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Australian Acacias in Developing Countries

Proceedings of an international workshop held at the Forestry Training Centre, Gympie, Qld., Australia, 4–7 August 1986

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Nitrogen Fixing Tree Association (NFTA)
CSIRO Division of Forest Research
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Foreword

The Australian Centre for International Agricultural Research (ACIAR) was established to help identify priority problems requiring agricultural and forestry research in developing countries, and to support collaboration with Australian scientists who have a demonstrated capacity to assist in their resolution. Workshops are one of the primary avenues for identifying where ACIAR might most effectively implement this mandate.

The genus *Acacia* includes about 1200 species of trees and shrubs with a natural distribution in Australia, Asia, Africa and the Americas. Over 800 of these species are endemic to Australia. A few are planted extensively outside their natural range for timber, pulpwood, tannin, fuelwood and erosion control; others are little known but have attributes that suggest they could be more widely utilised to improve the well-being of people in developing countries.

In many countries, the critical shortage of fuelwood in rural communities, and the need for multipurpose trees to be integrated into agricultural systems has required a reappraisal of tree and shrub species available for planting. Most acacias produce excellent firewood and charcoal, and have the potential to become a component of farming systems providing wood, shade and shelter, and soil improvement.

Australian acacias possess many attributes which characterise successful exotic trees. They are adapted to a wide range of tropical environments including acid infertile soils, saline and arid sites; and can be readily established and managed. They have the ability to fix biological nitrogen and many are pioneer species with high rates of growth, especially when grown outside Australia.

The aims of the workshop were: firstly to bring together current knowledge on the taxonomy, genetic resources, ecology, silviculture and utilisation of Australian acacias of interest to developing countries; secondly, to identify the most important problems and constraints preventing greater use of the *Acacia* resource; and finally, to identify research needs and priorities around which ACIAR might develop collaborative research projects.

The workshop was sponsored by ACIAR, as part of its Forestry Program and by the Nitrogen Fixing Tree Association. ACIAR wishes to thank the Queensland Department of Forestry and CSIRO Division of Forest Research for their assistance in organising the workshop and the associated study tours to southeastern and northern Queensland.

The 65 participants came from Australia, The People's Republic of China, Fiji, Italy, Kenya, Malaysia, Papua New Guinea, Sri Lanka, Thailand, Tanzania, United States, and Zimbabwe. Our thanks to those who presented a total of 43 papers which when published will form a valuable new reference source for the genus. We would also like to thank Reg MacIntyre for his valuable contribution to the editing of the proceedings.

J. R. McWilliam
Director
ACIAR

Summary of Discussions and Recommendations

J. W. Turnbull*

Participants at the workshop demonstrated that the Australian acacias may play a dual role in developing countries contributing to industrial forestry plantations, for timber, pulpwood and tannin, and at the village level in the provision of fuelwood, land rehabilitation and as a component of agroforestry systems.

In most countries research on acacias has been confined to very few species. It was agreed that research in countries where acacias grow, or have the potential to grow, be strengthened in view of the very considerable socioeconomic benefits which can flow from their cultivation. High priority must be given to the exploration and critical evaluation of the genetic resources, and international support and cooperation will be needed for this activity. More intensive studies of the biology, silviculture, management and utilisation of acacias will be essential if they are to become acceptable crop plants. The background papers cover in detail many of the research needs while specific priorities for research and other attention were identified after discussion as follows:

Genetic Resources

The *classification, nomenclature,* and *especially field identification* of acacias constitute a major problem to researchers. It was recommended that a series of field keys be produced to identify species in subsets of the genus. The species in a subset might differ from one region to another but the tropical Juliflorae, the Botrycephalae and species for the humid tropics were cited as examples of subsets. It is important that illustrations be provided and that the keys be multi-access using different characteristics rather than being dependent on a fixed set of botanical attributes. The use of a computer-based identification system similar to the one developed by CSIRO Division of Forest Research for eucalypts should be explored.

There was very strong support for *organised seed collections* of a range of potentially valuable acacias for international distribution. High quality seed for research, expansion of a genetic base for breeding, and for commercial use, is required. *Acacia auriculiformis, A. mangium, A. melanoxylon, A. holosericea* and *A. mearnsii* and related bipinnate acacias were cited as having very high priority. The need for proper information objectives and environmental conditions by those requesting seeds for research, and for full documentation of the origin and genetic history of seeds to accompany all seed consignments, was emphasised. It is desirable that seed sources be vouched by a herbarium specimen lodged in a recognised herbarium.

International collaboration in making seed collections of acacias was recognised as essential. Researchers from developing countries should be encouraged to assist local staff in planning and collecting *Acacia* seeds in Australia and adjacent

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countries. Support of such activities should be seen as a legitimate use of funds by international aid agencies.

It was noted that while the identification and collection of genetic resources is an essential first step, subsequent *evaluation* is both critical and complex. Greater attention needs to be paid to the methodology for assessing the potential value of species. Development of climatic matching techniques to assist species selection and the synthesis and distribution of information on species/provenance trials through the TREDAT data base were seen as valuable ACIAR initiatives requiring continuing support.

Biology and Ecology

Genetic improvement depends on a basic knowledge of reproductive biology, breeding systems and vegetative propagation. Little information is available for acacias and the workshop strongly recommended ACIAR support this area of research. *Acacia mangium, A. melanoxylon, A. mearnsii* and other bipinnate acacias, and selected phyllodinous arid-zone species, should receive priority.

One of the major attributes of acacias is their ability to thrive on infertile soils. It is essential that assessments be made of the role the symbiotic rhizobia and ecto- and endo-mycorrhizas play in the growth and development of acacias. The development of a reliable method to measure nitrogen-fixation will be crucial to research aimed at selecting effective rhizobial strains. Basic research on these organisms is necessary so that advantage can be taken to inoculate plants at the nursery stage. The practice of using nursery-grown plants for introductions may provide a once-only opportunity to transfer efficient microorganisms into the field. Complementing research on microorganisms should be laboratory and glasshouse experiments to provide an understanding of the nutrition of key *Acacia* species.

There is a lack of information on the underlying physiological mechanisms by which acacias achieve salt and drought tolerance. Rapid methods of effectively screening species for salinity and drought tolerance are required to reduce the amount of expensive field trials. The selection of salt-tolerant genotypes was seen as one of the highest priorities for ACIAR-sponsored research.

Silviculture

Many areas of silviculture were put forward as worthy of increased research support. These included:

(a) direct seeding
(b) nursery techniques
(c) site preparation and maintenance, including weed control and fertiliser studies
(d) coppicing
(e) spacing trials
(f) species mixtures
(g) management systems especially the combination of trees with food crops and the establishment of acacias in the arid zones
(h) control of significant pests and diseases, especially termites, shoot borers and heart rots.

Utilisation

It was recommended that the evaluation of species and provenance trials should include an assessment of the utilisation potential especially with respect to wood properties such as sawn timber, veneer, pulpwood and fuelwood, and other products such as fodder, green manure and human food values.

High priority was given to assessing the forage value of *Acacia* fruits and foliage for different animals and the factors which determine the nutritive value and palatability of acacias.

Socioeconomics

As research to select and propagate Australian acacias in developing countries proceeds there will be an increasing requirement to study socioeconomic factors so that the species will be accepted and incorporated into appropriate management systems. This research is especially important for species which are selected for use in agroforestry systems in rural communities.

Research Cooperation

International cooperation is clearly necessary if the potential of acacias is to be fully realised. There have been outstanding individual contributions which have led to an understanding of the biology and management of some species, but effective cooperation, coordination and communication will result in more rapid advances in knowledge and techniques.

The synthesis of information and its communication to researchers and managers is a very high priority. It can be achieved through personal contacts, workshops, newsletters and publication in international journals. The valuable role of IUFRO working groups and networking initiatives in Asia and Africa promoting communication and cooperation was noted.

Australian Acacias: Taxonomy and Phytogeography

Les Pedley*

To understand current classification of *Acacia* an appreciation of how it was treated in the past is desirable. Despite the name *Acacia* having a wide use in pre-Linnean literature (see Ross 1980) Linnaeus did not use the name in a generic sense at all. In the first edition of his *Species Plantarum* (1753), which is taken as the starting point for the binomial system of botanical nomenclature, he described *A. nilotica*, the type of the name *Acacia*, under *Mimosa*, under which he also included species of *Albizia, Desmanthus,* and *Inga*. In the next year Miller in the abridged edition of his *Gardeners' Dictionary* took up the name *Acacia*, but later adopted Linnaeus's wide concept of *Mimosa* and the name fell into disuse. The earliest described species of Australian acacias were described as species of *Mimosa*. Willdenow (1806) took up the name *Acacia* again. He referred 102 species to the genus. Of these 16 were phyllodinous. Forty-five of the remaining 86 species were later placed in other genera, mainly *Prosopis* (8 species), *Albizia* (7), *Mimosa* (6) and *Calliandra* (not formally described as a distinct genus until 1840, 6 species). In fact Willdenow treated only 57 species of *Acacia*.

De Candolle (1825), the next to deal with the whole genus, listed 258 species. Of these 64 were phyllodinous, a fourfold increase in 19 years. De Candolle's concept of the genus was less confused than Willdenow's, though a third of the species were later placed in other genera, mainly *Mimosa* (16 species), *Calliandra* (13), *Albizia* (12) and *Piptadenia* (not recognised as distinct until 1840, 12 species). Some of the errors of both Willdenow and de Candolle can be attributed to the poor specimens they had. De Candolle divided the genus into four named sections and a residue of 'Acaciae non satis notis.' Section Phyllodineae consisted of all the known phyllodinous species.

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The tendency to split large genera into smaller ones, usually as a matter of convenience, began when Wight and Arnott (1834), considering *A. farnesiana* unusual in the genus *Acacia*, described *Vachellia* to accommodate it. Martius (1835), in a seed list from the royal gardens in Monaco, treated de Candolle's section Phyllodineae as a genus. Rafinesque (1838), an eccentric working in North America, split off seven genera and probably would have been more drastic if he had had more specimens.

This process of fragmentation would have resulted in taxonomic chaos, but this was prevented by George Bentham. In a series of papers from about 1840 on, he worked on the Mimosoideae including *Acacia*, work which culminated in his revision of the subfamily (Bentham 1875). Initially he advocated recognising the Australian acacias as a distinct genus (Bentham 1840: 136) but later found *Acacia* difficult to subdivide. In his account of the Australian species (Bentham 1864) which he treated in two divisions, Phyllodineae with eight series and Bipinnatae with three, he wrote 'I have noted on each of the three occasions when I have gone through the genus in detail, with a large number of specimens before me, in vain sought for any better mode of distributing species in *Series*, founded chiefly on foliage and inflorescence.' In his final classification of the genus (Bentham 1875), he again stressed his unwillingness to recognise infrageneric taxa at a high rank and reduced the eight series of 'division' Phyllodineae to subseries under series Phyllodineae. He grouped the bipinnate-leaved species into five series two of which were not known to occur in Australia. He recognised 432 species, 295 of them Australian, of which 277 are phyllodinous. Two points are significant: Bentham was the last to revise the entire genus and he afforded the Botrycephalae and Pulchellae equal status with the Phyllodineae. Bentham's classification remained virtually unchallenged for a century. Taubert (1894) did consider *Acacia* but his treatment is a copy of Bentham's with series raised to sectional rank. Niether Mueller nor Maiden who both described and knew a large number of Australian species either commented or altered to any serious extent Bentham's classification.

Workers continued to recognise segregate genera. *Delaportea* was described (Gagnepain 1911) for a single species from Laos and *Manganaroa* (Spegazzini 1924) for a number of species from Argentina. Both genera were characterised by a small gland on the top of the anther. Britton and Rose's (1928) treatment of *Acacia* for the Flora of North America was most radical. The species were distributed among 11 genera, eight of them newly described and two already described by Rafinesque. About 25 more species from South America and the West Indies were added to these segregate genera, mainly *Senegalia* and *Acaciella*, by Rose and his associates. After Rose's death in 1934 Britton and Rose's treatment was ignored and the species they recognised transferred back to *Acacia* where necessary. Chevalier (1934) put an African species, *A. albida*, into a distinct genus *Faidherbia*.

The strongest challenges to Bentham's classification have come from France. Guinet (1969), as part of a study of the pollen of Mimosoideae, examined pollen of almost 250 species of *Acacia* from all of Bentham's (1875) series. His conclusions were, in part, that the Filicinae and Vulgares are closely related and form one group, that the Australian acacias (Phyllodineae, Botrycephalae and Pulchellae) form a second homogeneous group more closely related to the Vulgares and Filicinae than to the Gummiferae, that the Gummiferae is isolated from the other two groups, and that the three groups should be recognised as distinct genera. He found *Faidherbia* to be distinct and better placed in the tribe Ingeae than in the Acacieae. Vassal (1972), after a study mainly of seeds and seedlings of a considerable number of species, and taking into account Guinet's palynological studies, recognised three subgenera with the same circumscription as the groups proposed by Guinet as genera.

At about the same time as Vassal's work was published I had become convinced that *Acacia* subg. *Acacia* (*Acacia* ser. Gummiferae) warranted recognition as a genus distinct from the remainder of the genus (that is, *Acacia* subg. *Aculeiferum* and subg. *Heterophyllum*) and advocated (Pedley 1981) recognition of a genus 'Z.' Bentham (1840) had considered a similar split. After further consideration of morphology, palynology, chemistry of heartwoods and seeds, cyanogenesis and susceptibility to rusts, I have recognised (Pedley 1986) three genera: *Acacia* Miller, *Senegalia* Rafinesque and *Racosperma* Martius. Those correspond to the subgenera recognised by Vassal. The scientific grounds for taking this course are considerable, but I have also thought long and hard about the economic and social effects of the name changes involved. The names of almost all the Australian acacias would have to change, a process that has already begun (Pedley, in press). Proposed classifications are compared in Table 1.

In its narrow circumscriptions, *Acacia* is a pantropical genus of perhaps 200 species best represented in Africa and South America. There are about eight endemic Australian species, one long-established introduction (*A. farnesiana*) and one more recent one (*A. nilotica*). *Senegalia* which has about the same geographic range, has probably about 150 species. There are only two Australian representatives, *S. albizioides* which is confined to rainforests in the central parts of Cape York Peninsula, and another unidentified species from the northern tip of the Peninsula which may be the same as a wide-ranging Southeast Asian species.

Racosperma is a genus of some 850 species all of which have previously been referred to *Acacia* subg. *Phyllodineae* Seringe (*A.* subg. *Heterophyllum* Vassal). The genus is virtually confined to Australia. Eight northern Australian species extend to New Guinea or eastern Melanesia, one of them reaching Vanuatu and New Caledonia. Nine other species do not occur in Australia. One occurs in Madagascar, one in the Mascarene Islands (Mauritius and Reunion), one in Indonesia, one in the Philippines and Taiwan, three in Fiji (one of which extends to Tonga, Samoa, New Caledonia and Vanuatu), and two in the Hawaiian Islands (though St John (1979) accepts three species).

The infrageneric classification of *Racosperma* requires further study. There appear to be fundamental differences between plurinerved and uninerved phyllodinous species, with *Acacia* section Botrycephalae included in the latter group. The position of *Acacia* section Pulchellae and *Acacia* section Lycopodiifoliae is not at all clear. Consequently I (Pedley 1986) treated the genus as having four sections: *Racosperma* section Racosperma, uninerved species, *R.* section Plurinervia (including *Acacia* section Juliflorae), *R.* section Lycopodiifolia and *R.* section Pulchella.

A fruitful approach to the finer classification of *Racosperma* might be an agglomerative rather than a divisive one. Pryor and Johnson's (1971) treatment of *Eucalyptus* is an attractive model. Preliminary work with chiefly eastern Australian species indicates that groups of interrelated species can be recognised, defined and put into a hierarchical system. Names legitimate under the International Code of Botanical Nomenclature can be applied to

Table 1. Classification of *Acacia* sensu alto from *Flora Australiensis* to the present (s = series, ss = subseries, sg = subgenus, sc = section)

Bentham (1864)	Bentham (1875)	Vassal (1972)	Pedley (1978)	**Pedley (1986)**
ACACIA	ACACIA	ACACIA	ACACIA	RACOSPERMA
		sg Heterophyllum	sg Heterophyllum	
s Botrycephalae[1]	s Botrycephalae		sc Botrycephalae	sc Racosperma
	s Phyllodineae			
s Alatae	ss Alatae	sc Uninervea	sc Alatae	
s Continue	ss Continuae		sc Phyllodineae	
s Brunioideae	ss Brunioideae			
s Uninerves	ss Uninerves			
s Plurinerves	ss Plurinerves	sc Heterophyllum	sc Plurinerves	sc Plurinervia
s Pungentes	ss Pungentes			
s Calamiformes	ss Calamiformes			
s Juliflorae	ss Juliflorae			
		?	sc Lycopodiifoliae	sc Lycopodiifolia
s Pulchellae[1]	s Pulchellae	sc Pulchelloidea	sc Pulchellae	sc Pulchella
		sg Aculeiferum	sg Aculeiferum	SENEGALIA
	s Vulgares[2]		sc Spiciflorae	sc Senegalia
	s Filicinae[3]		sc Filicinae	sc Filicinae
s Gummiferae[1]	s Gummiferae	sg Acacia	sg Acacia	ACACIA

[1] Referred to division Bipinnatae, as opposed to division Phyllodineae for the others.
[2] Not known to occur in Australia at the time.
[3] Not occurring naturally in Australia.

some of the groups while others have none. The Microneurae group which I have discussed (Pedley 1986) and the Oligoneurae group (Pedley, in press) are nice, well-defined groups which must be recognised in any system of classification. However, some species seem to stand alone without any near relatives. If *Racosperma* is a long established genus, relict species are to be expected. *Racosperma ancistrocarpum* and *R. oswaldii* (including *Acacia sessiliceps*) appear to be two such species. *Racosperma peuce* is often considered to be a 'primitive' species quite isolated in the genus, but it and *R. crombiei* appear to be close with unusual morphology, chemistry and distribution.

A complete infrageneric classification will have to wait until the account of Australian acacias is written for the Flora of Australia. With an acceptable classification, a cladistic study might be possible. Further splitting of *Racosperma* is possible. Segregation of section Lycopodiifolia would be most likely, but the number of names affected would be small.

There have been several studies on the phytogeography of *Acacia* sensu lato in Australia. Hopper and Maslin (1978) considered the acacias of Western Australia. They discussed distribution of species and centres of species richness with reference to the Botanical Provinces of Beard (1969) some of which correspond roughly with principal floristic regions of Burbidge (1960). Hopper and Maslin found that inland areas of the South-West Botanical Province were by far the richest in species with more than 90 recorded from some 1° × 1½° grids. Minor centres of richness with 20 or more species per grid were found in the Pilbara Region, the Desert Region and the Northern Botanical Province. Maslin and Hopper (1982) analysed the *Acacia* flora of the area covered by the Flora of Central Australia (Jessop 1981), an area rather arbitrarily defined, contained wholly within the arid zone. They concluded that the region is only a minor centre of species richness and endemism and that it has a preponderance of species with tropical affinities. Hnatiuk et al. (1983) again considered the distribution of *Acacia* in Western Australia. They generated *Acacia* phytogeographical areas rather than adopting already defined ones. They distinguished three regions, the South-West Region, the Eremaean Region and the Kimberley Region. These agree remarkably well with the South-West Botanical Province, the Eremaean Botanical Province and the Kimberley Botanical Province respectively of Beard (1969). The distinctiveness of the South-West Region was again emphasised. It has 324 species, 59% of them endemic, and 24 of which occur in other States. The Kimberley Region contains 101 species, only 22 endemic, and 68 with ranges extending into other States. They suggested that the region probably represents the western end of a pan-continental *Acacia* district. The Eremaean Region has 224 species, 15% endemic, and 31% extending to the east. Using the data of Maslin and Pedley (1982), Hnatiuk and Pedley (1985) examined the distribution of 275 species that occur in Australia north of 24°S latitude. Three major regions were recognised: an eastern region (coastal and subcoastal Queensland including Cape York Peninsula), a northern region (two districts: the Kimberleys and Arnhem Land) and the Eremaean region (the remainder). The northern/Eremaean boundary in Western Australia is farther north than the boundary of Kimberley Region of Hnatiuk et al. (1983), but corresponds to the boundary between their South and North Kimberley Districts. The inclusion of Cape York Peninsula in the eastern region rather than the northern region is contrary to the suggestion of Hnatiuk et al. (1983) that there might be a pantropical region. Analyses of the distribution of *Acacia* have therefore unambiguously identified a well-defined South-West Region with a large number of species and a high degree of endemism. The Eremaean Region has also been recognised but not defined. In addition there are a Northern Division and an Eastern Division, but exact definition of these will require analyses of the distributional data for the whole continent.

Until such analyses have been done, the phytogeography of Australian acacias can be discussed only in general terms. I have used the regions distinguished by Burbidge (1960), except that the Tropical Zone has been divided into a Tropical and North-East Zone and the Kimberley District has not been extended along the northwest coast. This adopts the findings of Hnatiuk and Pedley (1985). Burbidge's Interzone Areas have been added to the Eremaean Zone except for a small area in Queensland. Five zones are then recognised: Tropical, North-East, South-East, Eremaean and South-West. Occurrences of major groups of species, using the classification of Pedley (1986), are summarised in Table 2.

The importance of the southwestern zone cannot be exaggerated. Some grid squares have more than 100 species. Few grids in the North-East and South-east zones have more than 50, while only one each in the Tropical and Eremaean Zones exceeds 40. Slightly more than 40% of all species occur in the South-western Zone and two-thirds of them are endemic to the region. Less than 10% of species are shared with the Eastern zones and scarcely any with

Table 2. Distribution of *Racosperma, Senegalia* and *Acacia* in phytogeographic zones derived from Burbidge (1960). The classification of Pedley (1986) is followed. Each x indicates the occurrence of about 12 species in the grid-square with the highest concentration of species in the zone. + indicates occurrence of a lower number of species. Data derived from Maslin and Pedley (1982).

