conditions. As a result, the best strategy for obtaining optimal growth and yield cannot be determined.

This paper explores efforts that have been conducted on quantifying the performance of *A. mangium* plantations, focusing on the study of its growth and yield. This exploration examines the current state of knowledge of growth and yield, and proposes a program for filling gaps in these important aspects.

The Progress of Plantation Establishment

A. mangium has been selected by reforestation programs in Indonesia since the late 1970s. Large-scale establishment has taken place at Riau, North Sumatra (PT Arara Abadi 1992). Having started planting 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. Widyarsono (1992) reports that his company is producing 89 million seedlings to be planted this year. Arisman and Prakarsa (1992) state that the target is to cover 300,000 ha of forest land in South Sumatra, predominantly with *A. mangium* plantations, in order to supply 1.2 million tons of annual pulpmill capacity. At Pulau Laut, South Kalimantan, mangium has also been selected for timber estate development. In West Java, Perum Perhutani, a state enterprise, has established 36,000 ha of forest plantation, of which *A. mangium* is one of the main species.

Outside timber estates, *A. mangium* can also be seen planted in South Kalimantan, East Kalimantan, Sulawesi, and other parts of Indonesia, particularly for site rehabilitation.

Thus progress and experience in *A. mangium* study, especially in Indonesia, will yield important benefits.

Recent Growth and Yield Studies on *Acacia mangium*

The literature on this subject is patchy. Some literature, both published and unpublished, are maintained in libraries, but others are scattered. It is believed that research on *A. mangium* have been conducted intensively, particularly short-term studies. Scientists ranging from senior researchers down to undergraduate students have been involved in *A. mangium* studies.

Unsurprisingly, quite a few studies can be classified as "growth and yield" research, with primary attention on the "growth" (in the silvicultural context). In other words, research focusing on yield, in the management context, has been insufficient. Yield is more often presented in the form of (local) volume tables. When there is a need for projecting yield through time, mean annual increment is the most commonly used measure.

Table 1 presents a morphological analysis of eight "selected out of available" references.

Table 1. A morphological analysis of eight growth and yield studies of *Acacia mangium* in Indonesia.

Item of Comparison	Reference 1	2	3	4	5	6	7	8
I. Dependent Variables								
1. Diameter			x	x		x	x	x
2. Height	x	x	x	x		x	x	x
3. Volume	x		x		x	x	x	x
4. Biomass								
5. Stand structure			x					
6. Crown			x					
II. Independent Variables								
1. Age	5-6yrs	6mo	4yrs	2-3yrs	4-12yrs	various	3,5,7	1-4 yrs
2. Diameter	x					x	x	
3. Height	x						x	
4. Crown								
5. Leaf area								
6. Site								
7. Stock								
8. Density								
9. Structure								
III. Management Factors								
1. Seed quality		x						
2. Land prep.								x
3. Fertilizing								
4. Spacing	3 x 3m		$2\text{-}4m^2$		$3\text{-}4m^2$	3 x 3m	3 x 3m	3 x 3m
5. Weeding				x				x
6. Pruning				x				
7. Thinning				x				
8. Mixed cropping					agroforestry		taungya	
IV. Environmental Factors								
1. Soil type	ultisol	5 types	ultisol		various	ultisol	various	
2. Location	EK	Bogor	EK	S. Sum	EK	various	S. Sum	W.Java
3. Rainfall/climate	A					A-B	A	B-C
4. Water stress								
5. Nutrient stress								
6. Altitude	200 m					various	80m	various
7. Topography	light					light-med	light	various

1 = Bustomi (1988); 2 = Daryono (1988); 3 = Djazuli et al. (1986); 4 = Sutomo (1988); 5 = Hadi et al. (1988); 6 = Sadono and Setyarso (1992); 7 = Soemarno and Bustomi (1986); 8 = Setyarso (1991).

Four conclusions can be drawn from Table 1. First, there is no complete and comprehensive growth and yield study on *A. mangium* in Indonesia. Yield and stand tables are consequently not available to forest managers. Second, tree and stand volume— not biomass—are the most preferred measures. Although the plantations' objective is to supply pulpmills, measurement in cubic meters is still needed. Third, private companies have made no significant contribution to promote (more explicitly, fund) research on growth and yield, thus discouraging long-term, comprehensive studies on growth and yield. Fourth, many managerial and environmental aspects influencing growth and yield remain to be studied before more accurate and consistent growth and yield projections can be made.

Guidelines for Future Programs

Future research should be systematically guided for increased effectiveness and efficiency. For *A. mangium*, some specific recommendations for prioritizing the information to be explored and investigated are:

1. Initially, define the "beneficiaries" or users of the information. They might be researchers who need the information to develop or improve their systems of research interest. For them, quality of the data in terms of completeness, accuracy, consistency, and continuity, is important. Forest managers of both small- and large-scale operations need tree and stand tables for their planning and monitoring. Finally, extension workers need study results for disseminating the information to tree farmers.

2. Conduct an inventory on what has been achieved so far in the field of growth and yield study. The inventory can be designed by stratifying the countries that deal with *A. mangium* establishment, by the research institution and research funding agencies, and their respective libraries. Compendiums and other database systems must be checked. The inventory should result in lists of documents (both published and unpublished) according to the specific subject, coverage (in terms of area as well as type and number of parameters investigated), and if possible, the quality (statistical tests).

3. Formulate priorities for future research by contrasting the results of the inventory in (2) with the needs of beneficiaries in (1). Priorities should be ranked according to what is most needed and simultaneously least investigated.

Constraints to This Approach

Some factors constraining such prioritization on growth and yield studies are:

- the logistical process of assigning someone (or a team) to do the job

- funding the activity

- the demands of initiating the needed information network for continuity of research collaboration. This is not a simple task, given that every research agency and even each researcher has their own independent ideas about research objectives.

A Proposed Strategy

1. Construct a preliminary formulation of the beneficiaries and the respective needed information on the growth and yield of *A. mangium*.

2. Conduct preliminary checking on the availability of information.

3. Propose a hypothetical rank of priorities. Steps 1-3 can be performed during this COGREDA meeting.

4. Design a worldwide inventory on growth and yield study on *A. mangium* (as well as other species if necessary), including: the type of information to be gathered; the procedure; the system of processing, maintaining, utilizing, and communicating

information; and inventory budgetting. A separate meeting is needed to accomplish this task.

5. Implement the inventory and managing the results. The inventory can be initially finished within 1-2 months and should be maintained to track the continuous flow of information.

6. Prepare reports, both on the basis of fulfilled specific objectives (e.g., preparation of the *A. mangium* monograph) and of routine objectives (e.g., updating of information).

Conclusion

Growth and yield studies are often considered to be routine activities in forestry business, but are rarely realized. This is frequently the case in developing countries, where hardware development is considered more important than developments in the software side.

Today, hundreds of thousands of hectares of *A. mangium* have been planted without any sound stand growth and yield projection.

Inventory on growth and yield studies from all other locations are vital for filling this information gap. An inventory like the one outlined above should aim to satisfy the needs of academics, forest managers, and extension workers.

Discussion Notes

Many studies describe the environment surrounding the experiment but fail to assess its affect on the trees—for example, water nutrient stress imposed by unusually low rainfall.

Growth is commonly reported expressed as the mean (y/A) or rate of g th (dy/dA); the information normally required by forest managers, however, is cumulative growth (y). A further lack is of yield tables, which are often not available to forest managers.

Mangium, together with *Eucalyptus* spp., is now used to supply pulp mills. In Sumatra there are two, one requiring 5,000 tons/day (North Sumatra) and another requiring 1,000 tons/day (South Sumatra). Yet there is little work to see how this requirement will be met. Private corporations in Indonesia have not promoted research on growth and yield. They receive incentives from the government, but plantation establishment is based on very rough estimates of yield. In general, they assume 25 m^3/ha/year. In fact, however, yield varies greatly, anywhere from 10 to 40 m^3/ha/year in the case of mangium.

The author's specific proposal is for: (1) an inventory of users and need, current achievements, and prioritization; (2) an information network for validating and monitoring that would use MPTGro, the growth simulation component of the computer package MPTSys, as a tool.

Question: Is there any cross-national study of MPTS on growth and yield, management, and products?

Answer: The committee for development of MPTGro is pursuing this now, but experience shows that a very committed core group is needed to share information.

Q: Your suggestion to include environmental factors in calculating yield requires much work. Is there data to show that the added factors justify this input?

A: I mentioned t   factors mainly to avoid ov oking any overriding factors at the outset. From there, we must screen the key variables to a minimum.

Different users measure yield in different terms. For example, forest managers speak in terms of fiber yields; farmers may be interested in calorific values for fuel; ecologists have a different yield factor. Guidelines for calculating yield should accommodate these different users.

Q: The problem in improving yield calculations is to pursue data that already exists. A network among large-scale producers, such as SFI in Sabah, would be useful, provided that it is made attractive to them to share the data. In Sabah, some plantations have been monitored through a complete rotation; thus potentially filling the gaps cited for longer periods. Often, however, producers are not worried about leaf production or nutrient cycling.

A: Again, users differ. Scientists are sometimes trapped in academic paradigms. Can we therefore have access to the information from Sabah industries?

SFI: The point is that such information is often provided with no return to the company. Sabah Softwood has similar experiences.

A: However, there is often a trade-off between academia and what companies receive. In this example, the company benefits from receiving analyses of growth and yield for prediction. Research results are thus often useful to companies although they don't directly provide cash.

Comment: CSIRO and the F/FRED Project are two non-profit interests that aim to share information liberally, in the interest of better research resource allocation.

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Insect Pests of Acacias: An Overview

Chaweewan Hutacharern

This paper provides a brief overview of known pest associations of *Acacia* species and outlines procedures for better pest control.

A review of 56 documents (including Turnbull 1986, who listed 32 species as being unassociated with pests or diseases) identified 34 acacia species as pest-associated. Among these 34 species, only 9 showed appreciable insect damage (Table 1).

Because a species is included in Table 1 does not necessarily mean that it is in urgent need of control measures. None of the species carried extremely serious pests, although most of them are potentially hazardous.

Acacia mangium is an outstanding multipurpose tree in the humid to subhumid tropics, with excellent potential for use as pulp and chips, fuel, and site rehabilitation. As it is an important reforestation species in many tropical countries, it is both worthwhile and economically wise to pay special attention to insects associated with it.

Insects on *A. mangium* appear to have greater significance in Malaysia, the Philippines, and Thailand. In other countries they are considered of only minor importance. In those countries, pests are found to associate with *A. mangium* from seed to grown trees (Table 2).

Table 1. Some acacia species suffering significant insect damage, for which control measures may be needed.

Tree Species	Insect pests	Sources
Acacia auriculiformis	*Sinoxylon* spp.	Hutacharern et al. 1989
A. farnesiana	*Oncideres pustulatus*	Rice 1989
A. ligulata	*Acizzia uncatoides*	Halperin 1986
A. mangium	*Acizzia* sp. *Helopeltis* sp. *Indarbela* sp. *Sinoxylon* spp.	Brasa 1991a Luego 1990 author's observation Hutacharern et al. 1988
A. mearnsii	Twig, branch girdler stem borers	Vulcano and Pereira 1978 Sherry 1971
A. nilotica	*Euproctis lunata* *Sphenoptera chalcichroa*	Rahman and Chaudhury 1987 El-Atta 1988
A. pendula	*Terria lunifer*	Cunningham et al. 1981
A. tortilis	*Corydon serratus* *Julodis* sp.	Singh and Bhandari 1987 Harish 1987
A. tumida	Termite	Turnbull 1986

Table 2. Insect pests affecting *Acacia mangium*.