	Racosperma						
	Plurinervia						
	cap.	spic.	Racosperma	Lycopodiifolia	Pulchella	*Senegalia*	*Acacia*
Tropical		xx	+	+			+
North-East	x	xx	xx	+		+	+
South-East	x	x	xxxx				
Eremaean	x	x	x	+			+
South-West	xxx	xx	xxxxx		x		

the Tropical. In contrast Tasmania has only 21 species, two of which are endemic.

When the distribution of groups of species within the genus is examined some patterns emerge. Section Pulchella (27 species) is confined to the South-West Zone while section Lycopodiifolia is rather diffusely spread over northern Australia with a concentration (5 species per grid) in the Kimberleys.

Section Racosperma (about 390 species), which consists of *Acacia* section Phyllodineae and section Botrycephalae, has a predominantly southern distribution. The greatest concentration of species is in the South-West Zone where some grids have more than 50 species. There are some moderately high areas exceeding 40 species per grid in the South-East Zone. The Botrycephalae group which is confined to the southeast of the continent makes a significant contribution, especially in central coastal New South Wales. The section is poorly represented in the tropics with large areas such as the Kimberleys and Cape York Peninsula without any species at all.

Section Plurinervia which has about the same number of species as section Racosperma has a different pattern. Once again the South-West Zone has the greatest concentration of species with some grids with more than 50 species. Areas with moderately high species numbers are scattered across the Tropical, North-East, South-East and adjacent parts of the Eremaean Zone. The pattern can be further analysed by considering juliflorous and capitate species separately. They are in about equal numbers. The capitate species (*Acacia* section Plurinerves) are most concentrated in the South-West Zone with only one area of moderately high species numbers in the South-East Zone. The section is not well represented over much of the northern part of the Eremaean Zone but occupies a considerable part of the east Eremaean. *Racosperma harpophyllum, R. cambagei* and related species that occur on heavy and calcareous soils account for much of this pattern. The distribution of juliflorous species is, except again for the concentration in the South-West Zone, different.

Species-rich areas occur around northern Australia and in the North-East Zone. Present centres of species richness can possibly be explained in terms of land form and substrate, but the different patterns of distribution shown by different taxonomic groups suggest that these patterns are correlated in some way with phyletic trends within the genus. Broad patterns of distribution must already have been established before the isolation of the South-West Zone in the Miocene. Pollen of *Racosperma* first appeared in the Miocene in southern Australia but, despite the lack of direct evidence, I believe it to have been well established in some northern parts of the continent before that period (see, however, Martin (1984) for comment). Hopper and Maslin (1978) discussed possible reasons for areas of species richness in Western Australia and their arguments could apply to the genus throughout its range. Considering the large number of species in the South-West, the high degree of endemism there, and the lack of relationship with species in northern and eastern Australia, however, some conditions favouring speciation probably applied only there.

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Potential of Australian Acacias from Arid and Semi-Arid zones

J. E. D. Fox*

ACACIA species from higher rainfall zones in Australia have already been successfully introduced to other countries. Both the Mediterranean climate of the southwest and tropical humid zones of the northeast have provided a number of useful, fast-growing species. This paper outlines the potential for introduction to other environments of the *Acacia* species from drier parts of Australia. Insofar as seed can be obtained all species could be tried. The paper attempts to shorten the list of selections by drawing attention to features of the various species which may influence those who wish to try them out.

Aspects included are the distribution of the species within Australia, the potential performance in terms of attainable height and growth rates and the form of the species. Climatic matching is discussed and the gregariousness of species is considered. The value of the species for fodder, firewood and as ornamental plants is outlined.

A number of authors have dealt with the climatic zones of Australia. On Fig. 1 the outer dashed line demarcates the 'arid zone' boundary of Northcote and Wright (1982). This definition is of an area bounded by the 250 mm isohyet in the south, the 375 mm in the east and north, and the Indian Ocean in the west.

An interesting aspect of the vegetation of central Australia is the occurrence of trees and shrubs. Vegetation types dominated by woody plants do not occur everywhere, but they do occupy large areas of the type of country that we refer to as desert. The other main type of vegetation is hummock grassland where *Triodia* species are dominant. For more information on vegetation types reference may be made to Beard (1980) for Western Australia, and Neldner (1984) for Queensland. It must be stressed that many woody species of arid country occupy drainage lines and other parts of the landscape where run-on adds to effective soil moisture. Species which occur on elevated topographical positions tend to be extremely drought-tolerant, slow-growing and of low stature.

An important point to note is that the arid zone total of species is not great. Of the 729 described species of *Acacia* at 1982 (Maslin and Pedley 1982) for Australia as a whole, only 108 occur in 'Central Australia' (Maslin 1981). The inner line of Fig. 1 shows one definition of 'Central Australia,' produced with the Flora of Central Australia. By any definition, this inner part of Australia is the arid core. Of the 108 species a number extend into more favourable regions in respect of rainfall. Fifteen of those listed are endemic to Central Australia and a further 14 extend slightly into adjoining regions (Maslin and Hopper 1982). Species from coastal, humid or Mediterranean zones will not be considered.

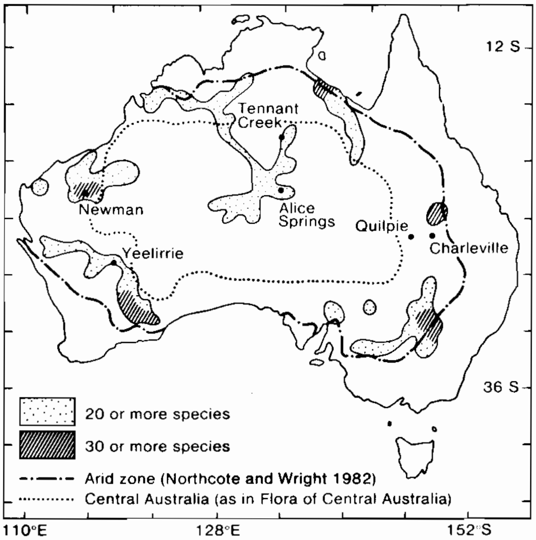

Fig. 1. Central Australia and the Arid Zone in relation to *Acacia* species.

In some cases identities are problematical (e.g. the widespread species *A. ligulata*). The name was formerly applied to a subspecies of *A. bivenosa* in Queensland. Recently Pedley (1979) suggested this species (*A. ligulata*) may be the same as *A. rostellifera*. This is most unlikely. Various authors treat the *Acacia brachystachya* group of *A. brachystachya, A. ramulosa, A. linophylla* as one, two or three taxa. In this account I follow Maslin (1980, 1981) and use the group. There would seem to be little potential amongst this group, other than for sand

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stabilisation. A fourth species (shrub 5–8 m tall) *Acacia subtessarogona* in northwestern Western Australia is allied to the group also (Tindale and Maslin 1976).

Widespread Versus Local Distribution

Some of the classic examples of tree species which have been successful as exotics occur in fairly limited areas within their natural distribution. It is problematical as to whether a species which is successful in Australia on a wide scale should also be successful elsewhere. Lately considerable emphasis is being placed on provenances to fit local environments. It is a strong possibility that species with a wide distribution that are successful exotics may have originated from a single provenance from their natural range. Equally it is likely that a successful introduction will rest on selecting from an appropriate ecotype. Climatic matching may be important in this respect.

Maslin and Pedley (1982) have provided distribution maps for 729 species using a grid of 1° latitude by 1.5° longitude. This corresponds with the National Mapping series of 1:250 000. The area of each map sheet is 14 000 km^2. Presence on a sheet does not, of course, imply that the species is found everywhere within that area. However presence on sheets is at least an indicative measure of distribution. The three species with greatest distribution on this basis are *Acacia ligulata, A. victoriae* and *A. aneura*. These species are important components of ecosystems on a broad scale and must be presumed to possess a great deal of adaptability.

Acacia ligulata (195 sheets) is an important component of low coastal dune scrub-heath on the west coast north of Geraldton in Western Australia and also in South Australia. Elsewhere it is nowhere dominant and mainly occurs on sandy soils with *Triodia* species. The inland arid populations are not well documented but the generally low attained height and shrubby nature of the species suggest that it may be of little value. In the Western Australia Goldfields the species grows rapidly after fire, reaching 2.5 m in 7 years. It is killed by fire and presumably has a short life span. Whibley (1980) reports that *A. ligulata* is a fast-growing species, and is probably susceptible to termite attack.

Species with a large distribution across the continent tend to have a number of forms. This variation complicates successful introduction in that performance of one may be quite different from others. In some cases the differences are sufficient for subspecific rank (e.g. *A. victoriae*; Pedley 1979). *Acacia victoriae* is the second most widely distributed species. It occurs on 173 map sheets between latitudes 15° and 36°S and longitudes 114° to 152°E. The main value of this species is in its availability for forage (Fox and Davies 1983).

Acacia aneura often occurs in dense stands, has a wide distribution across Australia (165 map sheets) and is probably the most numerous woody species on the continent as a whole. It is also exceptionally variable in form, height and morphology, notably phyllode shape and size. With such a wide range of ecotypes it may be expected that growth rates will differ considerably. At Perth (31°57′S) plants from Charleville (26°25′S) in Queensland grow more rapidly than plants from Meekatharra (26°36′S) or Newman (23°21′S). An account of the variability within this species is currently in press. This species is termite resistant.

Acacia tetragonophylla (128 map sheets) is widely distributed often occurring as a shrubby associate of *A. aneura*, but much less common, or with *A. victoriae* on moist sites where stock have removed more palatable forage. *Acacia oswaldii* also has a wide range (121 map sheets) but is nowhere common. This species has a moderate growth rate (Whibley 1980). *Acacia hemignosta* is another example of a widespread but uncommon species. It forms a well-shaped tree (Petheram and Kok 1983). The more recently described species tend to have more restricted (known) ranges in terms of map sheets. For example Maslin (1980) has described *A. abbreviata* (2 sheets), *A. auricoma* (3), *A. dolichophylla* (1), *A. jamesiana* (9), *A. latzii* (2), *A. nelsonii* (3) from Central Australia. Similarly Maslin (1982) described a number of species from the Hamersley Ranges of Western Australia, six of which are endemic to the area.

A better-known species is *Acacia peuce* which has a restricted range but is locally common. It has a restricted distribution in only three localities. This distribution pattern may reflect relict status (Chuk 1982). It has very hard and heavy wood, grows slowly, and will coppice and produce root suckers (Hall et al. 1975).

Potential Performance

The vast majority of species from arid zones are likely to be able to survive and grow in regions with more moisture. Some species may have horticultural or pharmaceutical potential. In terms of productivity potential the most important criteria are probably attained size and growth rate. Little information is available on growth rates and in any case the comparatively slow growth in arid conditions may not apply in more favourable environments. Attained size in the natural habitat is a known criterion.

Figure 2 shows the distribution of attained heights amongst the species of Central Australia. Of the species in this suite only 19 of the 108 species are generally recorded to attain 10 m or more in height. Of the 19, 12 are of tree habit. These are *Acacia cambagei, A. catenulata, A. coriacea,*

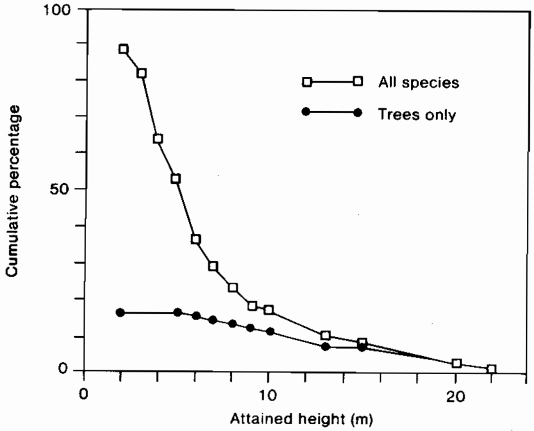

Fig. 2 Distribution of attained height for Central Australian species. Lines give cumulative percentages of species exceeding the height shown.

A. estrophiolata, A. excelsa, A. harpophylla, A. microsperma, A. petraea, A. peuce, A. pruinocarpa, A. shirleyi and *A. tephrina*. The designation 'tree' is somewhat arbitrary. For example many ecotypes of *A. aneura* adopt a tree habit whereas a number appear to remain as shrubs. *Acacia coriacea* is a rather shrubby tree. A further six species attaining less than 10 m height but of tree form are *A. ensifolia, A. georginae, A. inaequilatera, A. torulosa, A. ammophila* and *A. pickardii*.

Figure 3 illustrates the distribution by map sheets, and general geographical area, of the 25 species which are generally recorded as attaining 8 m or more in height. Of the taller species *Acacia harpophylla* and *A. cambagei* predominantly in the east, have the greatest distribution. Figure 3 suggests that the tallest species occur predominantly in the east. *Acacia peuce* exceeds 13 m in the Northern

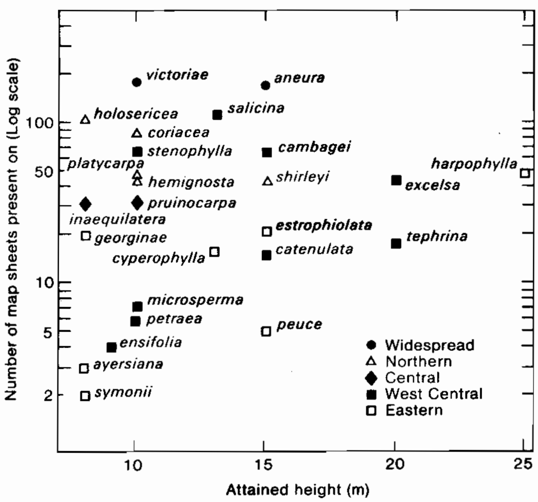

Fig. 3 Distribution and attained height for Central Australian species.

Territory and reaches 17 m in Queensland (Chuk 1982).

Although large specimens of *A. murrayana* appear to be uncommon it will exceed 5 m. A specimen of *A. murrayana* observed near Menzies (29°42′S, 121°02′E) attained 3.5 m height in 4 years and 6 m by 8 years. At 8 years the specimen was still healthy. However its life span is unlikely to exceed 15 years (Fox 1985a). *Acacia murrayana* to 8 m is reported to be grown successfully in Brisbane (Simmons 1981). *Acacia rigens* may reach 6 m (Whibley 1980).

The group *A. murrayana, A. pachyacra* and *A. victoriae* are closely related (Pedley 1979). The first two are pioneers. They are short-lived, rapid growers and tend to invade degraded or burnt areas with adequate moisture available. In considering potential for introduction it is important to examine the ecological status of the target species. Short-lived pioneers often show rapid early growth which may be useful for some purposes. Late successional or climax species are those likely to characterise ecosystems and to be present in some density. This is considered later. At this stage some emphasis is given as to which other species may be classed as pioneers, and then some information is given on growth rates. Arid zone species grow in response to rainfall events rather than to regular seasons (Chuk 1982) so that considerable long-term measurement runs are required for reasonable comparisons between species.

Acacia holosericea tends to form dense clumps in disturbed places or near water courses (Petheram and Kok 1983). This habitat preference is shown by a number of northern pioneer species. *Acacia holosericea* is reportedly fast-growing with a maturation time of 2 years (National Academy of Sciences 1980). It grows rapidly in Queensland, where it is used for screening (Simmons 1981).

Acacia ancistrocarpa occurs in dense thickets (Petheram and Kok 1983). This species occupies burnt patches in *Triodia* grasslands and along drainage lines. *Acacia cowleana* is an invasive species with a similar pattern (Fox 1985a). Other northern species include *A. eriopoda* and *A. platycarpa* which are prevalent along roadsides in the Kimberley region. Both are relatively short-lived and even large trees of both species are killed by hot fires and termites (Petheram and Kok 1983). *Acacia lysiphloia* is a good coloniser of eroded areas where it forms dense thickets (Petheram and Kok 1983). *Acacia tenuissima* grows rapidly in the first few seasons, reaching 1 m within 2 years of fire in the Pilbara (Fox 1985a). In the Western Australia Goldfields *A. murrayana, A. ligulata* and *A. jennerae* are pioneers showing rapid growth in areas opened up by fire (Fox 1985a).

A number of species are described as having moderate or moderate-to-fast growth rates by Whibley (1980). These include *A. victoriae, A. burkittii, A. kempeana, A. prainii, A. olgana, A. cambagei* and *A. cyperophylla*. The same author suggests that *A. aneura* and *A. brachystachya* (but not *A. ramulosa*) are slow-growing species. No good published accounts of actual growth rates under natural conditions are available for the majority of species. Time to maturity (seed production) is short in the pioneer, short-lived species. In most studies of *A. aneura* growth has been slow. However this species dominates so much of the vegetation where it occurs that in the long-term its growth may exceed its competitors.

Height growth has been measured over an 11-year period for four species first observed as seedlings in 1975. At that time all seedlings on a 10 × 10 m plot of disturbed ground were tagged. Assumed time from disturbance was 2.5 years. At that time (1975) those *A. aneura* (14) which survived the next 11 years had a mean height of 0.73 m whereas *A. pruinocarpa* (9) averaged 0.85 m. Estimated mean annual increments are presented in Table 1. Initially *A. pruinocarpa* grew faster than *A. aneura* but in the longer term the latter maintained its growth.

In addition one specimen only of *A. victoriae* grew from 30 cm to 2.34 m over the period, MAI height 0.19 m and one *A. tetragonophylla* grew from 53 cm to 1.6 m, MAI height 0.10 m. Thus the ranking of mean height increment for these four *Acacia* species is *A. aneura* > *A. pruinocarpa* > *A. victoriae* > *A. tetragonophylla*. Nevertheless, best early growth was shown by *A. victoriae*, confirming Whibley's (1980) generalisation in respect of small plants. It is likely that elsewhere *A. tetragonophylla* may also show moderate to fast growth as a seedling (Simmons 1981). The mean annual height increment of 20 cm for *A. aneura* in this northern locality is greater than for plants growing in the Western Australia Goldfields. Here available data suggest that growth of seedlings is much less, averaging below 10 cm per annum. Very little change to height of established *A. aneura* stands has been observed.

A number of *Acacia* species from arid areas are characterised by red scrolling bark ('minneritchee'). This would appear to be indicative of very slow growth and relatively hard wood. Growth may be more rapid in northern representatives of this group. Species in this group are *Acacia chisholmii, A. cyperophylla, A. grasbyi, A. lysiphloia, A. monticola, A. rhodophloia* and *A. trachycarpa*. *Acacia rhodophloia* may attain 1 m in height in 2 years after germination following fire, but subsequent growth is very slow (Fox 1985a). The hard-wooded *Acacia peuce* is capable of 30 cm height growth per annum in the Northern Territory. It can attain only 2 m in 7 years with regular watering (Chuk 1982).

Performance in Central Australia is unlikely to be indicative of performance in other countries. *Acacia farnesiana* is present on 93 map sheets, reaching 3 m height. This species is also present in the American tropics where it is a tall tree. If, as some believe, it came to Australia from America, then its performance is either constrained by environment or a narrow genetic base. As a species, however, it must be rated successful in colonising such a wide area of Australia. In northwestern Australia it is confined to alluvial river banks.

Form

Species which invariably have a shrub-like habit will not be preferred when clean boles are required. The tree habit is sometimes a function of age. Plants may develop one main leader after some time as a multi-stemmed bush-like plant. In other cases the same species may grow as a shrub under some

Table 1. Annual increments in height (m) for Sandhill seedlings.

	Estimated height increments 1975–86									
	Presumed Age From Germination									
Species	2		5		8		10		13	(CAI 2–13)
Acacia aneura										
MAI (m)	0.34		0.23		0.22		0.19		0.20	
CAI (m)		0.16		0.21		0.06		0.22		(0.17)
Acacia pruinocarpa										
MAI (m)	0.39		0.25		0.21		0.18		0.16	
CAI (m)		0.15		0.15		0.07		0.09		(0.12)

environments and as a tree elsewhere. Some species vary in form over their range. *Acacia platycarpa* is a shrub in the south of its range but a tree to 10 m in northern Australia (Pedley 1978). Although the following species attain 7 m or more in height, they may have either shrub or tree form, at least at younger stages: *A. aneura, A. cyperophylla, A. hemignosta, A. platycarpa, A. salicina, A. stenophylla, A. victoriae, A. ayersiana, A. holosericea, A. symonii, A. ampliceps, A. jensenii, A. olgana, A. papyrocarpa* and *A. tumida*.

Species of *Acacia* which occur in *Triodia* hummock grasslands tend to be of lower stature than in other vegetation types. Many of them are able to resprout from epicormic buds after fire. Consequently they may have coppicing potential which is an important attribute for species grown for firewood. A useful account of fire response may be found in Hodgkinson and Griffin (1982).

Initial height growth of fire-induced sprouts may be much more rapid than new seedling growth from the same species. For example, *A. aneura* sprouts in the Pilbara grew to 1.26 m in 5 years, three times faster than seedling growth at the same site (Fox 1985a). This species is generally killed by fire however, and the ultimate form of resprouts is not clear. *Acacia inaequilatera* is rarely killed by fire and will resume its small tree form by both sprouts and crown regeneration.

For tree species adapted to an arid environment the shift to less arid localities may result in a change in form. Most species respond to rainfall by flowering and fruiting heavily and it is possible that some species may put excessive resources to reproductive growth. While this may be disadvantageous for wood production it may be beneficial for ornamental use or for fodder where pods are edible.

There can be little potential for the low-stature species, other than as ornamental plants. Of the total of 108 species in Central Australia 15 reach a maximum size of 2 m or less.