Plant parts	Pests	Sources
Seed	Seed borers	Turnbull 1986
Leaf	*Acizzia* sp	Braza 1991a
	Aphids	Braza 1988, author's observation
	Archips micacaena	Hutacharern 1992
	Atractomorpha spp.	Hamid 1987
	bagworms	Braza 1988
	Cryptothelea sp.	Hamid 1987
	Deretina sp	Braza 1991
	Eunococephalus sp.	Hutacharern et al. 1989
	Eurema spp.	Braza 1988, Mohamad 1986
	Grasshopper	Braza 1988
	Helopeltis sp.	Hamid 1987
	Hypomeces squamosus	NRC 1983, Hutacharern et al. 1989
	Lymantria sp	NRC 1983, Hutacharern et al. 1989
	Looper	Braza 1988
	Lymantrid	Braza 1988
	leaf folders	Braza 1988
	Nisitrus vittatus	Hamid 1987
	Parasa sp.	Hutacharern et al. 1988
	Pteroma plagiophleps	Anonymous 1985
	Scale insects	Braza 1988
	Thosea asigna	Hamid 1987
	Thosea sinensis	Hutacharern et al. 1989
	Valanga nigricornis	Hamid 1987
Sap	*Cletus trigonus*	Hutacharern et al. 1989
	Dysdercus cingulatus	Hutacharern et al. 1989
	Homoeocerus walkeri	Hutacharern et al. 1989
Stem	*Callimetopus gloriosus*	Braza 1991b
	Camponotus sp.	NRC 1983
	Sagra femoralis	author's observation
	Sinoxylon spp.	Hutacharern et al. 1988
	Xystocera sp.	NRC 1983
	Coptotermes spp.	NRC 1983
Bark	*Indarbela* sp.	author's observation
Root	*Coptotermes* spp.	Anonymous 1985
	Leucopholis irrorata	Braza 1991b
	Macrotermes distans	Anonymous 1985
	Sternocera aequisignata	Hutacharern et al. 1988
	S. ruficornis	Hutacharern et al. 1988

A. mangium is exotic to many countries and, despite the substantial list of pests associated with it, is not considered to be vulnerable to insect attacks. Reports of new pests have been widely documented, but these have generally been locally known pests that previously affected other crops and which have adapted themselves to a new host. As a result, they are usually dismissed as being minor and unimportant. However, a closer examination of available literature indicates an increasing number of new insects being found, and suggests that control measures should be introduced. Prior awareness of local insects is essential. Whenever a species is selected for reforestation or widely planted for commercial use in a region, effective advance and continuing surveillance of insects is necessary for prevention, or at least prompt detection, of a pest outbreak.

Although it is accepted among entomologists that *A. mangium* suffers from fewer insect problems than other selected species, actual investigative and research experience on its vulnerability to insects is limited. In light of this, as long as *A. mangium* monoculture is prevalent in many countries researchers should pursue all sources of information on insects and disseminate this knowledge so as to anticipate future needs. Toward this objective, we urge concerned scientists to consider the following practices.

In countries where *A. mangium* is planted on a large scale, concurrent insect survey projects should be required. Surveillance should be conducted at appropriate intervals in order to avoid unanticipated insect outbreaks. Outbreaks of insects occur when biotic, climatic, and physical changes disturb an area's biological balance. The introduction of a new plant species unquestionably amounts to such a disturbance of this biotic equilibrium. Accordingly, it is important not only to be aware of existing pests, but also to assess and rate the damage incurred by individuals pests and to identify their host trees. Periodic sampling of population density can be helpful.

Species performance trials are recommended with the cooperation of forest entomologists for diagnosing slow growth and mortality of tested species when they occur.

A forester without entomological experience may misinterpret insect abundance and susceptibility in a particular area due to a lack of awareness of seasonal variations, differences in population peak periods, and other influences. Alternatively, misreporting can attribute damage and similar evidence of infestation to factors other than the presence of insects. For instance, some insect damage can be disguised or mimicked by drought, nutrient deficiency, and rootrot.

Silvicultural management can also affect insect population. Practices such as intensive site preparation and control of herbaceous vegetation, while promoting tree growth, may also have the effect of increasing the population of certain insects.

In some circumstance mixed plantations, instead of monoculture cropping, can avoid serious pest problems. Trials of mix-planting various species with *A. mangium* are required in order to identify the most compatible species. Also needed are observational evaluations of relative species performance with regard to insect problems. This information assists forest managers to determine research needs and priorities.

Reports of potential pests, their outbreaks, and control trials should be distributed among scientists in the participating countries to avoid duplicative research and to save time, cost, and effort in updating individual country records.

Discussion Notes

The most important insect problems of *A. auriculiformis* relate to branch and twig borers. In Thailand, the "powder post beetle" attacks small stems and branches early in the tree's growth. Its damage is potentially lethal only at collar level.

For *A. mangium*, most reports from Philippines and Malaysia cite termites as a problem. Overall, however, insects are not a significant problem.

Regarding prevention, intercropping can avoid many problems. This does not just mean alternate rows -- mixed block plantations are a manageable form of mixed cropping. To control "powder post beetle" damage, remove broken branches, as females lay eggs there.

The red coffee borer wilts the top portion of the tree.

Question: What about disease problems? Heartrot and root diseases are problems of some acacias. Termites, coupled with heartrot, pose a difficult problem in Malaysia.

Answer: Disease problems were to be covered by my tree pathologist colleague, the co-author of the chapter in the monograph on *A. mangium*, but she could not attend this meeting. Regarding the combination of termites and heartrot: termites are secondary to the heartrot problem, as they are attracted to individuals already vulnerable due to heartrot. Once the heartrot is addressed, the termites cease to be a problem.

Q: *A. holosericea* appears to survive termite attack best. What are the factors that contribute to termite problems?

A: On very dry sites and during summer months, termites can be a problem.

Q: Shouldn't a survey of insects on acacias include biocontrol agents?

A: Again, insects on *A. mangium* are a minor problem. Problems are also slow to appear in introduced areas. But yes, natural enemies are a routine part of an entomological survey.

Q: Are any of these insects potential disease vectors?

A: Aphids and other sucking insects can be, but with acacias there is as yet no evidence to suggest they are.

Q: *Sinoxylon* appears to be a threat to *A. auriculiformis*. What control measures do you suggest?

A: Improved management (removal and burning of dead and broken branches) in the first two years helps. Chemical measures are not as effective as proper management, l spraying can be done during the dr season.

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Processing and Utilization of Acacias, Focussing on *Acacia mangium*

A.K. Razali and S. Mohd. Hamami

To assess the utilization potential of acacias, we must explore the full range of products and their requirements for development. Requirements for saw logs, for example, differ from those for veneer. In this exploration we should learn from the experience of rubber growers, who have developed an industry of rubber furniture manufacture after years of viewing rubber as only a latex crop, and who now are pursuing ways to use even the roots of the tree.

The three categories of products to be considered for acacias are:

solid
particle/fiber
chemical

The sequence of use and processing to be considered is: (1) logs, (2) chipping, and (3) fiber and chemical uses.

Wood Properties

For solid wood conversion, desired properties are cylindrical stem with minimum taper. If trees are pruned early, wastage can be confined to the juvenile core.

Among acacias, *A. mangium* is the best known in terms of wood properties and utilization. It has distinct sapwood and heartwood. The former is light in color; the latter dark brown. The wood is hard, dense, and straight-grained, with a density ranging from 420-483 kgm^{-3} (green soaked volume), or 500-600 kgm^{-3} air-dry (Razali and Kuo 1991; Wang et al. 1989; Ong 1985; Peh and Khoo 1984; Logan and Balodis 1982; Peh et al. 1982). The basic anatomical description of *A. mangium* wood is (Peh and Khoo 1984):

growth rings:	Absent
vessels:	Simple perforation; medium-sized to moderately large; few or moderate in number; mostly solitary; the rest in radial pairs and radial multiples of three (rarely more); diffused with a tendency to alignment in oblique line; tyloses generally absent; gum-like deposits present.
wood parenchyma:	Paratracheal type, some conspicuously surrounding the pores whereas others consisting of narrow sheaths to the pores.
rays:	Moderately fine, barely visible or just visible to the naked eye on cross-section, not prominent on radial surface.

Green wood moisture content varies from 75% at the top of the trunk to 105% at the bottom (Ong 1984). Moisture content in that study was not affected by sites, but there were considerable differences between trees growing on similar sites.

Wood Solid Products

Table 1 shows the basic mechanical properties of 12-year-old *A. mangium* as compared with other popular furniture species. In this context, it is classified as a Light Hardwood (i.e., with low to moderate strength properties). With younger stock, Wang et al. (1989) indicated marginally lower strength properties:

Modulus of rupture (MOR) 745 N mm^{-2}
Modulus of elasticity (MOE) 9908 N mm^{-2}

However, Mohd. Zin et al. (1991) states that the strength properties of *A. mangium* are not affected by tree age. Comparing the modulus of rupture for rubber with that of mangium (Table 1), we see that mangium is a promising furniture tree.

Table 1. Strength properties of *Acacia mangium* and some popular furniture species. Sources: Lee et al. 1979; Ong 1985.

Species	Air-dry density (kg/m^3)	Static bending (N/mm^2) Modulus of rupture	Modulus of elasticity	Compression parallel to grain (N/mm^2)	Compression perpendicular to grain (N/mm^2)[1]	Side-Hardness[2] (N)	Shearing strength parallel to grain (N/mm^2)
Hevea brasiliensis (rubber)	650	66.0	9,240	32.2	4.69	4,350	11.0
Shorea platyclados (dark red meranti)	610	77.0	12,100	30.6	4.14	3,650	8.7
Shorea leprosula (light red meranti)	575	75.0	13,600	41.4	2.51	2,940	6.8
Sindora coriacea (sepetir)	690	92.0	13,600	46.3	5.93	5,210	13.6
Palaquium gutta (nyatoh)	675	79.0	12,200	44.5	-	5,430	11.0
Gonystylus bancanus (ramin)	675	88.0	15,900	48.8	-	4,580	8.5
Acacia mangium (12-year-old firebreak, not plantation)	570	97.0	10,891	43.4	-	3,550	6.8

In fact, *A. mangium* is reported to make attractive furniture and cabinets, mouldings, doors, and window components (National Research Council 1983). It has good machining properties and is fairly stable, with green to air-dry shrinkage of 6.4% tangentially and 2.7% radially (Salleh and Wong 1991). The timber has been found to kiln dry well and fairly rapidly without serious defects when suitable kiln schedules are used. Studies have indicated no problem sawing the species and that the timber planes well for a smooth and lustrous surface (Peh and Khoo 1984). Sanding is easy and free of torn fibers. *A. mangium* is easy to drill and turn, as long as turning pressure is not excessive.

Besides furniture and cabinets, Mangium is suitable for light structural works, agricultural tools, boxes, and crates.

In peeling studies, *A. mangium* veneers proved tight, smooth, and of acceptable quality (Wong et al. 1988; Chai 1989; Salim 1992). They were dried easily using a normal schedule comparable to that for other commercial species. The recovery, however, was low, ranging from 35-45%. This could be due to irregular shaped logs or small diameters. At present, plywood mills are not equipped to peel small-diameter logs.

The processing technology that can make use of small-diameter acacia logs is still expensive, but can show return within 18 months of installation. New processing technologies are showing greater returns. Where stems are difficult to slice, steaming or 'cooking' can be done. This technological shift will mean translating the processing means used for rubber to more sophisticated machinery.

Pulp and Paper

For pulping and paper-making properties, *A. mangium* is again the most studied acacia species (Logan and Balodis 1982; Peh et al. 1982; Khoo et al. 1991). With sulphidity and active alkali of 11-12%, yields of sulphate pulping were 46.9-49.6% and 49.8-52.3% with Kappa Number below 25 for four- and nine-year-old material, respectively. Logan and Balodis (1982) concluded that the paper-making properties of *A. mangium* and *A. auriculiformis* are similar, but the former would obtain a lower FOB price for exported woodchips.

Particle and Fiber Products

The basic fiber morphology of *A. mangium* has been well studied (Pensook 1990; Logan and Balodis 1982; Peh et al. 1982). The following is a summary:

fiber length	0.94 - 1.12 mm
fiber width	21.8 - 25.0 microns
fiber lumen	16.3 - 18.8 microns
Runkels ratio	0.32 - 0.34
Coefficient of suppleness	74.5 - 75.3%
Felting power	37.7 - 51.3

Although magnified photographs of mangium cell structure show that *A. mangium*'s fast growth leads to thinner cellular walls, particleboard made with *A. mangium* has satisfied international standard requirements. Single-layer Mangium boards can be made to exceed the minimum strength requirements for Type 1 board of the British Standard (Chew et al. 1991). Razali and Kuo (1991) found that particleboards of *A. mangium* and mixtures with *Gmelina arborea*, bonded using 7% urea formaldehyde resin adhesive, displayed strength properties exceeding Type 200 board of the Japanese Industrial Standard (JIS) A 5908 specifications.

Mangium particles have been converted into cement-bonded particleboards (CBP) with various wood to cement ratios and chemical additives (Rahim et al. 1991; Tachi et al. 1988).

A. mangium has also been successfully converted into medium-density fiberboards (MDF). Boards bonded with urea formaldehyde resin or isocyanate binder met various grade requirements of JIS A-5906 standard (Khoo and Matsuda 1990; Pensook 1990).