Climatic Matches

As examples of the environments represented by the pool of available species, rainfall data are presented for seven localities (Table 2). These are the Marillana (22°32′S, 119°24′E, altitude 450 m)/Wittenoom area (22°14′S, 118°20′E, 460 m); Tennant Creek (19°38′S, 134°11′E, 375 m); Alice Springs (23°36′S, 133°36′E, 547 m); Yeelirrie (27°17′S, 120°06′E, 487 m); and the Quilpie (26°38′S, 144°16′E, 198 m)/Charleville area (26°25′S, 146°17′E, 304 m).

A useful account of the climate of the Alice Springs area is available in Slatyer (1962) where the notion of effective rainfall is given attention.

Summer rainfall dominance declines from north to south, and across Central Australia from west to east. Charleville to the east where *Acacia aneura* reaches perhaps its best development has a more evenly spread rainfall than Quilpie. Alice Springs is the most drought-affected. The other locations have summer rainfall exceeding 60 mm in at least 2 months.

Species lists for five localities are given in Table 3. A total of 66 of the Central Australian species are included from a total of 10 map sheets (two for each locality). The Alice Springs/Hermannsberg map sheets have a total of 32 species, all Central Australian by definition. To the north the Tennant Creek/Bonney Well sheets have 24 species and there are 10 common to these two areas. The four sheets thus have 46 of the Central Australian species set.

The Newman/Roy Hill sheets have 37 species of which 28 are Central Australian. This area, part of the Hamersley Range region, is an important focus of *Acacia* species numbers. In considering these two sheets and another five comprising the Hamersley Range, Maslin (1982) adds a further 10 species of which five are Central Australian. The large number of species in this area may be related to the wide variety of available habitat types from mountains,

Table 2. Seasonal year (after Davies 1976) rainfalls for representative stations corresponding to species lists in Table 3.

Station	Summer (Nov–Mar)	Autumn (April)	Winter (May–Aug)	Spring (Sept–Oct)	Year Total
Tennant Creek	297	15	27	20	359
Wittenoom	273	21	96	5	395
Marillana	195	21	63	6	285
Alice Springs	169	17	50	28	264
Charleville	203	35	110	56	501
Quilpie	210	18	77	39	344
Yeelirrie	106	19	74	12	211

Table 3. Comparison of *Acacia* flora for five areas.

	Area of two map sheets centred on				
	Tennant Creek	Alice Springs	Newman	Yeelirrie	Quilpie
Species present	Sheets 352 + 358	Sheets 375 + 376	Sheets 158 + 169	Sheets 216 + 217	Sheets 674 + 675
Central Australia					
acradenia	+	–	–	–	–
adoxa	–	–	+	–	–
adsurgens	+	+	+	–	–
ammobia	–	+	–	–	–
ampliceps	–	–	+	–	–
ancistrocarpa	+	–	+	–	–
aneura	+	+	+	+	+
basedowii	–	+	–	–	–
brachystachya group	+	+	–	+	+
calcicola	–	+	–	–	+
cambagei	–	–	–	–	+
catenulata	–	–	–	–	+
chippendalei	+	+	–	–	–
colletioides	–	–	–	+	–
coriacea	+	+	+	–	+
cowleana	+	+	+	–	–
cuthbertsonii	+	–	–	–	–
dictyophleba	+	+	+	–	–
dolichophylla	–	+	–	–	–
ensifolia	–	–	–	–	+
estropholiata	–	+	–	–	–
excelsa	–	–	–	–	+
farnesiana	–	+	+	–	+
georginae	–	+	–	–	–
gonoclada	+	–	–	–	–
helmsiana	–	–	–	+	–
hemignosta	+	–	–	–	–
hilliana	+	–	+	–	–
holosericea	+	–	+	–	+
inaequilatera	–	+	+	–	–
jamesiana	–	–	–	+	–
jutsonii	–	–	–	+	–
kempeana	–	+	+	–	–
ligulata	+	+	+	+	–
lysiphloia	+	–	–	–	–
macdonnelliensis	–	+	–	–	–
maitlandii	–	+	+	–	+
microsperma	–	–	–	–	+
monticola	+	+	+	–	–
murrayana	–	+	–	+	+
nelsonii	–	+	–	–	–
orthocarpa	+	–	–	–	–
oswaldii	–	–	–	–	+
pachyacra	–	+	+	+	–
perryi	+	–	–	–	–
petraea	–	–	–	–	+
prainii	–	–	–	+	–
pruinocarpa	–	+	+	+	–
pyrifolia	–	–	+	–	–
quadrimarginea	–	–	–	+	–
retivenia	+	–	–	–	–
rhodophloia	–	–	+	+	–

	Area of two map sheets centred on				
	Tennant Creek	Alice Springs	Newman	Yeelirrie	Quilpie
Species present	Sheets 352 + 358	Sheets 375 + 376	Sheets 158 + 169	Sheets 216 + 217	Sheets 674 + 675
Central Australia (Continued)					
salicina	–	+	–	–	+
sessiliceps	–	+	–	–	–
spondylophylla	+	+	+	–	–
stenophylla	–	–	–	–	+
stipuligera	+	–	–	–	–
stowardii	–	+	+	+	+
strongylophylla	–	+	–	–	–
tenuissima	+	–	+	–	–
tetragonophylla	–	+	+	+	+
torulosa	+	–	–	–	–
tumida	–	–	+	–	–
validinervia	–	–	+	–	–
victoriae	–	+	+	+	+
wanyu	–	–	+	–	–
Not Central Australia					
arrecta	–	–	+	–	–
bivenosa	–	–	+	–	–
citrinoviridis	–	–	+	–	–
hamersleyensis	–	–	+	–	–
sclerosperma	–	–	+	+	–
trachycarpa	–	–	+	–	–
arida	–	–	+	–	–
atkinsiana	–	–	+	–	–
marramamba	–	–	+	–	–
acuminata	–	–	–	+	–
coolgardiensis	–	–	–	+	–
craspedocarpa	–	–	–	+	–
exocarpoides	–	–	–	+	–
longispinea	–	–	–	+	–
uncinella	–	–	–	+	–
deanei	–	–	–	–	+
decora	–	–	–	–	+
ixodes	–	–	–	–	+
leptostachya	–	–	–	–	+
longispicata	–	–	–	–	+
omalophylla	–	–	–	–	+
sparsiflora	–	–	–	–	+

gorges, rivers, to alkaline stony plains. The Alice Springs/Newman sets have 17 species in common.

A total of 23 species of *Acacia* are found in the Yeelirrie area. Of these 16 are Central Australian species with 10 in common with the Alice Springs area. On the Charleville/Quilpie sheets 28 species are represented of which 21 are Central Australian and 12 are common to Alice Springs/ Hermannsberg.

Peripheral Species

Distribution patterns of related species are discussed by Maslin and Hopper (1982). These authors note that several predominantly Central Australian species have relatives occurring on the periphery of the central zone. Examples include *A. pruinocarpa* predominantly central and west in distribution with relatives *A. ensifolia* in subtropical central Queensland and *A. beckleri* in western New South Wales and northeastern South Australia; *A. estrophiolata* in the centre and its relative *A. excelsa* in subtropical central Queensland; and *A. aneura* with relatives *A. catenulata* in subtropical central Queensland and *A. craspedocarpa* in arid/semi arid Western Australia.

Similarities between species is a general feature of the large number of taxa present and it is not always straightforward to name species in the field in the absence of flowers or fruit. For the collector this may be of no importance but it renders ecological typing rather tedious. An example of similarity is that between *A. gonoclada* and *A. cowleana*. These species overlap in northern Australia. In some cases related species may offer the potential for consideration of introduction to a new environment.

Peripheral species of potential value are *Acacia acuminata, A. citrinoviridis, A. distans* and *A. xiphophylla*. Though not of the 108 Central Australian species set, they share some territory with many of the species included.

Acacia acuminata grows as a shrub or small tree to 5 m or more. It is a hardy species, considered to be drought, frost, salt and lime tolerant. It is fast-growing in warmer areas and is useful for shelter and erosion control. The timber is hard, heavy, durable and termite-resistant. It is used as fence wood and for charcoal and turnery (Simmons 1981). This species occurs in the southwest and occupies 36 map sheets including Sandstone/Sir Samuel.

The other three species occur in the northwest of Western Australia, in the Newman/Roy Hill region. *Acacia citrinoviridis* occurs on 18 map sheets. It is allied to *A. acuminata* with which it overlaps on only three sheets. *Acacia citrinoviridis* is a tree to 8 m or more in height reaching best development near creeks and rivers. It also occurs on stony soil away from watercourses (Tindale and Maslin 1976). *Acacia citrinoviridis* may resprout after fire when new growth is prolific. Seedling regeneration is also stimulated by fire (Fox 1985a).

Acacia distans has been recently described (Maslin 1983) as a tree 5–8 m tall with a dense bushy crown, forming dense almost monotypic stands along the banks of the Gascoyne River at Landor (25°08′S, 116°54′E). It has subsequently been observed in the Fortescue Valley further north at 22°06′S, 118°26′E. In this area it occurs on heavy soils with scattered specimens of *Eucalyptus microtheca*, a habitat not unlike that described for *A. peuce* (Chuk 1982).

The fourth peripheral species of interest is *Acacia xiphophylla*. This is a gnarled, twisted tree occupying 18 map sheets in the northwest of Western Australia. It occurs on a variety of sites from stony hillsides to saline run-on areas. It may have potential as a firewood species in harsh environments.

Occurrence in Pure Stands

Species which occur naturally in pure stands must be able to locally dominate any competitors. For the particular local environment and the available species pool such examples must be presumed to be highly competitive over time. Examples of species forming pure stands include *Acacia cambagei, A. shirleyi, A. aneura* and *A. catenulata*, as well as the four peripheral species just described, and *Acacia peuce* mentioned earlier.

Pedley (1978) records a catenary sequence of *A. petraea, A. ensifolia, A. catenulata* and *A. microsperma* down scarps of the Grey Range in Queensland. *Acacia catenulata* occurs on shallow soil over sandstone in the middle of the sequence. Elsewhere, to the east and north, it forms the uppermost slot in the sequence.

A number of species tend to occur in moister microhabitats with increased aridity. *Acacia salicina* is confined to creek banks in Queensland dry country. Nearer the coast it occurs away from streams. Similarly in the northwest of Western Australia *A. coriacea* is only found along river courses and *A. stenophylla* forms monospecific stands along watercourses.

Where *A. cambagei* and *A. harpophylla* occur together *A. harpophylla* occupies moister sites (Pedley 1978). *Acacia cambagei* occurs generally to the west of *A. harpophylla* in Queensland.

Soil moisture availability is not directly dependent on rainfall. In arid areas best vegetative growth of perennials is on areas receiving run-on. Low-lying alluvial basins and valley systems will often support more woody growth than uplands and hill slopes.

Potential Forage Species

Stock generally prefer grass and soft herbage to the relatively harsh phyllodes of arid zone *Acacia* species. However in Australian rangelands this material often forms the only abundant plant material in drought times. As such there is some interest in the potential of Australian species for use in other countries.

The ability of plants to persist in the face of grazing pressure is not well documented. Petheram and Kok (1983) report that *A. ancistrocarpa, A. orthocarpa* and *A. translucens* are not eaten by stock. *Acacia lysiphloia* is considered unpalatable to stock by virtue of its sticky foliage (National Academy of Sciences 1980).

In terms of palatability Askew and Mitchell (1978) rank *A. estrophiolata* as 'very good,' *A. aneura, A. georginae* and *A. kempeana* as 'good,' and *A. cambagei, A. farnesiana, A. peuce, A. ramulosa, A. tetragonophylla* and *A. victoriae* as moderate. In Central Australia, Foran (1984) suggests cattle browsing, mainly *A. aneura* and

A. kempeana, contributes up to 40% of the diet at particular times, although the level is normally less than 20% when grass is abundant. Everist (1969) gives digestibility values for a number of species and suggests that *A. aneura* and *A. cana* are more useful for sheep than are *A. brachystachya, A. cambagei, A. catenulata, A. excelsa, A. farnesiana, A. harpophylla* and *A. tetragonophylla*. Moore (in Leigh and Noble 1972) suggests that *A. aneura, A. excelsa* and *A. estrophiolata* are amongst the best forage species for sheep. *Acacia coriacea* is said by Whibley (1980) to be eaten by stock. The value of *A. cambagei* is suspect as it gives off an offensive odour (Whibley 1980).

The review of Moore (in Leigh and Noble 1972) suggests that sheep prefer the narrow phyllode form to the broad in *Acacia aneura*. He also notes that acacias are often only eaten when dry.

Field observations at Sherwood Station, Meekatharra, showed that cattle preferentially browsed the terete and broad leaf forms of *Acacia aneura* and did not use the narrow leaf forms. The results of analyses of different leaf types (Table 4) suggests that younger plants may be less palatable than older, larger ones of the same leaf type. Flavonoids are more frequent from younger samples. The young specimen of broadleaf mulga had more saponin and more ether-extractable materials than the other presumed edible types (Pedrotti and Fox 1979).

Mulga foliage has low digestibility (37%) but high protein (13%) and may provide a maintenance diet, supplemented with phosphorus. Mulga has low energy value and 1.4 kg dry matter/day is just sufficient for maintenance of a merino at 32 kg liveweight. Sheep movement should be restricted when fed such material (Moore, in Leigh and Noble 1972).

In a review of the acacias, New (1984) suggests that the value of *Acacia* pods and foliage as fodder for stock may be counterproductive when taken in excess. New refers to the following possibilities: *Acacia aneura*—a tentative link with 'black liver' disease in sheep; *Acacia georginae*—poisoning due to fluoroacetate; and *Acacia salicina*—poisoning associated with high foliar tannin. It has been estimated that 1 in 20 species may produce hydrocyanic acid (Conn and Maslin 1983).

It has been suggested that *A. victoriae* may be useful for planting in dry inland areas as a low shelterbelt or for soil stabilisation (Whibley 1980). However it cannot withstand heavy grazing or drought in northern Australia (Petheram and Kok 1983). As with *Acacia nilotica* in Sudan (Jackson 1977) both *A. tetragonophylla* and *A. victoriae* may form a source of refuge for grain-eating birds. *Acacia colletioides* may form dense impenetrable thickets. As it is spiny-foliaged this species could be a useful hedge for dividing grazing areas.

Potential Firewood Species

People often prefer to use hard, heavy wood from slow-growing trees for firewood. When firewood crops are cultivated this preference is foregone as growth rate takes precedence.

Large trees (55 cm diameter) of *Acacia peuce* may exceed 500 years of age (Chuk 1982). Almost any destructive use seems unwarranted for plants of such antiquity. Both *A. aneura* and *A. acuminata*

Table 4. Mulga leaf analyses from Yeelirrie.

Sample	Phyllode type	Assumed edibility	Saponin	Terpenes	Wax (% w/w)	Ether extract (% w/w)
C1	long terete	edible	+ +		4.6	7.6
H1	long terete	edible	+ +		5.4	8.6
B1	broad (tree)	edible	+	1,2	3.8	8.4
G1	broad (shrub)	edible	+ + +	1,2	3.2	9.8
E1	long narrow	inter	+		2.0	6.2
F1	short narrow	inter	+ + +	1,2	3.0	14.2
X1	long narrow	inter	+ + +	1,2	7.4	27.0
D1	long ½ broad	inedible	+		2.2	6.6
A1	long broader (shrub)	inedible	+		1.6	8.0
A2	long broader (tree)	inedible	+ + + +		1.4	4.4

are valued as fence posts in Western Australia. As the latter grows more rapidly than the former, it should perhaps be ranked higher for firewood production.

Acacia ampliceps occurs along creeks and rivers in the northwest often forming dense communities. It is a large bushy shrub or small tree, very similar in superficial appearance to *A. saligna* (Maslin 1974). As the latter species appears to have some value as a firewood species in other countries (but not in Australia) perhaps *A. ampliceps* could also be considered.

A useful property for firewood crops is the ability to resprout. Sucker growth has been reported in a number of species. These include *Acacia carnei, A. harpophylla, A. murrayana, A. pickardii, A. peuce, A. ramulosa* and *A. salicina*. It is not by any means certain however that all populations of the more widespread species (e.g. *A. murrayana*) will sucker. *Acacia peuce* will produce coppice growth but this is not a common feature in Australian arid-zone species.

The National Academy of Science (1980) has featured *A. brachystachya* and *A. cambagei* as Australian arid zone species suitable for overseas use in firewood production. It is not certain that *A. brachystachya* would be any better than others discussed above and nomenclatural considerations suggest some caution is warranted.

Potential Ornamental Species

Species of relatively short to prostrate habit merit attention for gardens. These include *A. adoxa, A. hilliana, A. minutifolia, A. spondylophylla* and *A. translucens*. Whibley (1980) recommends *A. maitlandii, A. olgana* and *A. strongylophylla* for rockeries.

Trees with weeping foliage have value as standards. *Acacia salicina* is widely grown in Townsville and *A. coriacea* has considerable potential. Both the peripherals *A. citrinoviridis* and *A. distans* would provide decorative ornamentals also. *Acacia pyrifolia* is reported to be slow-growing in Melbourne (Simmons 1981). It is an untidy species in Perth where it dies back from the top each year. Similarly both *A. victoriae* and *A. tetragonophylla* grow in an untidy manner in cultivation.

Simmons (1981) reports that *A. platycarpa* is cultivated as an ornamental in Townsville and Rockhampton. Of the Mineritchee group *A. grasbyi* has been grown successfully in Bute, South Australia, and Simmons also reports *A. acantholada* as a cultivated species in Melbourne and *A. acradenia* in Townsville.

Special Features

Salinity tolerance is of some interest. *Acacia stenophylla* can withstand flooding with what must be saline water at times. Several other species may be classed with this (e.g. *A. distans*). Saline sites feature *A. latzii* and *A. anaticeps*, and in the northwest *A. victoriae* and *A. xiphophylla*.

Acacia tetragonophylla is considered at least moderately salt-tolerant. *Acacia ligulata, A. sclerosperma* and *A. wiseana* should also tolerate moderate salinity as all occur in environments exposed to salt. *Acacia salicina* may also tolerate saline conditions (Simmons 1981).

A number of species occur on calcareous soils (e.g. in South Australia *A. carnei, A. confluens, A. nyssophylla* and *A. rigens*; (Whibley 1980). Ecotypes of the more widespread species occur on both calcareous and doleritic soils. A wide range of species is available from acid soils.

Conclusions

Those involved in species introduction are advised to be wary of problematical species and to make sure that the precise source of seed is known. Widespread occurrence is usually associated with considerable variation, and this must be taken into account. Where possible climatic referencing, particularly to the temperature regimes, may assist in choosing ecotypes. There may be little advantage in obtaining seed from inland arid provenances when the same species has ecotypes available from well-watered sites.

For general purpose material, where a range of products may be envisaged the following species may be useful: *Acacia cambagei, A. catenulata, A. citrinoviridis, A. coriacea, A. distans, A. estrophiolata, A. excelsa, A. harpophylla, A. microsperma, A. petraea, A. peuce, A. pruinocarpa, A. shirleyi, A. tephrina* and selected ecotypes of *Acacia aneura*. If *A. aneura* is used, then broad phyllode forms are to be preferred for well-watered environments.

For firewood production on short rotations the following could be tried: *Acacia murrayana, A. holosericea, A. tumida, A. cowleana* and in harsher environments *A. inaequilatera, A. xiphophylla, A. aneura* and *A. pruinocarpa* may produce useful material over a longer time span. *Acacia acuminata* probably falls between these two groups with *A. ampliceps* another analogue for more tropical environments.

A number of Australian arid-zone species have ornamental potential and a range of species may be selected for specific environmental hazards.

There is little potential value where attained height is considered important. Only *Acacia harpophylla* is a tall tree.

Despite the optimistic presentation it is hard to believe that species of arid Australia have much potential for cultivation as exotics in other countries. Adaptation to dry climatic areas suggests that growth is likely to be slow in other climatic zones. There can be little prospect for planting trees in arid zones generally, unless success is guaranteed. Trials are essential.

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Genetic Resources and Utilisation of Australian Bipinnate Acacias (Botrycephalae)

D. J. Boland*

AUSTRALIAN bipinnate acacias (section Botrycephalae) comprise an interesting group of 36 species. One of its members *A. mearnsii* (black wattle) is famous because it is the only Australian species (of all the Australian flora and fauna) that has warranted the construction of a special research institute (Wattle Research Institute, Pietermaritzburg, Republic of South Africa) for the study of its cultivation and utilisation as a commercial crop. *Acacia mearnsii* is not cultivated in Australia but is grown worldwide (especially in Brazil and South Africa, but also in India, Kenya, Zimbabwe and Tanzania) for the production of tannin from its bark for use in the leather industry. It can be argued that the development of intensive management techniques for its culture in plantations influenced the direction of development of later industrial plantations of softwoods (pines) and hardwoods (eucalypts). It was also the first Australian tree species in which tree improvement was conducted. Given the commercial history of *A. mearnsii* it is argued that related species from the Botrycephalae deserve more serious attention than they have hitherto received.

Section Botrycephalae has some specialised morphological features. All species maintain bipinnate foliage until maturity and do not develop phyllodes so typical of most other Australian acacias. Unlike African acacias they are evergreen and unarmed. The foliage is usually delicately displayed in more or less soft horizontal fronds and at least a few of the species (e.g. *A. dealbata, decurrens* and *silvestris*) exhibit a diurnal rhythm of pinnule movement in which the leaves open by day and close by night. The group typically has racemose inflorescences and in this more specialised character they differ markedly from a related but geographically separate group of southwest Western Australian bipinnate acacias (section Pulchellae—27 spp.) which have axillary inflorescences.

Table 1. Alphabetic list of species in subgenus Phyllodineae, section Botrycephalae.

baileyana	*glaucocarpa*	*oshanesii*
'blayana'	*irrorata*	*parramattensis*
cardiophylla	*jonesii*	*parvipinnula*
chinchillensis	*latisepala*	*polybotrya*
chrysotricha	*leucoclada*	*pruinosa*
constablei	*loroloba*	*pubescens*
dealbata	*mearnsii*	*schinoides*
deanei	*mitchellii*	*silvestris*
debilis	*mollifolia*	*spectabilis*
decurrens	*muellerana*	*storyi*
elata	*nanodealbata*	*terminalis*
filicifolia	*olsenii*	*trachyphloia*
fulva		

Species in Botrycephalae are listed in Table 1 and the natural occurrence of a selected range of potentially useful species is shown in Fig. 1. All species in Botrycephalae are confined to southeast Australia in the cooler and often moister parts of the continent. The most tropical species is *A. storyi* while *A. dealbata* extends into cold temperate areas. *Acacia nanodealbata* can thrive in areas receiving winter snow while *A. elata* is commonly a fringe rainforest species in New South Wales. The distribution of some (e.g. *A. mearnsii*) is wide, occurring sporadically across southern New South Wales, Victoria, Tasmania, and South Australia, while others like *A. olsenii* and *A. chrysotricha* are restricted to very localised areas of N.S.W. Most of the group occur typically in the understory of eucalypt forest. as robust shrubs or small trees. Most are not particularly drought- or cold-tolerant and all usually prefer well-drained acidic soils.

The evolution of the group is of special taxonomic and ecological interest. In the past it was accepted that the advanced phyllodineous condition had evolved from the bipinnate one in

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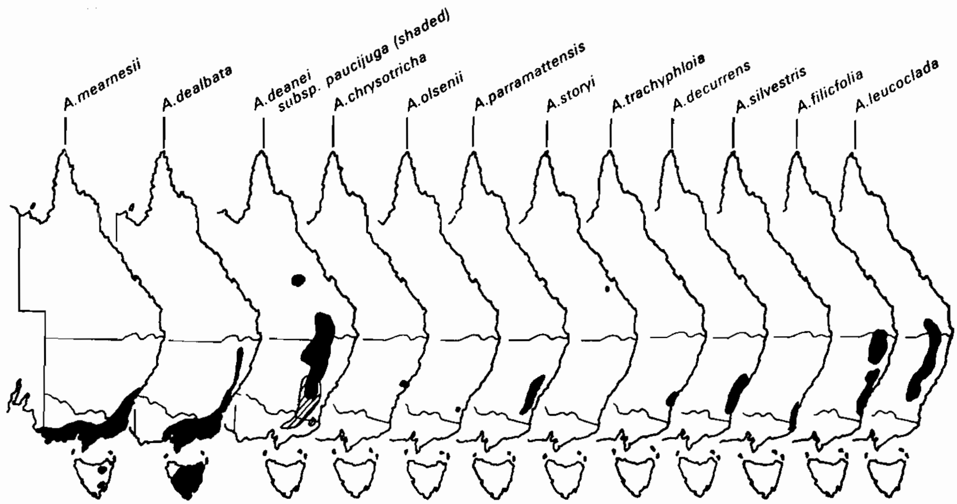

Fig. 1 Distribution of 12 bipinnate acacias (section Botrycephalae).

response to increasing aridity. In consequence the Botrycephalae were considered primitive stock in subgenus Phyllodinae. To Pedley (1986) this seemed anomalous in that Botrycephalae possessed advanced characters such as leaf cyanogens, racemose inflorescences and resorcinal A-ring compounds in the heartwood. He argued that the group probably arose from the mostly phyllodineous 'Racemosae' group with the production of bipinnate foliage being a secondary derived character, i.e. bipinnate leaves may have arisen twice in the evolution of the genus. Ecologically Pedley (1986) argued that Botrycephalae probably arose from pioneer-type species able to exploit gaps in the canopies of vegetation where seasonality of climate was less severe. Such a theory is in accord with some present-day species distribution patterns (e.g. *A. silvestris* forms gregarious single species clumps in disturbed patches of eucalypt forests and *A. mearnsii* thrives on roadside verges). In general the theory gives credence to the known rapid early growth of some members of Botrycephalae (e.g. *A. mearnsii, A. decurrens*), which can easily outgrow (in height) most temperate eucalypts in the early months of growth.

Some information on the general biology of the group is known. Most species of the group are short-lived (about 10–15 years) e.g. *A. mearnsii*, but *A. dealbata* and *A. elata* which may form larger more robust trees, have a life expectancy exceeding 20 years. Some species (e.g. *A. dealbata*) vigorously regenerate from root suckers. Manipulated vegetative propagation is possible in at least *A. mearnsii* where lower branches can be used to produce rooted cuttings (Zeijlemaker 1976) and the budding technique of clonal propagation (Garbut 1971) has been successful on a limited scale.

Flowers are typically produced in racemes of globular heads and these are usually pollinated by insects. The length of time between flowering and seed maturation is highly variable in the group being 12–14 months for *A. mearnsii*. Maturation periods (in months) for the following species are: *filicifolia* (5–6), *silvestris* (6), *elata* (12), *decurrens* (5–6), *dealbata* (5–6), *loroloba* (probably 9–11), *mollifolia* (about 6), *baileyana* (6) and *leucoclada* (4–5) (M. Tindale pers. comm. 1984). *Acacia parvipinnula* and *deanei* are known to flower twice in the same year. Typically seed can be shed and stored in the ground for many years with fire being the typical agent to break dormancy and stimulate vigorous germination.

The aim of this paper is to review the genetic resources and utilisation of the group giving brief attention to 18 species with potential for agroforestry-type pursuits. Future research directions are indicated.

Genetic Resources

Species

Eighteen species of Botrycephalae of known or potential value for industrial or agroforestry purposes are listed in Table 2 with information on their geographic occurrence and ecological range.

Seed Supplies and Related Factors

Collections from species in native forests. A guide to research seed collections from natural stands currently available at the Tree Seed Centre, DFR/CSIRO is given in Table 2. Of note are the first reasonably comprehensive provenance collections of *A. mearnsii* made between 1984 and 1986

Table 2. Brief notes on some known and potentially important bipinnate acacias—section Botrycephalae (N. Hall assisted in preparing much of the previously unpublished information in this table).

Species	Tree height (m) (range)	Tree form S = Shrub T = Tree	Lat (°S) (range)	Main altitude (m) (range)	Climatic Zone
'blayana' (ms)	10–19	S,T	36–37°	200–600	warm subhumid
chrysotricha	6–23	T	30–33°	25–125	warm/humid
deanei	4–6 (–9)	S,T	24½–35° (20–37½°)	160–360 (70–700)	warm sub-humid
dealbata	6–15 (–28)	S,T	29–43°	350–1000	cool to warm sub-humid
decurrens	8–13 (–22)	S,T	33–37°	100–700 (25–1000)	warm sub-humid to humid
elata	8–20	T	33–35°	100–750 (0–1200)	warm sub-humid to humid
filicifolia	5–10 (–20)	S,T	28–35½°	50–1000	warm sub-humid to cool humid
fulva	3–6	S,T			
glaucocarpa	6–10	T	23–29°	30–300 (–450)	warm sub-humid
irrorata	5–10 (–20)	S,T	26–36° (25–37°)	0–1000 (0–1300)	warm humid
leucoclada	5–10 (–18)	S,T	26–34°	300–1000	warm sub-humid to warm semi-arid
mearnsii	6–10 (–20)	S,T	33–44°	0–200 (0–900)	warm sub-humid to cool sub-humid
olsenii	3–8 (–15)	S,T	36°	900–1000	cool sub-humid
parramattensis	5–10 (–15)	S,T	33–34½° (–36°)	25–600 (–1000)	warm humid to cool sub-humid
parvipinnula	6–10	S,T	32–34½°	25–350 (–500)	warm humid warm sub-humid
silvestris	8–20 (2–30)	T,S	35–38°	30–300 (0–1000)	warm sub-humid
storyi	8–10	S,T	24°	500–800	warm humid
trachyphloia	10–15 (–24)	T	35–36°	0–900	warm sub-humid

Species	Approx. mean annual rainfall (mm)	Frost tolerance 0 = no frost 4 = heavy frost	Parent materials	Seed availability Tree Seed Centre (D.F.R.)	Comments and important references
'blayana' (ms)	900	2	quartzose sandstones	—	Boland and Midgley (1983)
chrysotricha	1200–1550	0–1	shales	—	Has showy ornamental value
deanei	500–650	2–3	sandstones, volcanics granites etc.	4 samples	With *A. leucoclada* this is the most drought tolerant
dealbata	600–1000 (300–1500)	4	granites plus range of types	3 samples	Boland et al. (1984)
decurrens	900–1150	3	sandstones shales	2 provenances	

(Continued)

Table 2 (*Concluded*)

Species	Approx. mean annual rainfall (mm)	Frost tolerance 0 no frost 4 heavy frost	Parent materials	Seed availability Tree Seed Centre (D.F.R.)	Comments and important references
elata	1000–1250	2	sandstones shales, alluvium	1 sample	Temperate rainforest and in gullies Anderson (1968)
filicifolia	750–1000	2–3	basalt, sandstone shales	2 samples	
fulva					
glaucocarpa	650–850	0–1	schists sandstones	2 samples only	Turnbull (1986)
irrorata	750–1100	0–2	alluvium, shales igneous	—	Turnbull (1986)
leucoclada	500–1000	2	basalt, granite black soil plains	—	With *A. deanei* this is the most drought tolerant (2 subspecies)
mearnsii	600–925	3–4	basalt, dolerite shales, slates etc.	20 provenances	Sherry (1971), Turnbull (1986) Boland et al. (1984)
olsenii	750–1000	2–3	shale, quartz	—	Tindale (1980)
parramattensis	600–1000	2–3	shales, basalt sandstone	4 samples/ provenances	
parvipinnula	725–900 (300–1000)	2	shales, sandstones	1 sample	
silvestris	800–1100	2	slates, sandstones	3 samples	Turnbull (1986) Can be coppiced
storyi	1000	0	sandstone	2 samples	
trachyphloia	800–1000	2	alluvials	1 provenance	

involving commissioned private collectors (3) and CSIRO collectors. Both single tree and bulk provenance collections were made. One serious difficulty encountered was the identification of introduced versus natural material especially in disturbed sites along roadsides. No seed is available of some potentially important species (viz. *A. blayana, olsenii* and *chrysotricha*). Several planned collections of these species were unsuccessful because of lack of information on the correct period to collect seed. Ripe seed is apparently shed over a very short period (1–3 weeks in some cases).

Collections from improved sources. Traditionally the Wattle Research Institute (now the Institute for Commercial Forestry Research) has carefully controlled the release of improved seed of *A. mearnsii*. In 1965 a seedling seed-orchard was established near Pietermaritzburg. From 170 progeny-tested trees, 12 were selected for the orchard. At half rotation age (5 years) trees raised from seed collected from the orchard had significantly less gummosis, more tannin, and straighter stems than the commercial control but their height, diameter and bark thickness were not significantly different (Nixon 1977). Hagedorn (1985) reports slightly better performance from a later seed-orchard (the 5th) which contained some reciprocal family crosses as well as selected progeny lines.

Biosystematic studies. No biosystematic studies have yet been completed on any species in Botrycephalae. Isozyme studies in progress for *A. mearnsii* have found major differences in one enzyme (leaf perioxidase) between southeast Victorian provenances and N.S.W. provenances (P. Brain, Natal Institute of Immunology, pers. comm. 1986). Such studies are important in providing a better base from which to select provenances for field trials.

Hybrids. The occurrence of bipinnate hybrids under natural conditions has not been formally studied. Nevertheless, Tindale (1960) reports that *A. baileyana* and *A. decurrens* at Blaxland (Blue

Mountains, N.S.W.) hybridise quite freely. Two closely-related sympatric species (*A. parvipinnula* and *A. filicifolia*) are reproductively isolated in their flowering times and no naturally occurring hybrids have been found despite careful searches (Tindale 1960). In contrast, in South Africa manipulated hybrids between *A. mearnsii* and *A. decurrens* have been studied (Moffett and Nixon 1958) and natural hybrids in cultivation between *A. mearnsii* and *A. irrorata* have been reported (Moffett 1965).

Utilisation

Information on the utilisation of Botrycephalae is dominated by papers on *A. mearnsii* but some other species have shown promise. General information on the silviculture and yields of black wattle plantations is provided by Sherry (1971) and Stubbings and Schonau (1982). Information on other species is less readily accessible and is summarised below.

Wood Products

Poles. Acacia mearnsii is used for poles in mining operations in South Africa (Jarmain and Lloyd-Jones 1982) and is used for hut roofing poles in localised areas near tannin plantations in Zimbabwe and Kenya. In Indonesia, at Ledokombo (1300–2000 m altitude) *A. decurrens* (probably *A. mearnsii*) has been planted on the borders of agricultural land for poles (Arismoenandar and Rappard 1951). *Acacia decurrens* and *A. silvestris* form better poles, but their reputation of lower tannin yields has inhibited their wider cultivation.

Pulp. Acacia dealbata is a superior pulping species in temperate regions of Australia (Batchelor et al. 1970). South Africa is exporting *A. mearnsii* chips to Japan for pulping (Jarmain and Lloyd-Jones 1982) while in both South Africa (Sherry 1971; Jarmain and Lloyd-Jones 1982) and India (Nilgiris area) *A. mearnsii* is used in the production of rayon.

Charcoal. Charcoal from *A. mearnsii* tannin plantations is made in Kenya for the Nairobi domestic market, while in Brazil *A. mearnsii* charcoal is used in the barbeque trade. A Brazilian company, Tanac, has developed special kilns for the production of activated carbon (for use in pollution control) from *A. mearnsii* for the European market.

Fuelwood. Acacia mearnsii is used in Indonesia as a domestic fuel and for curing tobacco leaves (NAS 1980). *Acacia dealbata* was introduced into the Nilgiris (India) as a fuelwood and it is considered good for this purpose especially since it coppices freely (Troup 1921).

Miscellaneous products. In Australia the Forestry Commission of N.S.W. has recommended *A. silvestris* for the tool and axe handle market. Vuuren and Grove (1978) considered that it was technically feasible to manufacture laminated *A. meansii* pick handles. The perceived advantages of laminated handles were the quicker drying rates of the thinner laminated blanks over solid timber and the high wood recovery per stem. The wood of some species (e.g. *A. blayana*) turns readily and could have ornamental use.

Bark Products

Tannin. Acacia mearnsii produces the world's most important vegetable tannin. Yields are high, from 35–40% (Sherry 1971), and the industry is worth more than R20 million in foreign exchange to South Africa (Stubbings 1977). The industry is declining worldwide with reduction in leather usage and impact of synthetic substitutes. This decline can be dramatically seen in the reduction of South African plantations from 361 002 ha in 1960 to 141 154 ha in 1977–78 and the plantation area is probably still declining (Anon 1980). This reduction is felt by all major world producers but in contrast China has a severe domestic shortage of tannin, particularly for pig leather manufacture, and is hoping to expand its own plantation areas. Australia currently imports about $A1.8 million worth of *A. mearnsii* tannin. Not unexpectedly the declining demand and prices per unit weight have resulted in a strong effort to diversify products (e.g. charcoal, glues, foams, pulp). Nevertheless the returns on investment from *A. mearnsii* plantations in South Africa are reputed to be higher than those from either pine or eucalypt plantations. The economics of wattle plantations have been discussed by Stubbings and Schonau (1978).

Somewhat surprisingly little effort has been made to explore the tannin yields and potential of other bipinnate acacias. Taking South Africa as the industry leader non-replicated trials have been undertaken for only *A. baileyana* (seed from 9 trees), *A. parramattensis* (seed from 6 trees) and *A. irrorata* (seed from 1 tree) (K. Nixon, pers. comm. 1984). Only in *A. silvestris* were replicated progeny trials made and here stem form and branching were excellent but tannin yields low.

Adhesives, Foams and Other Products from A. meansii. Wood adhesives extracted from tannin are used as a substitute for adhesives obtained from petroleum products or these are mixed together to form a more reliable product. Such adhesives can be used for producing laminated wood products (Saayman and Oatley 1976) and tannin formaldehyde resins have been developed as fortifiers for starch adhesives in the production of weather-resistant corrugated containers (Saayman and Brown 1977). Foams of the polyurethane type can be used in packaging. The extract can also be used in water purifying processes, core binders in foundry practice, clay conditioners in the ceramic industry, wool-scouring and in oil-well drilling (Jarmain and Lloyd-Jones 1982).

Gums. Anderson (1978) and Anderson et al. (1971, 1984) suggested that the Botrycephalae could be divided into two groups based on their gum chemistry. Anderson (pers. comm. 1984) considers that neither gum group has a role in foodstuffs nor is likely to be of commercial importance. Most are relatively insoluble in water.

Foliage

The group is not especially known in Australia for its animal fodder value. Nevertheless the Natural Resources Conservation League of Victoria (Anon 1985) advertises *A. dealbata, A. decurrens* and *A. mearnsii* as ideal fodder trees under Australian conditions. By comparison Goodricke (1978) in sheep-feeding trials found that dried and milled *A. mearnsii* leaves were unpalatable to sheep when fed on its own (additions of feed supplements improved palatability) although the protein per cent on a dry weight basis was high (14–16%). Goodricke considered that digestibility was probably affected by the high tannin content in the leaves and twigs (5.7% on an oven-dry basis). No data are available on the relative digestibilities of foliage of members of Botrycephalae. In central Java *A. mearnsii* foliage is used as a green manure to improve agriculture yield (N.A.S. 1980).

Flower Products

Perfumes. A perfume industry based at Grasse, France, makes use of *A. farnesiana* (Section Acacia) and *A. dealbata* flowers in perfume production. This industry is based on private plantations in the region. Extracts from *A. farnesiana* flowers fetch higher unit prices but larger areas of *A. dealbata* are grown and harvested (E. Lassak, pers. comm. 1986). Several private firms are involved and details of the industry are outlined by Guenther (1952). About 180–200 kg of *A. dealbata* flowers yield 1 kg of concrete which in turn gives 0.18–0.2 kg of absolute. French perfume manufacturers have long recognised its value as an excellent blender and 'smoothing agent' for synthetics and as an effective fixative in high-grade perfume.

Floriculture. A considerable industry exists in southern France for the production of sprays of mimosa for the cut flower trade in northern Europe. Mimosa (a name also applied to *A. dealbata*) consists of a hybrid clone between *A. podalyriifolia* (non-bipinnate) and *A. baileyana* grafted onto the stock of *A. retinoides* to assist growth on calcareous soils in southern France (Pryor 1984). The floral sprays produce a beautiful silver and gold combination. *Acacia dealbata* is grown on siliceous soils in southern France and is also popular in the European cut flower trade (Guenther 1952) and studies have been made of solutions to prolong vase-life of flowering branches (Accati and Sulis 1980).

Apiculture. Bipinnate acacias feature prominently amongst other acacias in Clemson's (1985) honey flora of New South Wales. Several species are particularly valuable sources of pollen in winter (e.g. *A. baileyana, A. silvestris, A. spectabilis* and *A. dealbata*) while *A. terminalis* and *A. parramattensis* have very limited value as pollen sources.

Environmental Protection

Windbreaks. Acacia decurrens is commonly used for windbreaks in the plantations in the highlands of Sri Lanka. *Acacia dealbata* is moderately favoured for farm windbreaks in New Zealand (Anon 1984).

Erosion Control. Acacia mearnsii and *A. decurrens* are commonly planted along roadsides in southern Australia to revegetate graded areas. *Acacia decurrens* has been used very successfully to stabilise coal ash produced from a power station near Port Kembla (N.S.W.) after the ash had been sluiced with saline water and allowed to settle in large ponds and covered to a shallow depth with soil (Junor 1978). *Acacia decurrens* has also been used effectively at high altitudes in Rwanda to stabilise hills from erosion (Nzindukiyimana and Sabasajya 1977). *Acacia mearnsii* and *A. dealbata* and other bipinnates are favoured in New Zealand for control of gully and hillside erosion (Anon 1984; Sheppard 1986). Although potentially weedy, Troup (1921) reports that *A. dealbata*, because of its ability to root sucker, is almost unrivalled as a means of stabilising eroded hill slopes in India. By contrast *A. decurrens* (?) in Indonesia is reported to suppress weed growth to such an extent that soil erosion becomes a serious problem when this species is planted on steep slopes (Werff 1953).

Agroforestry. In Brazil both corn and manioc are commonly intercropped between rows in the first year of *A. mearnsii* plantations.

Discussion

This section is divided into two areas, firstly to cover those factors which will constrain future development of the group, and secondly to cover those factors which will influence research needs.

Constraints to Development

A realistic appraisal must consider the future of the tannin industry and the role of *A. mearnsii* in it. The large plantations already established in South Africa, Zimbabwe, Kenya, Tanzania and Brazil face declining world demand and returns. In the past this has proved a stimulus to improve productivity (increased yields per hectare) and to diversify products (e.g. adhesives, charcoal, etc). The need for salvage-type operations in existing plantations limits experimentation with other species in the group. Clearly in selecting new species there is a need to balance potential tannin yields against other possible benefits (e.g. a new species may have lower tannin yield) but this could be offset by better wood volume yields and stem straightness for pole production. To date a major limitation in South Africa has been cold tolerance and a similar limitation is possible in China. It is unlikely that species with better cold-tolerance and higher tannin yields than *A. mearnsii* will be found but there is a greater array of potentially valuable Botrycephalae species to be explored for wetter, warmer areas.