Composite Products

Proximate chemical composition for *A. mangium* is as follows (Jegatheswaran 1989; Peh et al 1982; Khoo et al. 1991):

Holocellulose	69.4-73.8%
Alpha-cellulose	44.0-47.2%
Alcohol-benzene	2.9-5.6%
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	19.7-24.5%

Generally this composition does not reflect any unfavorable features for pulping, although holocellulose, alpha-cellulose, and pentosans contents are slightly lower than for average temperate hardwood (Khoo et al. 1991).

There is a growing use of composite products combining wood with adhesives, and further acacia research should consider this. Plywood bonded with urea formaldehyde resin adhesive has been found unsatisfactory. Mohd. Hamami and co-workers (1991) found that laminations of Mangium wood glued with urea formaldehyde resin did not meet minimum industrial glueline quality. However, laminations glued with phenol-resorcinol formaldehyde resin adhesive exceeded the requirements of 5.5 MPa shear strength.

Research in converting *A. mangium* into laminated veneer lumber (LVL), which has potential for structural applications, indicate that bending as well as shear strengths of the LVL were much greater than the minimum values required by Japan Agricultural Standard for first-grade structural LVL (Sasaki et al. 1990; Wang et al. 1990; Salim 1992). The resin used was phenol formaldehyde, an exterior grade adhesive.

Concluding Remarks

Processing operations can and should be adjusted to meet market demands. For example, market preferences for color can be met by changing wood color through oxidation. Thus, the range of potential markets should be considered at the outset of processing research.

Discussion Notes

Question: Is there a relationship between age and wood properties?

Answer: Yes. For furniture, older trees are better. Heartrot problems tend to be confined to the juvenile core. The outer 2/3 retains value. In fact, with newer technologies, rotary peeling of hollow wood is now possible.

Q: Is there a relationship between tree size and wood properties?

A: No.

Q: Is wood parquet made from root and upper stem portions a potential product of acacias?

A: Actually, we're now looking into using mangium through a flashing process to produce the panel interior of Rolls Royce automobiles, replacing birch.

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Research on Economics and Marketing of Acacias

Hsu-Ho Chung

Introduction

In tree plantation development, species selected for planting are always those with excellent biological biomass production (in terms of quantity). The tree's growth characteristics (e.g., form and branching), resistance to stress (environmental, disease, insects, etc.), and the qualitative and marketing aspects of its products hardly receive any of the attention they deserve in the planning and development process. One reason for this — perhaps the main one — is that plantation development always starts with field trials to identify the fastest growing species or varieties in quantitative terms. Species thus identified are then selected for plantation. Qualitative features of tree growth, product characteristics, and market acceptability receive consideration only after the established plantation has shown initial signs of success. Some undesirable characteristics of plantation trees can be amended through silvicultural practices such as thinning and pruning. Others, however, including inherent physical and chemical properties, cannot be improved through management.

Acacia plantation ventures in the Asia region are no exception to this pattern. Hundreds of thousands of hectares of acacia (mostly *A. mangium*) plantations established in the region in the 1970s and 80s are now facing economic and marketing problems resulting from a lack of macro-level considerations in the ear' stages of plantation planning and development. These issues, and research needed to resolve them, are described in this paper.

Constraints to Using Acacia Plantation Wood

Wood of *Acacia* species, like that of other short-rotation, fast-growing plantation species, has the following inherent characteristics:

1. small diameter
2. knotty
3. low density
4. low strength
5. large portion of reaction wood
6. greater incidence of spiral growth
7. greater growth stress
8. greater proportion of juvenile wood

All of these inherent features can, in one way or another, become potential constraints to applications of acacia wood, particularly non-fiber uses. The utilization of acacias as affected by these inherent characteristics can be summarized:

1. **Wood as sawn lumber**: all of the above eight features are severe constraints in this application.

2. **Wood as block board**: the above-mentioned characteristics do not cause concern.

3. **Wood for pulp and paper**: low wood density may increase costs of production, but otherwise acacia woods are excellent for pulping.

4. **Wood for reconstituted panel board**: the features indicated above do not pose concerns. Acacia woods are excellent materials for this type of utilization.

5. **Wood for plywood/veneer**: the above-mentioned characteristics represent severe constraints to this application.

Research Needs in Economics, Policy, and Management

Obviously, acacias and other plantation woods will not command good prices if they are used only as a low-cost source of fiber and particles, or as general utility timber. The foregoing brief review of constraints reveals the need for research to overcome them in order that these species can become sources of high-value products and thus improve the economic return from the venture.

Genetic and breeding research to produce better-priced woods of higher quality are clearly warranted. With respect to existing plantation operations, research on tending (thinning and prunning) is certainly needed to minimize the costs associated with these silvicultural practices. The processing technology for handling small-diameter logs should also be developed. Cost/benefit analyses of investment should examine different processing facilities. Results of such analyses would be useful both to investors and policy makers in their decisions of how to provide incentives to investors interested in upgrading the uses of plantation species through investment.

Tree plantations undoubtedly can be profitable ventures, or enterprises like the Indah Kiat Pulp and Paper Corporation in Indonesia would not continue their plantation development. The question is, How profitable? And furthermore, Can the profitability be improved and made comparable to that of other plantation crops? Some early reports of viability assessment have shown that tree plantation revenue is economically viable and acceptable. Cost-revenue analyses have shown that the internal rate of return (IRR) for plantation projects is between 13% and 20%, which compares favorably to the 15% value that any new plantation crop should obtain in order to be viable in the Asia region (Mahmud and Sirin 1991; Rahman and Johari 1991; Cruz 1991).

Several observations should be made concerning the results of these viability assessments.

1. All the prices used in the cost-revenue analyses were stumpage prices, which tend to overestimate the expected revenue from the plantation venture. The prices of wood actually includes production costs, the price of stumpage *per se*, and the margin for profit and risk in wood production.

2. Many of the revenue calculations did not account for depreciation, amortization, and income tax.

3. Calculations of yield were based on the first rotation. The rapid depletion of nutrients from the site by fast-growing trees (despite the fact that *Acacia* species may indeed enhance soil nitrogen contents, trees do not grow on nitrogen alone!) may result in lower production in the second and later rotations. Thus over the long term the results of cost-revenue analyses obtained this way may not be representative.