The tendency of some species to become weeds is cause for concern. Delabraze and Valette (1979) detail methods of chemical control of *A. dealbata* and indicate serious weed problems in France. Similar problems have been experienced in South Africa where *A. dealbata* in Transvaal is a more serious weed than either *A. mearnsii* or *A. decurrens* (Wells et al. 1979). With biological control in mind a survey of pests of native Australian acacias was undertaken by van den Berg (1982). Troup (1921) commented on the potential weediness of *A. mearnsii* and *A. dealbata* in India, although major problems have apparently not arisen with *A. mearnsii* in Brazil.

Future Research Needs

Many species in Botrycephalae are poorly known in Australia. Some species (e.g. *A. blayana*) are still undescribed and no key to all the species in the group has yet been constructed (regional keys have limited usefulness in Australia and especially overseas). There is a need for a detailed phylogenetic cladistic-type analysis of the group so that closely related species can be identified for species trials.

In view of the limited history of tannin exploration in Botrycephalae there is a need to undertake examination of other species in the group. No detailed work has ever been undertaken on provenance variation in tannin yields in *A. mearnsii* and it is anticipated that the current work supported by ACIAR in China will provide guidance in this area. More importantly perhaps is the need for basic research into the causes of gummosis in plantations (which reduces yields per tree quite significantly—Sherry 1971) and perhaps research into genotype vs. rhizobia strain interactions in selected members of Botrycephalae.

In order to commence some areas of research there is a need to make comprehensive seed collections. To undertake such work better information is needed on phenology to facilitate timing of collections. Seed collections for species trials have still to be made for *A. blayana, olsenii, irrorata, trachyphloia* and *chrysotricha*, and most species of bipinnate acacias have not been sampled systematically for provenance studies. This work should clearly be undertaken in conjunction with species/provenance trials in properly conducted scientific trials overseas. Studies on geographic variation involving isozyme studies are currently being conducted in South Africa but studies are needed on the breeding systems operating in *A. mearnsii*. Inexpensive means of vegetative propagation of high-tannin yielding clones could provide a rapid means of improving productivity.

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Distribution and Ecology of Papua New Guinea Acacias

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FOURTEEN *Acacia* species have been recorded from the island of New Guinea**, all of which occur in Papua New Guinea. Nine are indigenous, two are naturalised and three have been cultivated (Verdcourt 1979). The species with their approximate recorded maximum heights are: Large trees: *A. aulacocarpa* 35 m (indigenous), *A. auriculiformis* 30 m (indigenous), *A. crassicarpa* 30 m (indigenous), *A mangium* 30 m (indigenous), *A. mearnsii* 25 m (naturalised); Medium trees: *A. leptocarpa* 10 m (indigenous), *A. solandri* 12 m (indigenous); Small trees and shrubs: *A. deanei* 6 m (cultivated), *A. farnesiana* 4 m (naturalised), *A. flavescens* 7 m (cultivated), *A. holosericea* 6 m (cultivated), *A. simsii* 6 m (indigenous); Climbers (armed with scattered spines): *A. concinna* 18 m (indigenous), and *A. pluriglandulosa* tall shrub (indigenous).

Apart from the climbing species which are part of the Afro-Asian *A. pennata* group and *A. farnesiana*, which was introduced from tropical America, all non-indigenous acacias in Papua New Guinea acacias have been introduced from Australia. These Australian introductions, except *A. mearnsii* and *A. deanei*, therefore have phyllodes (flattened petioles or leaf rachis) replacing true leaves, the latter existing only during the early juvenile stage.

Papua New Guinea has a fairly wet to very wet tropical climate (1000 mm to 10 000 mm) with respectively mean annual maximum and minimum temperatures varying from 32 and 23 °C in the lowlands to only 11 and 4 °C in the high mountains (over 4000 m). Rainfall distribution is generally seasonal (except some islands and parts of the Highlands having an even rainfall) though timing and length can be unpredictable and the degree of seasonality is not great (McAlpine et al. 1983). The seven non-climbing indigenous acacias occur in distinctive drier (subhumid) parts of the country on the south coast where annual rainfall is 2000 mm or less in savanna/woodland/forest complexes associated with *Eucalyptus, Melaleuca* and *Tristania* species.

The main distribution is between the Digul and Fly rivers in southern New Guinea on a low plateau known as the Oriomo Plateau in Western Province, Papua New Guinea, and the Merauke Ridge in Irian Jaya, Indonesia. Here the shrub *A. simsii* and five of the large and medium tree species are common. It is unlikely *A. solandri* subsp. *solandri* has been found here despite an ambiguous map locality reference by Verdcourt (1979) which is probably a misprint. This is supported by Pedley (1975).

In Papua New Guinea, *A. aulacocarpa, A. crassicarpa* and *A. leptocarpa* have been observed only in this region.

Besides the Oriomo Plateau, a provenance of *A. auriculiformis* (planted ad hoc in Papua New Guinea for over 20 years) originates from the Brown River area, 30 km north of Port Moresby, 400 km east of the Fly River mouth across the Gulf of Papua. Port Moresby itself and a small area to its southeast have the lowest rainfall in the country (1000 mm) and naturally growing *A. auriculiformis* appears to be absent in the eucalypt-dominated savanna (mainly *Eucalyptus alba* and *E. papuana*). However from 20 km north and northwestwards in coastal areas where rainfall increases (but is still less than 2000 mm with a distinct dry season) eucalypt/melaleuca savannas occur in patches as far as Kerema (230 km from Port Moresby) and *A. auriculiformis* has been collected in some localities. Trees have been observed as small groups usually beside gullies on low hills. An herbarium voucher attributable to Millar in 1969 cited in Pedley (1975) from the Sepik River region is thought to be from introduced seed as by that time the species had been propagated by the Department of Forests in the district for extension and experimental plantations. *Acacia simsii* also occurs in areas immediately north of Port Moresby towards the Brown River.

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** New Guinea refers to the island encompassing Papua New Guinea and the Indonesian province of Irian Jaya.

The only recorded occurrence of *A. solandri* subsp. *solandri* is given at the mouth of the Aroa River behind the beach, 60 km northwest of Port Moresby, with *A. auriculiformis.*

Mature *Acacia mangium* has only been described from Western Province but recent regeneration (6–8 m tall) was seen on an old subsistence farm site near Kupiano, 130 km southeast of Port Moresby in 1981 (Doran and Skelton 1982). A group of young (15 m tall) trees was also discovered north of Mullins Harbour in Milne Bay Province in 1985 in secondary forest adjoining patches of melaleuca savanna. Unfortunately they were subsequently destroyed during logging operations. In neither location were parent trees seen and the trees may have been chance introductions by man or bird. Lorikeets have been seen opening developing *A. crassicarpa* pods in Western Province to eat the fleshy arils therefore *A. mangium* is probably similarly affected.

Acacias indigenous to Papua New Guinea are known to extend naturally to the western Moluccan Islands of Indonesia and north and eastern Australia.

Pedley (1975) cites eight extra-Australian tropical *Acacia* species present in the Asia-Pacific region which have not been observed in New Guinea (information from Pedley 1975, Turnbull 1982, and CSIRO 'Australian *Acacia*' leaflets). These are: *A. oraria* (east coast Queensland; Flores and Timor, Indonesia); *A. simplex* (Pacific Islands—Fiji, New Caledonia, Samoa, Tonga, Vanuatu and the Solomon Islands, probably introduced in the latter); *A. mathuataensis* (Fiji); *A. richii* (Fiji); *A. confusa* (Philippines and Taiwan); *A. wetarensis* (Wetar, Indonesia); *A. spirorbis* (New Caledonia and Loyalty Islands); and *A. solandri* subsp. kajewskii (Vanuatu).

As many areas of New Guinea are remote with difficult access some of these species may still be awaiting discovery, for the New Guinea 'landmass' in the past may have been a bridging point. *Acacia richii* and *A. confusa*, for example, though remote from one another are related, as well as being related to the indigenous *A. simsii* (and more distantly to *A. simplex* and an Australian endemic *A. complanata*) (Pedley 1975).

Ecology of the Oriomo Plateau

This low plateau south of the Fly River (30 m elevation in general but occasionally to 90 m) rises above the very low Fly-Digul Shelf, a part of the Australian Shield which extends from Cape York under the Torres Strait to the southern edge of the mountainous spine of the island. Both the Oriomo Plateau and the Fly-Digul Shelf are described as relict alluvial plains (Löffler 1974).

The Oriomo Plateau is a slightly undulating featureless plain through which a number of shallow-gradient, deep rivers have incised open valleys. This is in contrast to the Fly-Digul Shelf which consists of closely spaced narrow ridges and valleys with an intricately dendritic pattern (Blake in Paijmans et al. 1971), this probably being due to the higher rainfall. Oriomo Plateau mean annual rainfall varies between 1500 and 2100 mm (most rain falling between January and May), increasing northwards (substantially so, north of the Fly River) and westwards. 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 (Fig. 1).

The vegetation is unique to New Guinea but is similar to the far north of Cape York consisting of a dynamic mosaic of grass plains, savannas and forests influenced by fire, browsing and grazing animals (Rusa deer and wallaby—Liem 1977), soil drainage, relative elevation and to a lesser extent farming (population is quite low). Termites are common throughout the region but their influence on the vegetation is not known. Wild pig, also very common, may uproot a considerable number of young stems locally.

Paijmans et al (1971) have classified the vegetation specifically to a 90 km strip east of the Indonesian border, and Paijmans (1975) again reclassified it as part of a countrywide classification process. Although the map scales are similar (1:1 000 000) the classification terminologies are different and the mapping units do not entirely coincide. In all areas the vegetation mosaics are too complex to map individual forest types at that scale. Zones as mapped therefore are not particularly useful in locating potential *Acacia* stands nor in visualising all the vegetation types found within each zone.

Paijmans' vegetation types for the Oriomo Plateau (excluding mangrove and mixed herbaceous swamp) are given in Table 1 and used in the descriptions below. Acacias can be found in all of the types.

Littoral forest on beach ridge complexes and plains on the south coast (formed by longshore drift of silt deposits—Löffler 1974) contains frequent *A. auriculiformis*. Other genera include *Melaleuca, Aleurites, Alstonia, Intsia, Dysoxylum, Ficus* and *Canarium* (Paijmans et al. 1971).

The flood plains of the Bensbach and Morehead rivers are unique to the region being composite meander plains with flanking backplains and

Table 1. Paijmans' vegetation types on the Oriomo Plateau, Western Province.

1971		1975
Mapped vegetation types	Described vegetation types	Described vegetation types
1. Swamp grassland	1. (a) Low swamp grassland (b) Tall sedge-grass swamp vegetation	1. Swamp grassland
2. Grassland	2. (a) Mid-height grassland (b) Low-mid height sedge-grass vegetation	2. Grassland
3. Mixture of low mixed savanna and monsoon scrub	3. (a) Monsoon scrub (b) Low mixed savanna	3. Scrub
4. Melaleuca savanna	4. Melaleuca savanna	4. Savanna
5. Mixture of monsoon forest and mainly tall mixed savanna	5. (a) Tall mixed savanna (b) Monsoon forest	5. Dry evergreen forest
6. Melaleuca swamp forest	6. Melaleuca swamp forest	6. Swamp forest
7. Littoral forest	7. Littoral forest 8. Mixed woodland (and gallery forest)	7. Littoral forest 8. (a) Woodland (b) Swamp woodland

swamps (Löffler 1974) which are inundated to a depth of 1.5 m or more during the wet season. The plains support low swamp grassland (mainly creeping *Pseudoraphis* sp.), low to mid-height sedge grass vegetation (in the swampier areas) and mid-height *Imperata* grassland on the higher parts, some of which do not flood. Pandanus trees grow on the open plains and windswept *A. auriculiformis* frequently occur on the margins together with *Melaleuca* species. Many trees have a 'tide' mark extending 90 cm up the trunk although peak flooding exceeds this.

The back swamps contain *Melaleuca* swamp forest which consist of almost pure, generally straight 20–30 m tall trees, usually *M. cajuputi* (Paijmans et al. 1971) or *M. leucadendron*. On the raised levees of the Bensbach River and streams flowing through the swamps tall *A. auriculiformis* are often found. These levees at peak flood consist in many cases of a low, narrow strip of dry land between the river and the inundated back plain or swamp. Paijmans et al. (1971) describe *Dillenia alata, Barringtonia tetreptera, Mangifera* sp., *Vitex* sp. and *Sarcocephalus* (Syn. *Nauclea*) *orientalis* as well.

The plains are generally no lower than the floor of many *Melaleuca* swamp forests, and since *Melaleuca* appear to be encroaching at the edges it suggests that seasonally inundated plains are maintained as grass communities by deer and wallaby when they migrate to them as the water recedes. The formation of the plains is unknown but it is thought there was once a much higher human population. As the plains fertility is probably slightly higher than surrounding areas due to the annual flooding, and there is increased subterranean moisture during the dry season, the areas could have been cleared by subsistence farming.

Dry evergreen forest complexes are commonest on the upper part of the Oriomo Plateau above 30 m. In the west this descends in over 50 km through savanna mosaics to the littoral and mangrove forests but in the east near the Oriomo River, the land drops to the coastal mudflats in only 15 km. Here dry evergreen forest and mixed woodland merge directly into mangrove forest interspersed with relatively small areas of savanna.

Unique *Acacia* forests, not observed elsewhere, occur on the high banks of the Oriomo River extending some distance inland from it, upstream of Woroi. *Acacia crassicarpa* or *A. mangium* predominate (60%) in an even canopy forest containing *Flindersia, Grevillea, Syzygium* and *Planchonella* species (Vickers 1961). *Acacia auriculiformis* and *A. aulacocarpa* also occur but infrequently.

Elsewhere dry evergreen forest and mixed woodland contain *Terminalia, Calophyllum, Buchanania, Schizomeria, Mangifera* and *Acacia* species (Henty 1973), with often one species of the latter predominating. Between Morehead and Iokwa along 12 km of a ridge, moist evergreen forest has developed (currently 5 km wide).

Paijmans' (1975) descriptions for mixed woodland and dry evergreen forest are very similar and slightly ambiguous. This author interprets woodland as a younger mixed forest, often a 'thicket' with a denser ground cover of herbs, thorny climbers and young trees. Like dry evergreen forest, woodland retains its greenness during the dry season as grasses are uncommon (they being almost absent under dry evergreen forest).

The savannas are variable in their height, density and species composition. Tall mixed savanna may contain 5-20% acacia trees with *Tristania, Melaleuca, Alstonia, Dillenia, Xanthostemon, Grevillea, Parinari, Planchonia* and *Syzygium* species (Paijmans et al. 1971; Henty 1973). Low mixed savanna often contains eucalypts (*E. brassiana, E. confertiflora, E. dichromophloia, E. leptophleba, E. polycarpa* and *E. tesselaris* having been recorded to date). In both types *A. mangium* is widespread individually and *A. crassicarpa* common locally, especially in low mixed savanna. Three probable associations have been observed in which *Tristania* species (usually *T. suaveolens*) and 'brown bark' melaleucas (*M. viridiflora, M. quinquenervia* and/ or *M. cajuputi*) are common to all.

Melaleuca savanna can occur as dense stands of straight 'white bark' species (*M. leucadendron* with some *M. viridiflora*) in shallow depressions with seasonal high water tables or flooding, common amongst mixed savanna or, as an extensive more open savanna of *M. viridiflora* and *M. symphiocarpa* (Henty 1973). Other species are rare except along seasonal watercourses where acacias can be found.

Areas of scrub are common near Weam and east-southeast of Morehead. Mid-height *A. crassicarpa* frequently, and *A. leptocarpa* less frequently, occur on their margins beside low and tall savannas or dry evergreen forest. Lone *A. crassicarpa* are found periodically in the centre of these scrub areas which support a low sedge grass vegetation with stunted *Melaleuca viridiflora, Banksia dentata* and *Sinoga lysicephala*.

Role of Acacias

Acacias are fast-growing pioneer species and probably initiate the succession to dry evergreen forest regarded as the climax vegetation on the non-flooded sites. After fire *Acacia* regeneration under savanna can be dense and prolific during the next season's first rains. Subsequent exclusion of fire probably results in mixed woodland developing under the more stable conditions of this regeneration. Fire interrupts the succession (at any time) returning it to mixed savanna but once established mixed woodland would tend to resist fire although repeated encroachment would gradually reduce the size of the patches. A small proportion probably develop to dry evergreen forest. Frequent annual fires would prevent much of these areas of regeneration establishing as most young acacias are killed by fire hence large areas of savanna are maintained. Locally eucalypts may come to dominate the vegetation with *Melaleuca* and *Tristania* species. The time of *Melaleuca* fruiting appears to be variable and the seed being smaller than eucalypt seed, it is probably easily destroyed by fire. Fresh seed germinates immediately but it probably loses its viability relatively quickly. *Acacia* seed is long-lived and its hard seed-coat requires cracking (e.g. by fire) before germination is possible. The time at which fires therefore pass through an area probably also influences regeneration type and *Acacia* regeneration need not result from just the previous seed crop.

The very open *Melaleuca* savannas are probably botanically degraded by persistent annual fires and depletion of the soil seed bank, especially of acacias. Melaleucas, though relatively slow starters, once established are fire-hardy and will survive prolonged periods of annual burning.

All savannas and scrub are probably fire disclimaxes at various extremes after destruction of the succession of woodland to dry evergreen forest. Savannas probably only revert back to the succession through new dense regeneration underneath. Areas of thicket retaining their greenness in the dry season under remnant savanna *Tristania* and *Melaleuca* standards are common in the Bensbach/ Morehead area. These areas of woodland thicket when probably 10-15 years old are often well stocked with acacias and have been seed collection sites (Skelton 1983). West of the Oriomo River, tall *Eucalyptus brassiana* trees are a component of a remnant savanna overstorey, while in localised areas east and north of Morehead, senile 40 m tall and up to 90 cm diameter *A. aulacocarpa* emerge above mixed woodland. Other mixed woodland and dry evergreen forests, often rich in acacias, especially *A. mangium*, can be seen east of Morehead on the track to Dimisisi. Dry evergreen forests appear not to be good seed-producing sites, probably because they are environmentally stable and the trees are under little dry-season stress. However, west of Morehead and west of the ridge of moist evergreen forest, either side of a new road alignment cut through dry evergreen forest, seed was collected in 1982 from large codominant *A. auriculiformis* trees. Further into the forest where there had been no disturbance little fruiting was seen.

Many mixed stands containing *Acacia* are the result of subsistence farming in forest areas (villages are not located in the savannas). This may account for the *Acacia* forests on the banks of the Oriomo River.

Location of Acacias

Location of acacia trees has therefore been carried out entirely by surface reconnaissance. Areas explored for acacias are shown in Fig. 1 and described below:

Upper Bensbach/Tarl River

Potential seed collection areas were seen during the first reconnaissance made in May 1986. From Balamuk to north of Wereave village: (a) Levee banks of river, back swamp, plain complexes; abundant tall *A. auriculiformis* and some *A. crassicarpa* occur on narrow levee ridges. Open grass plains or *Melaleuca* swamp forest are found behind; (b) River banks of Bensbach River; *A. auriculiformis* is abundant with *A. crassicarpa* and some *A. mangium* and possibly *A. aulacocarpa*. Tall mixed savanna or *Melaleuca* savanna occurs further back; (c) River banks of Bensbach/Tarl River; acacias as small stands or isolated riverside trees occur on the edge of *Melaleuca* savanna.

Balamuk to Bula (dry season track)

Acacia auriculiformis occurs on edges of grass plains in tall mixed savanna south of Bandaber and in littoral forest 1 km north of Bula. Provenance collections were made near both locations in 1982 (Turnbull et al. 1983). *Acacia auriculiformis* × *A. mangium* hybrids occur 1.5 km east of Balamuk (2 trees growing openly on grassland) and 0.7 km south of Bandaber in tall mixed savanna (3 trees) north of *Melaleuca* swamp forest.

Balamuk to Iokwa (all season track)

This is a range of woodland, savannas and scrub, where acacias are common except in an area of eucalypt/melaleuca low savanna. *Acacia auriculiformis* is common in woodland immediately northeast of Balamuk and *A. mangium* is common a few kilometres northeast of this where collections were made in 1980 (Balamuk provenance; Skelton 1983). *Acacia crassicarpa* is very frequent north of Wemenever village where collections were made in 1982 (Turnbull et al. 1983). Elsewhere individuals are dispersed throughout the savannas.

Iokwa to Weam via Kandarisa (dry season track)

Localised areas of dry evergreen forest and woodland occur with *A. mangium* (collected 1980, Toko (Tokwa) provenance; Skelton 1983) with mainly low mixed savanna and scrub. Occasional low *A. crassicarpa* trees are found on the scrub sites but generally there is a poor representation of acacias. No other collections were attempted.

Kandarisa to Balamuk (dry season track)

The savannas contain *Acacia* individuals, mainly *A. mangium*, and *Melaleuca* swamp forests also

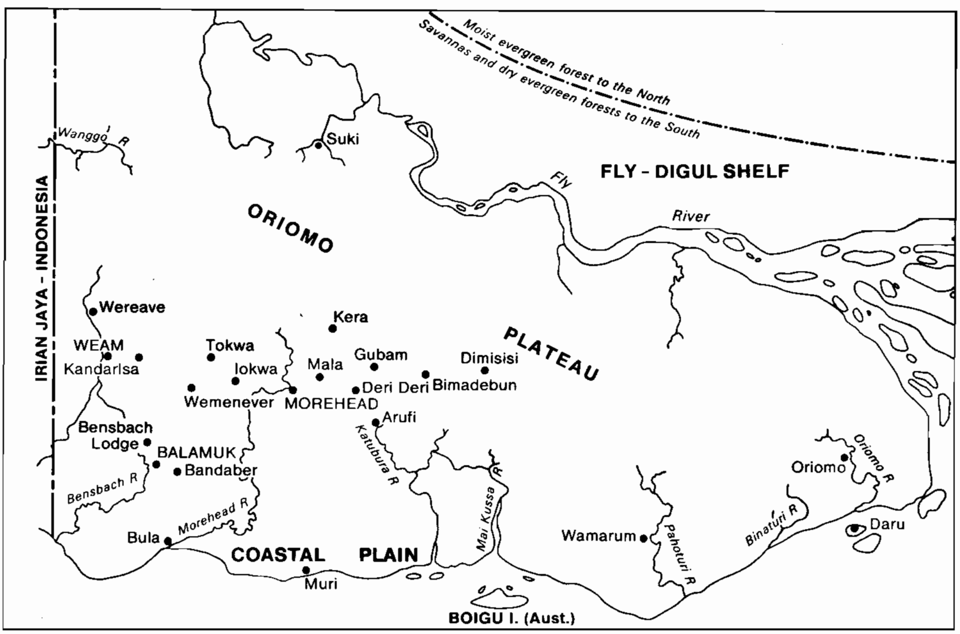

Fig. 1. The Oriomo Plateau region.

occur, the latter flooding by 1.5 m in the wet season. On mounds and stream levees tall, straight *A. auriculiformis* grow 2–4 km and 19 km north of Bensbach Lodge. No collections have been made owing to poor fruit set.

Iokwa to Morehead (all-season road)

Mixed savannas, dry evergreen forest and moist evergreen forest occur with some *Melaleuca* savanna towards Morehead. *Acacia mangium* seed was collected from old subsistence farm sites and tall mixed savanna in 1980 (Iokwa provenance; Skelton 1983) and *A. auriculiformis* seed was collected from dry evergreen forest and *A. aulacocarpa* seed from low mixed savanna in 1982. *Acacia simsii* was also collected from roadside regeneration (Turnbull et al. 1983).

Morehead to Dimisisi, Keru and Arufi (seasonal tracks)

Mosaics of all vegetation types occur but with extensive areas of woodland and dry evergreen forest. *Acacia mangium* is abundant in many of these areas. *Acacia crassicarpa* is locally abundant in low mixed savanna. Seed was collected near Mata in 1982 (Turnbull et al. 1983). *Acacia aulacocarpa* locally occurs as senile emergents above mixed woodland and dry evergreen forest east of Mata and at Keru. Seed was collected from the Keru trees in 1982 (Turnbull et al. 1983). The other trees were not producing seed.

Arufi to Sea, Kutabura and Wassi Kussa Rivers

Mainly gallery and mangrove forests occur. Occasional patches of *Melaleuca* savanna can be seen and one area of *E. brassiana* with *A. mangium* occurs at the confluence of the two rivers. No collections have been attempted.

Pahoturi River

This area was first reconnoitred in May 1986. Acacias are abundant but only as individuals and small stands. *Acacia crassicarpa* is the most common with some *A. auriculiformis* and infrequent occurrences of *A. mangium*. *Acacia aulacocarpa* was not positively identified. There are three areas with a higher-than-average density of *Acacia* trees near Kodoro, Wamarum and Kibuli.

Oriomo River

From Woroi downstream to the mangrove forests, only occasional acacias occur, usually *A. mangium* and *A. auriculiformis* associated with patches of savanna and old subsistence farm clearings. North of Woroi extensive *Acacia* forests occur along a 4 km length of the river. *Acacia mangium*, Oriomo provenance was collected in 1980 (Skelton 1983) and *A. crassicarpa* and *A. aulacocarpa* 'Oriomo River' provenances were collected in 1982 (Turnbull et al. 1983).

Woroi to Wipim (all season track)

Savannas, mixed woodland regeneration under remnant savanna and dry evergreen forest occur in this area. Acacias are widespread but nowhere abundant in stands. *Acacia crassicarpa* and *leptocarpa* were collected in 1982 (Turnbull et al. 1983).

Summary

The following generalisations can be made about Papua New Guinea indigenous acacias.

The *A. mangium* flowering flush occurs in April, *A. auriculiformis* in April/May, *A. crassicarpa* and *A. simsii* in May and *A. aulacocarpa* and probably *A. leptocarpa* in May/June. This is during the latter part of the wet season.

All acacias fruit from the end of September to early November which is the latter part of the dry season, in the following approximate order: (1) *A. mangium*; (2) *A. auriculiformis* and *A. aulacocarpa*; (3) *A. crassicarpa*. *Acacia simsii* and *leptocarpa* also mature at this time. Seeds, hanging by their arils usually fall out of the dehiscent pods gradually during the period. Tree-inhabiting ants (*Smaragdina oecophylla*) when present in large numbers on trees appear to increase seed crops, probaby by reducing seed-boring insect attack.

Acacias grow in soils which are highly weathered clay, silt and sandy loams with impeded drainage at various depths. They are acid to strongly acid (with a lowest recorded pH of 3.5).

Natural hybrids of *A. auriculiformis* × *A. mangium* have been found in two localities in areas rich in *A. auriculiformis* but few *A. mangium*. Stem form was poor in all cases.

Acacia mangium is the most prolific regenerator and is probably the fastest growing. Its scarcity in the upper canopy of tall dry evergreen forest suggests it is short-lived (30–50 years?). It prefers the slightly higher drier sites.

Acacia crassicarpa is the next most prolific regenerator. It appears to tolerate the more extreme sites and where fire is more common, but is probably less tolerant of vegetation competition. It is also found with *A. auriculiformis* on river banks.

Acacia auriculiformis probably requires higher soil moisture levels but is longer-lived than the above. In Western Province it is scarce in savannas but it is found as a codominant in dry evergreen forest, on river banks with *A. crassicarpa* and on the edge of the seasonally flooded grass plains. It probably tolerates flooding better than the other species provided the water is not stagnant. It exhibits a wide range of leaf morphology. In the Brown River area in Central Province it occurs as medium trees in small groups. Fruit pods are more linear than the Western Province 'auricular' type.

Acacia aulacocarpa is a rare tree appearing not to fruit prolifically. Lone trees are found in savanna and woodland and in Oriomo 'acacia' forest. Large senescent trees remnant of some earlier forest or savanna over developing woodland shows it is long lived.

Acacia simsii, a woody shrub, regenerates on cleared land and has not been seen elsewhere.

Finally, *A. leptocarpa*, a low tree, is restricted mainly to the edge of scrub and low mixed savanna. It does not grow as rapidly as the other acacias and is probably intolerant of competition.

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Acacias and Their Root-Nodule Bacteria

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THE questions which are posed concerning the nodulation and nitrogen fixation by acacias are not markedly different from those asked of agriculturally important pasture and crop legumes. Such questions include: Is it necessary to inoculate the particular species, if there are rhizobia in the soil are they effective? If suitable rhizobia are not present are there suitable strains available or is there a need to select strains and to produce a suitable inoculant? Following inoculation did the strain colonise the rhizosphere, nodulate the host and fix nitrogen?

An approach we have found useful with agricultural legumes, once a suitable strain has been selected, is to study rhizobia quantitatively. We therefore count rhizobia in soil and in inoculants, we follow their survival on seed with time, and we count their numbers in the rhizosphere and the number of nodules they form compared with those rhizobia naturalised in the soil.

Such studies have given some insight into how many organisms need to be inoculated onto seed to provide nodules on plants to be established in a range of environments. Further, how the environment, or the method of inoculation, may be modified to favour survival and multiplication of rhizobia is now better understood.

Very little is known about the root nodule bacteria for acacias and other tree legumes in either their free-living or symbiotic states. Whilst the principles and methods of study learned from work with other hosts may apply there are many special problems to be considered in studying symbioses with tree legumes.

The Root-Nodule Bacteria

Legumes and their rhizobia exhibit a degree of specificity; within the genus *Acacia* not all species will be nodulated by the one bacterial strain. It is therefore important to determine the degree of host specificity of the selected *Acacia* species to help in predicting firstly the need to inoculate them at sowing, and secondly, to develop a strain which will nodulate and fix nitrogen with as great a number of the useful species as possible (promiscuous strain). Conversely, a promiscuous host, that is an *Acacia* which may be nodulated by a wide range of *Rhizobium* strains, has more chance of being nodulated in a soil in which the *Rhizobium* population may be small.

Root-nodule bacteria which nodulate acacias belong either to the genus *Rhizobium* (fast-growing strains, 3–4 mm colonies in 3–4 days) or *Bradyrhizobium* (slow-growing strains, <1 mm after 5 days). Dreyfus and Dommergues (1981) were able to divide 13 *Acacia* sp. into three groups according to effective nodulation patterns with the fast- and slow-growing strains or whether they could nodulate with both. Both *Rhizobium* and *Bradyrhizobium* have now been isolated from Australian soils (Lawrie 1983); previous reports described only slow-growing strains (e.g. Lange 1961). Both genera may occur at the same site forming nodules on the same species of *Acacia* (Barnet et al. 1985). These authors also presented data to show that slow- and fast-growing isolates were serologically distinct with few cross reactions occurring between groups. Cross reactions within these groups were common.

Knowledge of their occurrence and distribution in soils is particularly sketchy. Bowen (1956) collated information on the occurrence of 33 nodulated *Acacia* spp. in Queensland. Beadle (1964) recorded the occurrence of nodules on 21 species of *Acacia* in arid zones of eastern Australia and noted that their rhizobia were widespread. Their method of distribution remains, as then, open to speculation; Beadle felt that wind distribution was unlikely as *Acacia* rhizobia were usually absent from wind-blown dust. Barnet et al. (1985) examined the distribution of *Acacia* rhizobia from two sand dune sites, one previously mined and the other, frontal dunes

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at Wanda Beach. All soil samples from the mined area where *Acacia* had previously grown contained bacteria whereas the Wanda Beach site was variable (22% of samples were rhizobia-free) and where rhizobia occurred they were sparse. They noted that root nodule bacteria could survive at this site in the absence of their host.

Habish and Khairi (1970) reported that five isolates from *Acacia* spp. had growth optima between 30 and 35 °C and seven isolates had pH optima between 6.5 and 7.5. No cell counts nor final media pHs were presented so the data should be considered at best as a guide only.

For a more general consideration of environmental factors known to affect *Bradyrhizobium japanicum* in soil, see Roughley (1985). However, this account should only be taken as a guide as to how *Acacia* root-nodule bacteria may behave until specific studies are reported. In particular, we lack information on the effects of salt, important in both arid and marine environments, hydrogen ion concentration known to vary widely between inland and highly leached coastal soils, tolerance to desiccation and high soil temperatures which could be important in considering inoculation strategies.

Factors which make ecological studies of these organisms difficult include: (1) isolation from plant material containing toxins may be difficult; (2) many are extremely slow-growing which makes initial inoculation difficult and their study in non-axenic conditions difficult; (3) *Acacia* strains are easily 'lost' in laboratory culture; (4) many strains don't nodulate *Macroptilium atropurpureum* or other small-seeded legumes used as a trap host to isolate strains from soil or to count bradyrhizobia by MPN method; (5) determining which strain has formed nodules is made difficult by serological cross reactions with other bradyrhizobia (Barnet et al. 1985) or by using antibiotically marked strains due to a high incidence of antibiotically marked strains in tropical soils (Roughley unpublished).

Nodulation Studies

In this paper I will consider only the reactions between strains isolated from known acacias and *Acacia* hosts. The relationship may be considered at two levels, that of infection and nodulation and that of subsequent nodule function.

The most comprehensive information on nodulation is that presented by Thompson et al. (1985) which included 20 strains of *Rhizobium* and 18 of *Bradyrhizobium* inoculated onto 63 species of *Acacia*. A summary is presented in Table 1. Further data indicating host specificity are given by Habish and Khairi (1970).

The relative promiscuity of 38 isolates from *Acacia* spp. is detailed in Thompson et al. (1985) and summarised in Table 2. Overall the slow-growing strains were more promiscuous but there were highly promiscuous fast-growing strains (e.g. CB405).

There is little information concerning the effectiveness of *Acacia* symbioses in axenic culture. Lawrie (1983), for example, found significant correlations between N content and nodule fresh weight, nodule number and C_2H_2 reduction in only two of four comparisons even though plants often appeared well nodulated. Lawrie concluded that suitable isolates could not be selected on the basis of host taxonomy, symbiotic effectiveness with *M. atropurpureum*, percent foliar nitrogen or serological affinities. This is not surprising as these criteria, with the exception of percent foliar nitrogen, have not been reliable in predicting effectiveness of strains with well-studied legumes.

Field Estimates of Nitrogen Fixation

There is ever-increasing literature dealing entirely, or in part, with estimating nitrogen fixation by *Acacia* spp. in the field (see e.g. Langkamp et al. 1979, 1981, 1982; Lawrie 1981; Monk et al. 1981; Hopmans et al. 1983; Adams and Attiwill 1984; Barnet et al. 1985). Fewer studies have utilised pot-grown plants (e.g. Habish 1970; Nakos 1977; Monk et al. 1981; Hopmans et al. 1983). Interestingly all the above authors use the reduction of C_2H_2 to C_2H_4 to measure nitrogen fixation. There have always been problems with this method when applied to symbiotic systems but these have been highlighted recently (see below). The validity of these studies is, therefore, open to some question. Further, comparison between studies is complicated by variability in plant density, difficulty in recovering nodules, the distribution of the root system, etc.

All reports agree that rates of N_2 fixation (C_2H_2 reduction) are extremely low and are commonly less than 2 kg/ha/year. The variation in the amount of nitrogen fixed was attributed by Lawrie (1981) to be due to differences in nodule number rather than specific activity. She suggests that the best approximation of the significance of N_2 fixation by particular legumes to the ecosystem is an estimate of host abundance and nodule number as recorded by Beadle (1964).

How Much Nitrogen do Acacias Really Fix?

Problems associated with using acetylene reduction to measure nitrogen fixation have been highlighted recently (Minchin et al. 1983, 1986;

Table 1. Host promiscuity; percentage of *Rhizobium* strains which nodulate individual *Acacia* sp.

0–25%	26–50%	51–75%	75–100%	
*armata**	*burrowii*	*aneura*	*acuminata*	*gittinsii*
	cometes	*cambagei*	*amoena*	*gladiformis*
	leiocalyx	*calamifolia*	*auriculiformis*	*hakeoides*
	pendula	*dunnii*	*baileyana*	*holosericea*
	shirleyi	*oxycedrus*	*binervata*	*implexa*
	urophylla	*papyrocarpa*	*blakei*	*iteaphylla*
		prominens	*brachybotrya*	*melanoxylon*
		pulchella	*cyclops*	*microbotrya*
		pyrifolia	*dealbata*	*mearnsii*
		trineura	*deanei*	*mountfordeae*
		verniciflua	*decora*	*myrtifolia*
			decurrens	*notablis*
			dimidiata	*oncinocarpa*
			discolor	*parramattensis*
			elata	*podalyriifolia*
			elongata	*pycnantha*
			extensa	*rubida*
			falcata	*saligna*
			filicifolia	*sophorae*
			fimbriata	*stricta*
			floribunda	*sauvolens*
				ulicifolia var *braunii*
				vestita
				victoriae

* Only tested against three strains (fast-growing).

Table 2. Relative promiscuity of root nodule bacteria isolated from *Acacia* spp.

Fast-growers			Slow-growers		
Rhizobium strains	No. hosts tested	No. nodulated	*Bradyrhizobium* strains	No. hosts tested	No. nodulated
CC405	60	58	NU281	58	57
QA4310	60	56	CB891	59	57
CC404	59	53	QA309	52	50
NA1550	61	55	WU400	60	57
TA201	58	52	QA306	57	54
CB1749	61	54	NU286	58	55
CB2883	63	54	WU337	58	54
NA1559	58	44	CC403	59	55
CC406	58	43	NU284	60	55
NA1542	60	44	NA848-1	47	43
NA1543	59	43	W115	59	53
CB2986	58	42	CB2133	56	46
NA1553	60	43	MAR1002	57	45
NU283	57	40	QA307	60	44
NA1548	61	42	MAR1030	59	39
CB2962	60	40	QA1071	59	36
NA1545	58	38	MAR1016	55	29
NA1547	62	40	QA313	60	27
NA1544	59	38			
NU258	58	24			

Witty et al. 1984, 1986). The situation is reviewed by Witty and Minchin (1986). These authors indicate the first assumption of the method that the assay does not affect rate of nitrogenase activity is invalid as both exposure to acetylene and disturbance of nodules have a major effect on activity. Their work demonstrated that the effect is due to O_2 limitation of bacteroid respiration resulting from increased resistance of the nodule to O_2 diffusion. Shaking root systems may reduce maximum activity by 75% (Minchin et al. 1986). Because stressed nodules have increased resistance to gaseous diffusion they will be less affected by disturbance than unstressed nodules offsetting real differences in activity (Witty and Minchin 1986).

The difficulty of recovering all nodules has long been recognised as a problem and as treatments can affect nodule distribution or a root system unreal treatment differences may be seemingly apparent.

Further difficulties occur in obtaining values for rate of nitrogen fixation from rates of acetylene reduced. The theoretical ratio itself has been shown to vary according to treatment (e.g. strain of *Rhizobium*; Witty and Minchin 1986).

It is an enigma in this centenary year of the discovery of the causal organism of nitrogen fixation that simple reliable methods of measuring nitrogen fixation are still not readily available. Methods such as the comparison of the nitrogen content of non-nodulated plants with that of nodulated ones, using ^{15}N to distinguish between nitrogen derived from soil from nitrogen fixed by nodules are possible alternatives. Attempting to measure the amount of nitrogen fixed in the complex environment in field studies before refining methods using plants growing in containers may make a difficult task even harder.

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Inoculation of Acacias with Mycorrhizal Fungi: Potential Benefits

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MYCORRHIZAS, symbiotic associations between plant roots and beneficial soil fungi, are formed by the vast majority of woody plants and they function to enhance nutrient uptake particularly in infertile soils (Trappe 1977). Many trees require mycorrhizas to survive and grow in natural forest ecosystems and research has demonstrated that, in certain situations, the productivity of trees in plantations can be increased by inoculating seedlings in the nursery with selected mycorrhizal fungi (Marx 1980; Garbaye and LeTacon 1986). To date, however, the potential for using mycorrhizal inoculation to improve the growth of hardwood plantings in tropical areas has been neglected (Mikola 1980).

The purpose of this review is to draw attention to the potential for using mycorrhizal fungi to improve the survival, establishment and growth of hardwood species in tropical plantations. Within this context, special attention is paid to the very limited information available on the mycorrhizal requirements of the acacias and their responses to inoculation with mycorrhizal fungi in both nursery and field.

Mycorrhizal Associations in Woody Plants

Two major groups of mycorrhizas are recognised on the basis of infection morphology: ectomycorrhizas and vesicular-arbuscular (VA) mycorrhizas.

Ectomycorrhizas are characterised by: (i) the development of an extensive fungal sheath around the short lateral roots; and (ii) the penetration of the fungus between, but not into, the cells of the root cortex. Ectomycorrhizas occur on forest trees belonging to the Pinaceae, Dipterocarpaceae, Myrtaceae, Fagaceae and Betulaceae, as well as some members of the Euphorbiaceae, Sapindaceae and Leguminosae—especially the Caesalpinioideae group (Alexander and Hogberg 1986) and certain *Acacia* spp. (Table 1). These mycorrhizas are formed by a large range of fungi (mostly Basidiomycetes). Some of these fungi show a high degree of specificity to their host trees while others have a broad host range (Trappe 1977; Malajczuk et al. 1982).

VA mycorrhizas are by far the most widely distributed; they occur on the great majority of vascular plants and in virtually all terrestrial habitats, from deserts to tropical forests. VA mycorrhizas are harder to recognise than ectomycorrhizas as they have no fungal sheath and cause little change to the external appearance of the root. In these associations, VA mycorrhizal fungi penetrate the cells of the plant root and spread within the cortex forming distinctive intracellular structures: arbuscules and vesicles (these structures can only be observed under the microscope following special staining techniques—Bevege 1968). Important tropical tree genera that form VA mycorrhizas include gymnosperms such as *Agathis, Araucaria* and *Podocarpus*, many rainforest hardwoods and most legumes (*Acacia*—see Table 1, *Albizia, Leucaena, Prosopis, Pterocarpus* and *Dalbergia*). Four genera of fungi form VA mycorrhizas, and unlike the ectomycorrhizal fungi show little or no host specificity. Some forest trees (e.g. eucalypts, acacias, casuarinas) are capable of forming ecto- and VA mycorrhizas.

Both ecto- and VA mycorrhizas increase plant growth by enhancing absorption of nutrients from soil. Networks of fungal hyphae extend from the mycorrhizal roots into the surrounding soil. These hyphae function as extensions to the plant root system, effectively increasing the volume of soil from which nutrients can be extracted. Mycorrhizas are particularly important for the uptake of nutrients that are immobile in soils (P, Zn, Cu, NH_4^+), although they are probably also important for uptake of more mobile nutrients (NO_3^-, SO_4^{2-}, K) in highly competitive situations (e.g. agroforestry) and in young plantations where trees have low rooting intensities (Bowen 1985). It should be stressed that in most ecosystems mycorrhizas are the normal 'mode' of plant nutrition, not the exception—tree nutritional studies which neglect the mycorrhizal factor can be misleading.

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Table 1. Reported mycorrhizal status of *Acacia* spp.*

Mycorrhizal type	*Acacia* species
ecto	*aneura, dealbata, decurrens, melanoxylon, mitchellii, pycnantha, platycarpa, retinodes, rubida, salicina, sophorae, sparciflora, verticillata*
VA	*albida, arabica, aulacocarpa, auriculiformis, concurrens, constricta, cyanophylla, farnesiana, floribunda, goetzei, greggii, holosericea, latescens, mangium, mellifera, nigrescens, nilotica, nubica, polyacantha, pulchella, pyrifolia, raddiana, richi, saligna, senegal, seyal, suaveolens, torulosa, yirrkallensis.*
VA and ecto	*myrtifolia, redoxylon, rothii, simsii.*

* This listing is compiled from the published literature and a number of other sources. It is probable that when examined, all *Acacia* species will be found to be VA mycorrhizal. Many species may be able to form ectomycorrhizas, but this requires further investigation.