4. Catastrophes caused by natural disaster, including large-scale insect and disease outbreaks, were not considered in the viability assessment. Large-scale damage, like that caused by tropical storms and heart rot to *A. mangium* plantations, and by the psyllid pest *Heteropsylla cubana* on *Leucaena leucocephala* plantations, should be considered as a variables in economical analyses.

Furthermore, the relatively long period (compared with other plantation crops) for payback may keep potential investors away despite the favorable IRR reported for various projects. Notwithstanding these minor shortcomings, the results of these cost-revenue studies still represent good indications of the financial feasibility of plantation development.

Results of cost-revenue analyses can be improved by considering the assertions mentioned above. A more realistic IRR, for example, can be derived if studies are carried out using the market price, which will become available as more and more acacias are marketed for various uses, instead of stumpage price.

Studies on governmental policies for providing incentives (e.g., tax breaks for long-term plantation investment and subsidies for losses caused by natural catastrophe) to both industrial plantation investors and tree farmers represent still another potential area for plantation economic research. Given the pressure being exerted on governments by ecological groups, governments may become more supportive of tree plantation efforts and provide greater incentives.

For small-scale tree farmers, a critically important area of research is assessment of the critical farm size needed for a viable tree plantation. In Taiwan, 10 ha is found to be the minimum viable size. Where farms are smaller than this, some form of collectivization, including some forms of nongovernment organization (e.g., tree farmers' associations), may be needed to help small-scale tree farmers in their plantation management. This is another topic deserving further study.

To ensure that small tree farmers are not being treated unfairly by large industries in their transactions, the government's role in safe-guarding the farmers'interests in this regard should be assessed. In Taiwan, for example, a pulp company had arranged with farmers to plant 10,000 ha of trees for use as pulp. When the pulp company started to import less expensive material from North America, the government stepped in to mediate on the farmers' behalf. Studies similar to those proposed for small tree farm plantations should be carried out for the case of farmers producing logs of fast-growing species through agroforestry.

Marketing Research

In view of the rapid rate of exploitation of natural forests, plantations are considered to have promising prospects in the Asia region. Plantation woods will undoubtedly play an important role in timber supply by replacing the wood obtained from natural forests. However, considering that plantation woods are substantially different, both in properties and processing characteristics, from mature, natural forest trees, promoting and marketing these species is not very easy. But the recent movement by environmental groups in the industrialized nations to boycott wood products from tropical natural forests may make plantation trees produced in Asia more acceptable in European markets. Government policies in response to this environmental conservation movement in developed countries needs to be assessed. A strong positive response to the movement would call for government's firm commitment to promote plantation ventures, and vice versa.

The use of fast-growing plantation species as fiber resources for pulping and panel-making has been well accepted by the industries due to these species' proven properties for these applications. In fact, most of the wood prices used in the cost-revenue calculations discussed above were estimated based on the assumption that the woods would be used for pulping. In this context, studies of the marketing aspects of supply/demand price elasticities for plantation woods as raw material sources for fiber and particle *vis-a-vis* other competitive materials are needed at national, regional, and global levels. As for the use of acacias for high-value-added products: although *A. mangium*, for example, has reportedly been used by furniture factories in Australia, market acceptance by both the producing nations in the region and the major importing countries (e.g., Japan) still needs to be assessed.

Discussion Notes

A. confusa is a branchy species indigenous to Taiwan, but is being selected for form. It is mainly used for fuel and charcoal, as it has high density and good calorific value. Anatomical and physical studies can be obtained through TFRI.

(See also the notes following the paper by Tan.)

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Economics of Planting and Marketing *Acacia mangium*

Raymund Tan Get Seng

In a seminar on Forest Plantation in Malaysia in 1984, I said that "with the imminent depletion of our natural forest resources, the role of forest plantations in ensuring our future supply and the production of timber has been generally accepted. The successful development of forest plantations will in fact serve a very important function" (Tan 1984). The same paper stated that Malaysian forestry research should aim ultimately at identifying and developing new opportunities and innovations that would stimulate the forest plantation sector.

On the economics of timber growing, I quoted our Malaysian Prime Minister: "Government servants by their very nature are not businessmen." The burden of forestry research and its application in the development of the forestry sector will rest squarely with the private sector. Our priorities therefore should be to develop a framework that will catalyze the private sector's participation in the timber-growing business.

Eight years have passed since we in Malaysia recognized the economics of timber growing, but tree plantation remains in the doldrums, despite all indications that by 1995 Malaysia alone will have a total supply deficit of 3.5 million m^3 of logs based on the current processing industry requirement. In a best-case scenario, that deficit would continue until 2010. In the worst-case scenario, Malaysia will face a deficit of 3 million m^3 in 2000, peaking to 14.5 millions in 2005 before recovering to 4.2 million in 2020.

Asia Pacific Forest Industries (1992) conjectured that the implication of surplus/deficit situation would result in:

- Closure of mills
- Running mills below capacity, or
- Importation of logs to supplement mill demand

Currently, Sabah Softwood Sdn. Bhd. (SSSB) is the only major commercial tree planting venture in Malaysia that has heeded to grow forest plantations as a business. The primary species grown are *A. mangium*, *Gmelina arborea*, and *Paraserianthes falcataria*. All of these are fast growing and have good commercial value in terms of mean annual increment (MAI), biomass, and export value. From SSSB's experience, *P. falcataria* is the most suitable for generating quick returns through round log sales. However, in the medium- to long-term, SSSB recognizes *A. mangium* and *G. arborea* as the two species with more varied applications as chips for pulp and paper and, to a lesser extent, for saw logs for lumber and veneer peeling. SSSB has also embarked on installation of a chipmill and from the experience gained over the years, wants to concentrate on *A. mangium* as the most desirable chip species to support a pulp and paper industry.

Types of Acacia

Acacia species commonly:

- are leguminous and fix nitrogen in the soil
- have dark heart wood and much paler sapwood

Keating and Bolza (1982) listed *A. mangium* as "a good plantation timber," capable of adapting to a range of rainfall and temperature conditions. Other important acacias are: *A. auriculiformis* (Ear-pod wattle), *A. cambagei* (gidgee), *A. granulosa* (black acacia), *A. harpophylla* (brigalow) *A. koa* (koa), and *A. erichii* (Qumu) (Keating and Bolza 1982).

Why *A. mangium*?