Tree Responses to Inoculation

There are numerous reports of mycorrhizal fungi (ecto and VA) stimulating the growth of tree species, both in nurseries (Kormanik et al. 1977, 1982; Marx et al. 1976; Theodorou 1984) and field plantings (Theodorou and Bowen 1970; Marx et al. 1977; Momoh and Gbadegesin, 1980; Delwaulle et al. 1982; Garbaye and LeTacon 1986). These responses to mycorrhizal inoculation have been recorded on a diverse range of planting sites, from adverse, poor quality sites (e.g. mine spoils and severely eroded areas) to more routine reforestation sites (Marx 1980).

Factors which influence tree response to mycorrhizal inoculation in the field include: (i) the tree species—some species are more dependent on mycorrhizas than others, often a reflection of their rooting intensity and nutritional requirements; (ii) the fertility of the planting site—the less fertile the site, the larger the response tends to be; (iii) the species composition and population level of the naturally occurring mycorrhizal fungi; and (iv) the persistence, competitiveness and effectiveness in promoting plant growth of the introduced fungus compared with the naturally occurring fungal population (Bowen 1985). Generally, the most dramatic increases in tree growth occur following mycorrhizal inoculation of introduced tree species that have not previously been grown in an area (for example, pines in Africa, see Momoh and Gbadegesin 1980) or where the planting site has been severely disturbed and lacks a native mycorrhizal population. Nevertheless, even in situations where there is an existing population of mycorrhizal fungi, beneficial growth responses to inculation with mycorrhizal fungi can occur (see Theodorou and Bowen 1970; Marx 1980; Garbaye and LeTacon 1986). These responses reflect differences in effectiveness between fungal species in their ability to promote tree growth under the site conditions, and illustrate that plantation productivity can be increased by inoculation with selected fungi.

Although most growth responses to mycorrhizal inoculation can be attributed directly to increased nutrient uptake, mycorrhizas may also benefit tree performance by reducing the impacts of drought and transplantation stresses (Parke et al. 1983; Menge et al. 1978), extreme soil conditions (e.g. high soil temperatures, low pH—see Marx 1980) and some soil-borne pathogens (Marx 1973).

Acacia Mycorrhizas

Many N_2-fixing trees and shrubs are especially dependent on mycorrhizas to absorb nutrients required for plant growth and efficient N_2 fixation. There are reports of both ecto- and VA mycorrhizas on *Acacia* species, with VA mycorrhizas seemingly predominant (Table 1). However, the importance of ectomycorrhizas for *Acacia* growth has not been adequately assessed.

Acacias have responded to inoculation with VA mycorrhizal fungi in pot experiments (Cornet and Diem 1982; Chang et al. 1986; D. Jasper, pers. comm.) and under field conditions following inoculation of seedlings in the nursery (Cornet et al. 1982). Cornet and Diem (1982) found that in a pot experiment with a phosphorus-deficient soil that had been sterilised to kill the native population of mycorrhizal fungi, inoculation of *Acacia raddiana* (= *A. tortillis* ssp. *raddiana*) and *Acacia holosericea* with the VA mycorrhizal fungus *Glomus mosseae* increased shoot weights by 170% and 850% respectively, and nodule weights by 10–12-fold (all pots were also inoculated with *Rhizobium*). Similar growth responses occurred when these two *Acacia* species were supplied with phosphate fertiliser instead of being inoculated with the mycorrhizal fungus. In a treatment in which the soil was not sterilised the effects of the introduced VA mycorrhizal fungus were masked by the native VA fungal population. This study also indicated a beneficial effect of mycorrhizas in enhancing the drought tolerance of *A. raddiana*.

Nursery and field responses to inoculation of *Acacia holosericea* with both a VA mycorrhizal fungus and a *Rhizobium* are recorded in Senegal (Cornet et al. 1982). Compared to plants inoculated with *Rhizobium* only, dual inoculation (both *Rhizobium* and VA mycorrhizal fungus) increased seedling growth in the sterilised nursery soil by almost 50%. Following outplanting the dual inoculated plants performed better than those inoculated with *Rhizobium* only. However, the relative effect of mycorrhizal inoculation diminished with time and 7 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 the uninoculated plants by the natural population of VA mycorrhizal fungi at the planting site. Even though in this example the effect of inoculation with the mycorrhizal fungus was only temporary, its short-term influence on plant growth may make the difference between initial success or failure of seedling establishment especially in semi-arid areas and other stressful environments. A further finding of the study was that following outplanting there was much less variability in growth amongst plants inoculated in the nursery with the mycorrhizal fungus than amongst the uninoculated plants. A somewhat similar effect in which ectomycorrhizal infection masked genetic differences in plant growth between several genotypes of *Pinus elliottii* has been shown (Marx and Bryan 1971). This suggests that perhaps mycorrhizal fungi compensate for genetic differences that occur between individual trees in their efficiency of root function.

Prospects for Forest Nurseries

Mycorrhizal fungi clearly benefit tree growth, both in the nursery and following outplanting, but what are the prospects for adoption of mycorrhizal inoculation as a routine nursery procedure? Is there a general need for mycorrhizal inoculation in nurseries? Are there any criteria by which we can predict whether the introduction of a selected mycorrhizal fungus to a nursery will be successful? What level of increase in tree performance could be expected in the long term?

These questions are extremely difficult to answer because we need to know a great deal more about the mycorrhizal requirements and dependency of potential plantation species in tropical areas. Mycorrhizal inoculation of nursery stock should certainly be considered when exotic, potentially ectomycorrhizal tree species are introduced to an area for the first time—these trees may be obligately dependent on relatively specific mycorrhizal fungi for their survival and growth (for example, there is some evidence that the failure of dipterocarps to regenerate in logged areas is due to the absence of their specific mycorrhizal associates—Smits 1983). Inoculation is also likely to benefit growth of trees to be planted on mine spoils and degraded and eroded sites where the native mycorrhizal fungal population is low or non-existent. Other opportunities for the successful application of mycorrhizal fungi arise in situations where the native population of ecto- and VA mycorrhizal fungi in the nursery soil is eliminated by routine fumigation or pasteurisation procedures used to control pathogens. In these cases selected ecto- and VA mycorrhizal fungi can be successfully introduced into the nursery without competition from an existing, possibly less effective background population of mycorrhizal fungi. For details of mycorrhizal inoculum production and inoculation methods see Trappe (1977), Marx et al. (1982), Theodorou (1984), and Menge (1984).

In this review we have outlined the important effects of mycorrhizas on tree growth. The basic technology for introduction of mycorrhizal fungi into forest nurseries does exist and should be encouraged where possible. With many plantation species mycorrhizas may not cause spectacular growth increases. Judicious selection of the most appropriate tree species for the particular site conditions is more likely to be important. Mycorrhizal fungi should be considered as another component of the plantation 'forest system' (together with tree genotype and silvicultural technique) that can be manipulated and managed to increase productivity and reduce requirements for fertiliser inputs.

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Reproductive Biology of Acacias

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AUSTRALIAN acacias have great potential for exploitation and are widely used around the world for timber, tanning, animal feed, fuelwood, agroforestry, ornamental horticulture, soil stabilisation, soil enrichment and essential oil production. Despite their wide range of uses there has been relatively little plant improvement effort devoted to acacias, and genetic constraints are still one of the major limitations to productivity. Essentially we are dealing with wild species with wide variability for economic characters. Plant breeding and selection work, for maximum returns for minimum inputs, requires a detailed knowledge of the reproductive biology of the species. Techniques for manipulation of the flowering and breeding systems are not generally available for Australian acacias. Recent research has greatly improved our understanding of the reproductive biology of the genus, but further detailed work is required on the species of particular interest.

Flowering

After the juvenile phase, *Acacia* plants normally flower each year. Floral buds are produced in all months of the year in *Acacia pycnantha* yet the trees flower only once a year in late winter (Buttrose et al. 1981). Buds produced during pod growth are generally shed from the plant, possibly due to competition between the developing pods and flower buds. Those buds which are produced immediately after seed shed develop more slowly than those which appear later in the season, with the result that flowering occurs only once a year.

The effects of temperature and light intensity on the flowering of *A. pycnantha* were studied by comparing development under ambient southern Australian conditions, in a controlled-temperature glasshouse, and under shadecloth (Sedgley 1985). Floral initiation, detected microscopically, occurred under all conditions. In the plants under 70% shadecloth floral development was inhibited at an early stage and the plants never reached anthesis. This may prevent flowering on shaded parts of the plant which would have a reduced chance of setting seed. There have been no studies of the effects of photoperiod on flowering of acacias, although it has been suggested that the strictly defined flowering seasons may be an effect of daylength change (Davies 1976; Newman 1936).

Temperature has a major effect on the flowering of *A. pycnantha*. In a glasshouse with the temperature controlled to a mean of 28 °C during the day and 16 °C during the night, floral development proceeded normally until the beginning of winter. Under ambient southern Australian conditions anthesis occurred in late winter whereas the plants in the glasshouse did not flower and the buds were shed. Microscopical investigation showed that the development was arrested at ovule and anther development and that megasporogenesis had not occurred. In winter the maximum and minimum temperatures were 8–9 °C higher in the glasshouse than outside, suggesting that flowering was affected by the temperature difference. Meiosis in the anther and ovule appeared to be inhibited by a temperature above 19 °C. This may explain why *A. pycnantha* flowers only in winter, despite the fact that flower buds are produced during every month of the year.

Transferring plants between the two environments appeared to support this idea. Plants transferred from outside to the glasshouse in early winter did not flower. Those transferred from the glasshouse to outside generally flowered although for a shorter period and there were fewer flowers per plant. This may suggest that irreversible inhibition of floral development can occur if the plants experience high temperatures for too long a period.

The results suggest that flowering of acacias involves a number of sequential processes and that different steps are sensitive to varying environmental conditions. Thus it may be possible to

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manipulate the flowering of acacias by controlling the conditions during floral growth.

Water availability is a factor in determining whether or not acacias will flower, particularly in the arid-zone species. *Acacia aneura* may flower during any month after rain has fallen, but the main flowering periods are summer and winter even if additional water is supplied (Davies 1976; Doran et al. 1983; Preece 1971).

Acacia flowers occur in spherical or cylindrical inflorescences which may be grouped into racemes. They are usually cream or yellow and the colour is contributed by the filaments of the stamens. The flowers are usually hermaphrodite with four to seven sepals and petals, numerous stamens and a single ovary with up to 20 ovules. In some species male flowers with reduced ovary development also occur. The pollen grains are grouped into composite structures called polyads consisting of 4, 8, 12, 16, 32 or 64 grains. The most common number in the genus is 16.

Breeding Systems

High rates of outcrossing have been reported in a number of *Acacia* species (Coaldrake 1971; Moffett 1956; Philp and Sherry 1946). There are three floral mechanisms in acacias which promote outcrossing. Many species show protogynous dichogamy with the stigma receptive to pollen before the pollen is released from the anther (Bernhardt et al. 1984; Newman 1934). Andromonoecy with male and hermaphrodite flowers on the same plant also promotes pollen transfer from flower to flower (Newman 1933; Sinha 1971) as does self-incompatibility, the failure of pollen to produce seed set in the same and related individuals (Kenrick and Knox 1985; Zapata and Arroyo 1978).

Pollen is transferred from flower to flower and from plant to plant by animal vectors. Bees appear to be the most important group although other insects and birds may also transfer pollen (Bernhardt and Walker 1984, 1985; Ford and Forde 1976). Vectors are attracted to the plants of Australian species by extrafloral nectaries located on the petiole or on the phyllode. The nectar consists of carbohydrate, protein and lipid and is secreted all year round by specialised secretory cells in the centre of the nectary (Marginson et al. 1985a, 1986). The structure of the nectary may be of taxonomic significance (Boughton 1981). When pollen is transferred from the anther to the stigma of the flower, the stigma responds by producing an exudate. Some secretion is present before pollination, but a large increase in the volume of exudate is stimulated by both self and cross intraspecific, interspecific and intergeneric pollinations (Marginson et al 1985b). Intraspecific and interspecific pollinations involving fresh pollen resulted in pollen germination on the stigma and pollen tube growth in the style of *A. iteaphylla* and *A. baileyana*. Non-pollen cells and non-living particles did not stimulate the secretion. The post-pollination secretion is probably a mechanism to facilitate the germination of all the pollen grains of the polyad, including those which are not in direct contact with the stigma surface.

Conclusion

There is still relatively little information available on the reproductive biology of acacias and very few of the approximately 800 Australian species have been investigated so far. Nevertheless our knowledge of flowering constraints and outcrossing mechanisms can be developed for manipulation of the genus. Hybridisation followed by selection of the progeny for improved characteristics for timber production and quality is an important requirement. Flowering may be manipulated by controlling the environmental conditions during floral development. Reliable hybridisation techniques may be developed by exploiting the outcrossing mechanisms of the flowers. A knowledge of the most fertile female stage of the flower can reduce the number of labour-intensive hand pollinations which need to be performed. In a strongly self-incompatible species emasculation may not be necessary and reliable hybrids may be produced with relatively little effort. A knowledge of the breeding system of the species of interest is essential before reliable crossing methods can be developed. In general the species which have been studied to date are those native to temperate southern Australia. Research into the reproductive biology of the more tropical species, with potential for developing countries, is now required.

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Treatments to Promote Seed Germination in Australian Acacias

J. C. Doran and B. V. Gunn*

THE seed coat of most *Acacia* species is characterised by a 'hard' water-impermeable seed coat. The protection this endows assists seed longevity but means that, before imbibition and germination can take place, the seed coat must be subjected to processes, either natural or artificial, that make it permeable to water. In contrast to the regular pattern, however, there are several *Acacia* species which have a 'soft' seed coat and pretreatment before sowing may be unnecessary or even lethal (*A. argyrodendron, A. cambagei, A. cyperophylla, A. georginae, A. harpophylla, A. latzii, A. maconochiana*). Species which have displayed sensitivity to prolonged heating but have given enhanced germinations under moderate heat pre-treatments (e.g. 90 °C for 1 min include: *A. aneura, A. pachycarpa, A. pendula, A. stenophylla, A. tephrina*, and *A. xiphophylla*.

Cavanagh (1985) believes that of the several layers of cells forming the relatively thin *Acacia* seed coat (testa) it is the continuous layer of tightly-packed, elongate Malpighian cells (Fig. 1) directly below the water permeable cuticle which provide the main barrier to water penetration. The Malpighian zone which varies in thickness both within and between species comprises about 36% of the total thickness of the seed-coat. It has also been found that under natural conditions and after most artificial treatments the first site at which water penetration occurs is the lens (Fig. 2). The lens is a site of structural weakness in the seed-coat comprised of shortened Malpighian cells loosely attached to the mesophyll tissue by thin-walled weak cells which rupture under the stresses induced by heating (Tran and Cavanagh 1984).

Acacia seeds are extremely variable in their characteristics. For example, size, shape and colour vary enormously both within and between species, and, more importantly in terms of the interaction between pretreatments and seed sensitivity, the degree of hardseededness varies greatly between species, between seedlots of the same species and between seeds of the same seedlot. The proportion of hard seed in a sample depends on the environmental conditions during the growth of the plant, the degree of maturation of the seeds when collected and the length of the storage period. It is not surprising then that workers have found it difficult to prescribe an 'optimum' treatment (or range of treatments) that is highly effective in stimulating germination in most *Acacia* seed.

The ACIAR-funded seed collecting project and various FAO-sponsored collections in the arid zone of Australia managed by CSIRO Division of Forest Research (DFR) has meant an increasing accession of seed of lesser-known *Acacia* species and provenances to the Division's Tree Seed Centre. It soon became apparent to staff of the Centre that the boiling water treatment (pour and soak) that, until that time, had been routinely applied to *Acacia* seed to break dormancy was giving erratic and frequently sub-standard results with the wide range of species and provenances under test. There was a need to determine a simple, efficient and more reliable method (or methods) for treating the seed for germination tests and also to prescribe to growers at the various ACIAR field trial sites. This paper discusses some of the tests that have been undertaken to date aimed at meeting this objective.

Materials and Methods

From the ACIAR priority listing of acacias, 16 species of apparently high potential for widespread planting were chosen as candidates for these experiments. Twenty-seven seedlots (1 species × 3 seedlots, 9 species × 2 seedlots and 7 species × 1 seedlot) were selected from store to represent these species (Table 1). Most were bulk lots representing different provenances and of seemingly good quality but had been collected at different times, undergone different extraction processes, and had been held in a common air-tight room temperature (24 °C) storage regime for different lengths of time (1.5–4.5 years). This storage regime and duration

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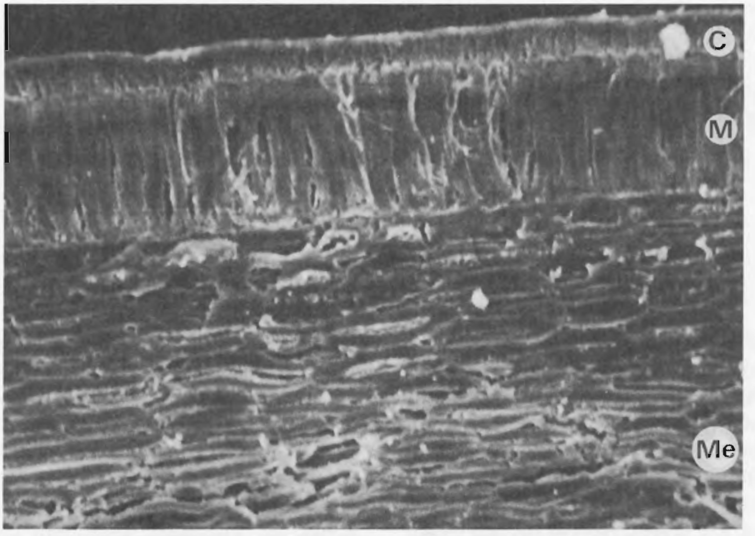

Fig. 1. Scanning Electron Micrograph showing a section through seed coat of *A. aneura*.
C = Cuticle M = Malpighian cells,
Me = Mesophyll cells. Magnification = × 300.

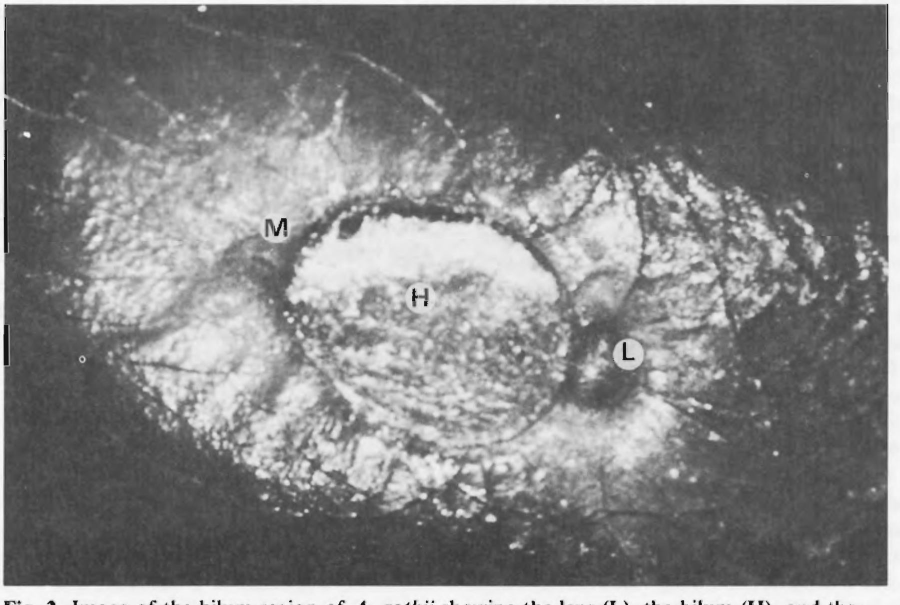

Fig. 2. Image of the hilum region of *A. rothii* showing the lens (L), the hilum (H), and the micropyle (M).

Table 1. Provenance details of the seedlots used in the germination trials.

DFR Seedlot No.	Collection locality	Lat. (°S)	Long. (°E)	Alt. (*m*)	No. of parent trees
A. ampliceps					
14631	Wave Hill, NT	17°26′	130°56′	230	10
A. aneura					
13719	Vaughan Springs, NT	22°12′	130°55′	600	10
A. cincinnata					
13864	Shotheel, Qld	16°57′	145°38′	440	5
A. crassicarpa					
13683	Oriomo Plateau, PNG	8°49′	143°00′	20	15
A. mangium					
15063	Mossman, Qld	16°31′	145°24′	65	100
A. mearnsii					
14769	Queanbeyan, NSW	35°29′	149°16′	670	12
A. melanoxylon					
14766	Samford, Qld	27°22′	152°47′	300	4
A. stenophylla					
14670	Cow Creek, WA	18°41′	128°21′	340	10

would normally ensure that hardseededness was fully developed.

From each seedlot varying numbers of 100 seed (25 seeds × 4 replicates) and 60 seed (20 seeds × 3 replicates) subsamples were removed from each seedlot with the deliberate exclusion of poor quality seeds (insect attacked, shrunken) and subjected to all or some of the presowing treatments described in Table 2. Except for the control (no pretreatment) and hot tap water (~ 70 °C) which was included for comparison purposes, all treatments were known to enhance germination in at least some acacias.

After treatment each 20- or 25-seed replicate was placed in a 9 cm glass petri dish containing vermiculite (7 g) moistened with 30 ml of distilled water. Three or four replicates representing each treatment were placed in a germination cabinet set at the recommended germination temperature for the particular species (a constant 25 or 30 °C depending on species) with light for 8 hours per day.