While *A. auriculiformis* was earlier known to be a hardy, nitrogen-fixing legume and good ornamental tree, its cousin, *A. mangium*, was introduced from its native Australia relatively recently. The two species have striking similarities, but *A. mangium* stands out as the better plantation species. It has grown faster and straighter in many provenance trials and studies over the last 25 years.

A. mangium plantations have been established even in areas dominated by tenacious weeds such as imperata grass (*Imperata cylindrica*), as in plantations established by the Sabah Forest Development Authority (SAFODA) on the West Coast of Sabah in Malaysia. On good sites in Sabah, some *A. mangium* trees have reached 23 m height in nine years. Annual average diameter increase of 2-3 cm is common. In trials, 13 year-old trees have reached a mean height of 25 m, mean diameter of 27 cm, and maximum diameter of 51 cm. Rotation cycles are 12-15 years for saw log production and 5-7 years for pulpwood (Udarbe 1984).

Silviculture

Pruning and thinning are not necessary in pulpwood production areas with rotations of about six years and a spacing of 3 x 3 m. However, if *A. mangium* is grown for saw timber and veneer log production, regular pruning is exptected to be necessary at an early age to produce a clear bole of 6-7 m (Chuan and Tangau 1991).

Commercial Suitability

A. mangium has shown itself very adaptable to a range of soil conditions, from akaline to acidic. Even barren soils compacted by logging are plantable, provided a suitable fertilizing regime is introduced early in establishment.

A. mangium's MAI has proven to be most suitable for quick return in terms of biomass derived from the prolific leaves, the bole, and branches. Its nitrogen-fixation ability is a good response to soil that is badly leached after removal of the vegetative cover.

Recent research on market demand has shown that *A. mangium* is highly acceptable for:

(1) fuelwood (high calorific value)
(2) straight bole for lumber and veneer
(3) wood chips for pulp and paper industries
(4) wood chips for particle board and medium density fiber-board

For veneer and plywood, testing has shown that the incidence of knots and flutes rendered the flitches unsuitable for commercial plywood manufacture (Waring 1983). However, that author mentioned that the 1983 test was carried out in a conventional plymill which was designed to process large-diameter logs. The scenario will of course change if the test is conducted in modern peeler mills such as those in the United States, Japan, and Scandinavia, which practice state-of-the-art peeling technologies for small-diameter logs.

Financial Return

In 1986, SSSB computed the financial returns for 10- and 8-year rotations of *A. mangium* and *G. arborea*, respectively. Both were found very attractive for export as chips at market price (Table 1). Internal rate of return (IRR) of 12.8% at MAI $20m^3$/hectare/year up to IRR of 15.9% at MAI $25m^3$/ha/year for new planting and IRR of 19.1% for replanting (Table 1) have been calculated. These are for a plantation of about 20,000 ha, averaging 10 years old, and could be realized on the assumption of a total investment of M$36 million on chipmill machineries, a loading terminal, and working capital (NBT 1986). The chipmill would be designed to process up to 600,000 m^3 of plantation timber and produce over 200,000 BDMT of chips annually.

Potential For Pulp, Paper, and Reconstituted Products

Mohd. and Salleh of Forest Research Institute Malaysia, in a paper presented to the 1992 National Seminar on Economics of Forest Plantation Malaysia, stated that establishment of a forest plantation can "provide a steady source of fibrous raw material to wood-based industries when the supply of existing raw material faces depletion or becomes expensive" (Mohd. and Salleh 1992).

Table 1. Financial return on 8-year rotation of *Gmelina arborea* and 10-year rotation of *Acacia mangium*, at mean annual increments of 20, 22, and 25 m^3/ha. Amounts are expressed in $M/ha ($M2.5 = US$1).

	New Plantings					Replantings				
Year	Direct Costs	O-head[1]	Total	Revenue[2]	Net Inflow/ -Outflow	Costs	O-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.
[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.

A. mangium, P. falcataria, and *G. arborea*, they noted, have attractive properties for making products such as pulp, paper, particleboard, wood-cement board, and medium-density fiberboard. They cited the fast-growing species' wood density, fiber morphology, and pulping properties.

Hardwood pulp is used primarily to produce coated and uncoated printing paper, fine writing paper, and the "fluff pulp" used in household tissue, diapers, and sanitary products.

Reconstituted Wood Products

Participants at the Ninth Malaysian Forestry Conference in 1986 agreed that wood-processing facilities were going to change away from solid wood panels in the direction of reconstituted wood products.

Reconstituted wood products with *A. mangium* that could have potential include:

block board - composed of core strips 18 mm thick edge-glued together and used for case-goods furniture

finger-jointed/edge-glued materials - strips with defects such as unsound knots removed can be finger-jointed to obtain lengths up to 20' long and edge-glued to desired widths. Work benches and shelves made from such material can substitute for wider boards from natural forest trees.

particle board - Mangium would make ideal particleboard, replacing the wood residue from timber-processing mills currently used.

Hardwood Chips

Logan and Balodis (1982) concluded that nine-year old *A. mangium* has higher basic density (420 kg/m^3) than most other recognized tropical plantation species at the same age, and therefore this species should yield relatively more wood per unit area and cost less to transport as chips to export markets.

So far as tested, both *A. mangium* and *G. arborea* have the necessary density to make higher weight chips that can be accommodated in the digester for more efficient production and reduced shipping freight costs.

Planting Efforts in Sabah

The following organizations in Sabah have set targets for forest plantations, envisaged to comprise mostly of *A. mangium, G. arborea*, and *A. falcataria*:

SSSB	60,000 ha
Sabah Forest Industries	50,000 ha
SAFODA	150,000-200,00 ha

While SSSB is halfway to its target, and SFI has achieved 21% of its goal, SAFODA is unfortunately still a long way from the stated target. Udarbe (1984) noted that *A. mangium* plantations are feasible primarily for pulp log production in northern Sabah, along with settlement of 900 families in 2 development centers. His study assumed that 25,000 ha would be planted on a 15-year rotation, with heavy thinning at Year 8 for pulp logs, and the best one-third of the stand left to produce saw logs for the final harvest in Year 16. The heavy thinning would induce natural regeneration for the next crop of pulp logs, which would be clear-felled together with saw log trees previously retained for the final harvest. Another assumption was that the stand would show an average MAI of 24 m^3/ha/year for pulpwood and saw logs. The calculation of financial return indicated a project IRR of 9.27% if the costs of the main trunk road, medical and school facilities, considered the responsibility of the Government, are excluded.

Marketing of Hardwood Chips

Wood chips from plantations in the Asia-Pacific region would find ready markets in Northeast Asia, particularly Japan, South Korea, and Taiwan. Because of their bulk and relatively low value, chip shipments are almost invariably confined to single-port loading and discharge, and freight costs favor making shipments as large as possible.

Among the Northeast Asian countries, Japan imports the largest volume of wood chips annually. In 1991, it imported about 22 million m^3 of woodchips, of which hardwood chips comprised 13 million m^3 (59%), and softwood (conifers) chips made up 9 million m^3 (41%). Japan is expected to import only about 5% less than that in 1992, but the proportion of hardwood chips to softwood chips will probably remain the same— about 59% to 41%.

The 1992 supply of hardwood chips to Japan is expected to come from the United States, Australia, Chile, China, Indonesia, and other countries (Table 2). The annual demand for hardwood chips in Taiwan and South Korea is about 1 million m^3 in both countries.

Table 2. 1992 supply of hardwood chips to Japan, by country.

Country	Volume (m^3)	% of total	Type of species
U.S.A.	4,200,000	34.0	Mixed hardwoods
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		

Conclusion

While Malaysian foresters in their many conferences are recognizing the importance of tree plantations to supplement supplies from the natural forest, it is the response from the private sector that is encouraging. Still, most businessmen are cautious in the face of: the high initial capital investment required, long rotation periods before initial harvesting and related interest costs, high risks due to biological and economic factors, difficulty of acquiring suitable land under favorable investment conditions, and unattractive investment incentives; and the large labor force required for fieldwork in the initial stages.

Despite these same obstacles, however, the private sector in Indonesia has started tree plantation on a large scale. Among the leaders are Indah Kiat Group, which has planted 35,000 ha of *A. mangium* at an annual planting rate of 20,000 ha, with a target of 200,000 ha. Indah Kiat Group has their own pulp and paper mill, which handles 500 metric tons of pulp per day. Barito Pacific, another Indonesian conglomerate, has planted 65,000 ha. In all, about 29 timber companies are committed to involvement in reforestation and aforestation in Indonesia.

I am hopeful that further positive action will be taken by the private sector to establish forest plantations in Malaysia, Indonesia, and Thailand. Plantation trees, especially *A. mangium*, will indeed be the predominant wood materials for reconstituted wood products such as particle-board and scrimber, in addition to becoming a desirable raw material for the insatiable global demand for pulp and paper.

I would like to see more conscientious efforts by the private investors in these and other ASEAN countries to provide more cash at the start of the growing periods, and their respective governments to establish more specific incentives for later at the harvest stage, as inducements for the private sector to go into large-scale, commercial forest plantation. The most important prerequisites for accelerating the development of forest plantations are the availability and approval of large tracts of forest land on a long-term lease basis, and sound fiscal incentives from governments (Tan 1990).

I will close by quoting Puan Kaziah Abdul Kadir, Deputy Director, Resource-Based Industries Division, Malaysian Industrial Development Authority: "Given a gestation period of 15-20 years and the relatively high risks involved, the Pioneer status, Investment Tax Allowance, and Agricultural Allowance are only beneficial as long as the company generates income." She further suggested "Group Relief" to encourage established wood-based industries and companies with other business ventures to undertake forest plantations activities, and soft loan facilities, which would provide more direct and significant assistance.

Discussion Notes

Question: Do you agree that ecological sustainability of these ventures should be included in risk analyses? It would also seem that more information is needed on market elasticity for these products. Finally, studies should consider the range of beneficiaries -- not just internal rate of return (IRR), but its distribution among the private company, small farmers, and the government.

RTGS: Sustainability—economic sustainability—depends on dollars and cents. When ecological terms are introduced, calculation becomes difficult. If a government dictates mixed plantations, it does not consider that mixed hardwood chips are unsaleable. A company's board must balance the risk of losing a monocrop to pests or disease against its greater market acceptance. If the board decides for the monocrop, it will address the risk in other ways -- for example, by harvesting early to pre-empt heartrot damage.

Second, regarding market elasticity: the market is very elastic. As mentioned earlier, Japan alone imports 22 million cubic meters of chips each year.

Third, regarding government incentives for tree growing: Malaysia has some such incentives, but they only accrue **after** the trees have been harvested. To help the farmer or company during the critical period when the trees are in the ground, these incentives need to be brought forward in time; for example, through deferment of government taxes.

HHC: It is very difficult to ask private companies to consider ecological sustainability of their operations. Note the case of the horned owl in the Northest United States. Requiring ecological sustainability assessments is generally applicable only when considering converting government land to plantation. In that case, the government must consider the issue of ecological sustainability.

Q: Regarding the economics of succeeding rotations mentioned in Chung's paper, I would like to comment that even eucalypts show higher yields in the second rotation, so the concern over reduced yields in later rotations may not be founded. My question is: Does Taiwan presently import chipping materials?

HHC: Until recently, Taiwan harvested 500,000 cubic meters annually for chips. For pulp, it imports up to 2 million cubic meters/year. In December 1991, a total ban on cutting of natural forest was made law in Taiwan, creating poor conditions for plantation development, although the land is often not suitable for other crops. Despite the ban, some plantations are being developed for leverage in import negotiations.

RTGS: In succeeding rotations, eucalypts will be replaced by *A. mangium* due to mangium's higher density and resulting financial considerations.

Q: Sustainability also means distribution of benefits in the area around the plantation. This has implications for small-farm production and related policies. In Thailand, the legacy of 50 years of this imbalance is a new emphasis on community forestry to redress this unbalanced situation. What practical incentives now exist for tree farmers?

RTGS: Right now in Malaysia, plantations owe no royalty to the government, unlike the situation for round logs harvested from government-owned natural forest. Second, state governments provide companies with 66-year leases under a sliding-scale rental agreement until the plantation is established. A third incentive is that costs of plantation establishment can be deducted from taxes owed. As mentioned before, however, incentives need to be brought forward to the period during the rotation. Sabah Softwoods has remained economically sustainable only because it hasn't demanded a dividend in 15 years.

HHC: I agree. Government support is needed for: (1) soft or low-interest loans; (2) price guarantees for tree products; and (3) market infrastructure development.

Comment: In Malaysia, the government also provides incentives for research and development.

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