Seed were considered to be successfully germinated when their radicles had reached the same length as the seed. Germination counts were made at regular intervals up to a maximum of 27 days. On counting, germinated seed were removed from the dishes, extra distilled water added when required and replicates badly affected by fungi sprayed with a solution of Karathane (0.8 g/litre). Fungal attack was so bad in lots where the treatment had been too severe that 'squash' test counts of viable but ungerminated seeds at the end of the test were not feasible. The calculation of cumulative germination percentages by seedlot, treatment and time were based on actual germination over total seed sown.

Results and Discussion

Graphs indicating the mean cumulative germination percentage versus treatment over time were constructed for each seedlot, and examples are given in Fig. 3. An analysis of variance was undertaken on arcsine-transformed percentages of the final count. In Fig. 3, final counts covered by the same vertical line were not significantly different at the 5% level (using t-test).

0 Control—As anticipated untreated seed of this suite of species largely gave low levels of germination usually in the range of 0–10% after 27 days of incubation. In the instances where 20% (*A. aneura*) and 50% (*A. auriculiformis* 13854) of untreated seed germinated, mechanical fracturing of the seed-coat during extraction rather than inherent lack of hardseededness is suspected as the reason for these atypically high figures.

1 Manual nicking—This treatment was best or near best in final germination percentage and rate of germination in all but a few instances (e.g. *A. coriacea* 13768) clearly showing its reliability over a wide range of *Acacia* species and supporting the view that final percentage germination following this operation approximates closely to the germination capacity of the seedlot.

Manual nicking or similar techniques are recommended as methods for pretreating *Acacia* seed

Table 2. Description of the presowing treatments applied to the *Acacia* seedlots.

Graph code	Treatment name	Description
0	Control	no pretreatment
1	Manual nicking	using nail clippers, a small piece (about 1 mm^2 of the seed coat was removed at the distal (cotyledon) end of each seed, and the seed sown immediately
2	Boiling water, pour and soak	*former standard treatment* seed were placed in glass beakers and 10 times the volume of boiling water added; they were left to soak in the gradually cooling water for 1 hour and then sown
3	Boiling water, immersion for 1 min	seed were contained in perforated plastic baskets and immersed in a container of boiling water for 1 min, then removed and sown immediately
4	Boiling water immersion for 2 min	as for 3, with 2 min immersion in boiling water
5	Boiling water immersion for 5 min	as for 3, with 5 min immersion in boiling water
6	Acid (H_2SO_4) scarification	seed were immersed in undiluted sulphuric acid (95%, 36N) at room temperature (24 °C) for a period of 30 min; after treatment the seeds were washed under cold running tap water for 10 min and then sown immediately
7	Hot water, 80 °C for 120 min	seed contained in perforated plastic baskets were immersed in a water bath at 80 °C for 12 min then sown
8	Hot water, 90 °C for 1 min	seed contained in perforated plastic baskets were immersed in a water bath at 90 °C for 1 min then sown
9	Hot water, (ca. 70 °C) pour and soak	seed were placed in glass beakers and 10 times the volume of hot-tap water (ca. 70 °C) added; they were left to soak in the gradually cooling water for 1 hour and then sown

before germination tests (ISTA 1985) and when sowing small and valuable research seedlots. The disadvantages are slowness of application and the care required not to cut away too much of the seed thus damaging the cotyledons and embryo.

2 Boiling water, pour and soak—These results confirmed our earlier observation that this treatment gives erratic performance in its effectiveness to break dormancy. While in some cases the technique gave results similar to nicking, in many instances it was significantly worse than this technique and some of the alternative hot water treatments.

Because of its erratic performance, this technique is no longer recommended as a standard method for pretreating *Acacia* seed at the DFR Tree Seed Centre.

3/4 Boiling water, immersion for 1 and 2 min.—In all but three species, these treatments gave reliable and effective enhancement of germination. Final figures regularly showed little difference to treatment 1 and were in several instances far superior to those achieved with the former standard pretreatment (treatment 2). The exceptions were *A. aneura* and *A. melanoxylon* where both immersion times were significantly worse than treatment 1 and *A. stenophylla* where boiling water treatments were generally too harsh.

5 Boiling water, immersion for 5 min.—Of the treatments applied in this series of experiments, this technique gave, by far, the most variable performance both between species and especially among seedlots of the same species. In extreme cases this treatment gave excellent enhancement of germination with no fungal attack in one seedlot, but when applied to the other seedlot of the same species it proved too severe, giving low germination percentages and severe problems with fungi (e.g. *A. aneura, A. coriacea, A. mearnsii, A. melanoxylon*).

Despite the good results achieved with some seedlots (e.g. *A. ampliceps, cowleana, crassicarpa*), the results overall suggest that this technique is frequently too harsh and should not be routinely applied to *Acacia* seeds to break dormancy.

6 Acid scarification—Immersion in acid leaves the seed coat dull and shallowly pitted. It is a more

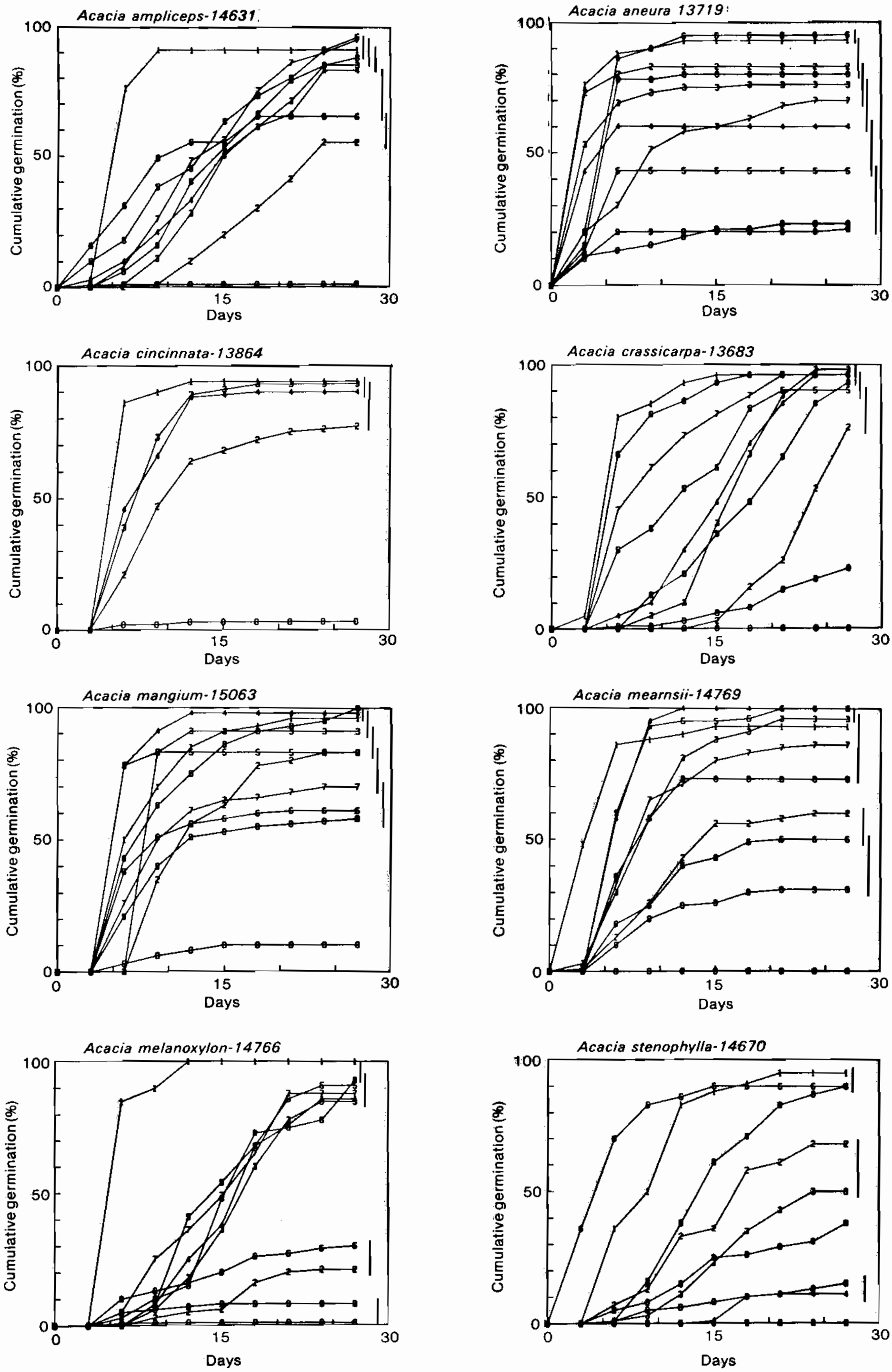

Fig. 3. Mean cumulative germination percentage by presowing treatment and time for eight *Acacia* seedlots. The final counts covered by the same vertical line were not significantly different at the 5% level (using *t*-test).

effective method than boiling water for many African acacias and is in regular use throughout Africa (Doran et al. 1983). Acid scarification, however, has seen little use in Australia most likely because of the effectiveness of easier and safer methods of pretreating local *Acacia* seeds.

Few conclusions can be drawn from the current series of experiments because only 11 seedlots (1 per species) were tested and only one relatively brief immersion time (30 min.) applied. Interestingly, in the case of *A. stenophylla* and *A. aneura*, where there was evidence of some sensitivity of these species to boiling water treatment, acid scarification gave excellent results supporting Cavanagh's (1985) view that acid treatment may well be more suitable for those lots which are adversely affected by heat. This technique, therefore, warrants much closer study.

Hot water treatments—Concern that boiling water treatments may prove too severe causing death of the embryo and high levels of mortality has led some workers to look at the effectiveness of hot as opposed to boiling water treatments. Hot water treatment (90°C for 30–60 sec) is now widely used on *A. mearnsii* seed in South Africa (Poggenpoel 1978) and deserves more attention in Australia.

7 Water at 80°C for 120 min—While showing some potential with some seedlots (e.g. *A. ampliceps, crassicarpa, melanoxylon*), this technique proved substandard with others (e.g. *A. aneura, A. mangium*) and, in several instances, caused unduly high mortality and serious fungal problems (e.g. *A. auriculiformis, A. coriacea, A. cowleana, A. stenophylla* and *A. tumida*).

This evidence suggests that this treatment is frequently too harsh and should not be routinely applied to *Acacia* seed to break dormancy.

8 Water at 90°C for 1 min—Generally this technique proved to be one of the most effective of those tested giving a high final germination percentage, good germination rate and no fungal problems in the dishes. Although the germination rate was lower than those achieved with nicking and acid, it gave equal final germination percentage to these techniques and proved far superior to the boiling water treatments when applied to *A. stenophylla* 14670. This result indicates the potential of this technique in pretreating the more heat-sensitive species.

9 Hot tap water (ca. 70°C)—The results clearly demonstrate the general ineffectiveness of this method which is sometimes applied by the inexperienced in pretreating *Acacia* seed. Under no circumstances can we recommend this method for breaking dormancy of Australian acacias.

In addition to the above 10 treatments, two other methods, namely dry heat at 100°C for 120 min and microwave energy where dry seed was treated for 100 sec (Sharp Carousel microwave oven, 2450 MHz at 650 W), were tried. Results from these two treatments were poor and have therefore not been included. More recent microwave tests on *A. mangium* indicate some success for exposure times of 10–15 min.

Potential for Storage and Distribution of Treated Seed

Nursery failures with acacias are all too common and are usually blamed on poor seed quality. It has been our experience that a substantial proportion of these failures can be directly linked to inappropriate presowing treatments (e.g. no pretreatment, using hot water from the tap, etc.).

To help avoid this wastage of resources we are presently looking at the feasibility of pretreating seed of the most popular species, storing them in airtight, refrigerated conditions until required and distributing them in hermetically sealed packages ready for immediate sowing on receipt at the nursery. Preliminary trials on manually nicked seed of *A. aneura, A. mangium* and *A. mearnsii* gave encouraging results in laboratory trials, and now with the acquisition of a machine scarifier for evaluation we are in a position to scale-up the testing of this procedure.

Conclusions

While recognising that we are dealing with a highly variable subject, there is nevertheless a need to specify a standard pretreatment method (or range of methods) that, despite the individuality of *Acacia* seedlots, gives reliable enhancement of germination of a wide range of species. In addition, the method(s) need(s) to be easy to apply, even under primitive field conditions, and easily repeated.

From this series of experiments and other data at DFR, three methods stand out as worthy of adoption as standard techniques for pretreating hard-coated Australian acacias, at least until more is known about individual species requirements. They are: *Manual nicking*—recommended for the treatment of seed for germination tests and when propagating small and valuable research lots; *Boiling water, immersion for 1 min.*—recommended as a standard treatment appropriate for many hard-coated *Acacia* seedlots. As well as being highly effective in breaking dormancy it is easy to apply and reproduce with a minimum of equipment. The similar performance of the 2 min immersion treatment means that, if by mistake, seedlots are left slightly longer than 1 min in boiling water then this is unlikely to adversely affect the results; and *Hot water, 90°C for 1 min*—recommended for hard-coated seedlots that are suspected of being sensitive to boiling water treatment (e.g. *A. stenophylla*).

Although requiring more testing before adoption as a routine procedure, the storage and distribution of pretreated *Acacia* seed from centres where pre-treatment methods can be optimised is worthy of serious consideration.

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Micropropagation of *Acacia mangium* and *Acacia stenophylla*

D. F. Crawford and V. J. Hartney*

In recent years the potential use of Australian acacias as exotics has been realised. The benefits of using selected material for planting are also known.

Vegetative propagation of selected clones is a valuable tool for any tree improvement program, even if the commercial plantations are based on seedlings. Clones can be used directly in clonal plantations or as parent trees in clonal seed orchards. Plant tissue culture is a form of vegetative propagation with many advantages: only a small space is required; there is a high multiplication rate and the plant material is free of specific pests and diseases (Hartney 1982).

In this study seedling material of *Acacia mangium* and *A. stenophylla* was used to investigate the possible use of tissue culture as a means of propagating acacias.

In Australia *A. mangium* has a limited distribution in North Queensland and is a fast-growing tree (to 30 m tall). Its fast growth rate and ability to control *Imperata* grassland make it an attractive exotic species (Turnbull 1984).

Acacia stenophylla is found in drier regions, having an extensive distribution in central and eastern Australia. It is typically a small tree, 4–10 m tall (Turnbull pers. comm.) and has a moderate to fast growth rate in cultivation (Whibley 1980).

Methods

Seeds without any obvious damage were selected and the aril removed (*A. mangium*, November 1985, CSIRO seedlot 15238 north of Cardwell, Queensland, altitude of 3 m; *A. stenophylla*, November 1981, CSIRO seedlot 13488 southeast of Windorah, Queensland, altitude 120 m). These were treated with 75% ethanol to remove waxes, surface sterilised in 4% sodium hypochlorite for 20 min and then washed in sterile water. Seed was pretreated for germination by removing a small piece of the seed coat with a scalpel in a sterile transfer chamber. The seeds were then placed onto a sterile basal medium (Table 1).

Table 1. Composition of the media used.

	Basal	Shoot multiplication
Murashige and Skoog salts (minus growth factors)	Full strength	Half strength
Sucrose	3.0%	2.0%
Agar	0.8%	0.8%
Benzylaminopurine	—	1μM
Naphthaleneacetic acid	—	1μM

After 2.5 weeks shoots of normal, well-developed seedlings were severed just below the cotyledons and placed onto a shoot multiplication medium (Table 1). This medium has been successfully used by Hartney (1982) to produce rapid shoot growth in *Eucalyptus* explants.

Plantlets of *A. mangium* were hardened by replacing the plastic screw lids with Sealwrap. After 5 days the plantlets were transferred into plastic pots containing a moistened mixture of vermiculite and perlite. These were covered with Sealwrap and placed on saucers containing distilled water.

The cultures and hardened plants were grown under fluorescent lights (cool-white) with a light intensity at the level of the culture tubes of about 40 $\mu Em^{-2}S^{-1}$, a photoperiod of 12 hours and at a temperature of 25 °C (±4 °).

Results

Seedlings of both species grew well on the basal medium. Shoot explants of *A. mangium* grew well on the shoot-multiplication-medium and after 2–3 weeks they also developed new root systems on the same medium.

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Shoot explants of *A. stenophylla* also grew well on the shoot-multiplication medium but did not develop roots on this medium. *Acacia stenophylla* produced taller shoots with fewer nodes compared to *A. mangium*. After 2–3 weeks shoots of both species were sufficiently tall enough for subculturing.

The *A. mangium* plantlets survived hardening and were successfully transplanted into pots.

Discussion

These preliminary results demonstrate that both *A. mangium* and *A. stenophylla* can be multiplied as shoots under axenic conditions. *Acacia mangium* also appears to be a species that is relatively easy to micropropagate, thus opening up the possibility of utilising clones in a tree improvement program.

Research is continuing at the Division of Forest Research on the micropropagation of a greater range of *Acacia* provenances and species. Another avenue of research that will be undertaken is the in vitro inoculation of *Acacia* clones with specific strains of *Rhizobium*. This research could lead to the selection of specific *Acacia/Rhizobium* combinations which produce increased rates of nitrogen fixation or tree growth.

The micropropagation of interspecific hybrids of *Acacia* species is another area of proposed study. Hybrids between *A. mangium* and *A. auriculiformis* which show the high growth rate and good form of *A. mangium*, along with the adaptation of a greater range of sites of *A. auriculiformis*, would be obvious candidates for micropropagation.

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Australian Acacias for Saline, Alkaline Soils in the Hot, Dry Subtropics and Tropics

L. A. J. Thomson*

THERE is an acute need to dramatically increase the scale of revegetation, for fuelwood and fodder production and for soil conservation and shelter, in many hot, dry parts of the world. For example, 18 of the 25 developing countries given by Spears (1983) as having acute fuelwood shortages are located in subtropical and tropical dry zones. This represents a vast area and includes countries such as Kenya, Senegal, Somalia, Sudan, Yemen Arab Republic and Peru where high salinity of soil and water may impede establishment of shrubs and trees. India and Pakistan, countries of medium fuelwood deficit, have extensive areas of saline/alkaline wastelands.

Australia has an extensive tropical and subtropical, dry (< 500 mm) zone, covering 1.7×10^6 km^2 (north of 24°S lat). The woody vegetation of this zone is dominated by the 120 or so species of *Acacia* which occur there. By way of comparison, the other major Australian woody plant genus *Eucalyptus* has about half this number of species in this zone. Many Australian dry-zone *Acacia* species have promise for planting on harsh sites, including saline and/or alkaline soils. Some of their potential uses include: wood production, especially fuelwood (firewood and charcoal) and round timber (posts and small poles); fodder, shade and shelter for animals; and human food reserves during famine (their seeds can be easily prepared for long-term storage).

As well as utilisation of degraded saline sites, some species have a potential role in the rehabilitation of such areas through: protection, shading and mulching of soil surface (their low foliar salt concentrations avoid recycling salt to the soil surface, *cf.* halophytes such as *Tamarix* and chenopods which accumulate high salt concentrations in their shoots); salt binding, especially root-suckering species; soil improvement, and nitrogen-fixation; and lowering saline water-tables (species which coppice following harvesting and rapidly recover leaf area, and transpirational capacity).

This paper provides information on a survey of potentially suitable Australian acacias for planting on saline, alakaline sites in the hot, dry subtropics and tropics, and discusses some of the factors which have constrained their use on these sites in the past.

Species with Potential

The characteristics and potential uses of *Acacia* species from Australia's subtropical and tropical (< 24°S), dry (< 500 mm annual rainfall) zone have recently been reviewed (Thomson, Turnbull and Maslin, paper in preparation). Details of species considered to have potential for planting on saline, alkaline soils are given in Table 1. The most promising species adapted to these conditions, i.e. those with high salt tolerance and several useful traits including a comparatively moderate to fast growth rate and a moderate to high coppicing ability, are *A. ampliceps, A. cuspidifolia, A. ligulata, A. maconochiana, A. salicina, A. sclerosperma, A. stenophylla* and *A. victoriae*.

During a seed collection expedition in Western Australia in March–April 1986 the opportunity was taken to further study some of the promising species. Data on soil properties and mineral composition of phyllodes for natural stands growing on apparently saline sites are given in Table 2.

Discussion

There exists a need for more detailed information and research on the species in Table 1. As most of the data on species characteristics and their potential uses and functions is based upon field observations of natural populations, there is a need to more accurately quantify these values through experimentation. Published and unpublished information has been gathered for some of the more

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promising species and species digests will be published soon (Turnbull 1986) (species 3, 6, 7, 10, 13, 14, 19, 23 and 25) and in CSIRO's *Acacia* leaflet series (species 4, 5, 8, 15, 18).

Together with site rehabilitation and fuelwood production, the production of fodder is a major potential benefit of revegetating salt-affected lands with *Acacia* species. Data in Table 2 indicate that certain *Acacia* species growing in saline environments do not accumulate the high foliar ion concentrations commonly observed for halophytes such as *Atriplex, Suaeda* and *Disphyma* (see Neales and Sharkey 1981); in fact their Na^+ and Cl^- levels are an order of magnitude lower. A number of chenopod halophytes such as *Atriplex* and *Maireana* have a very good potential for fodder production on saline soils, but a disadvantage is their high foliar salt concentrations. Sheep may be forced to reduce their intake of chenopods, especially if their drinking water is brackish or saline, and/or increase their consumption of water when grazing chenopod-dominated shrublands (Leigh 1986). There exists a potential to maximise the fodder potential of salt-affected lands through the establishment of complementary forage plantings of species which accumulate only moderate salt concentrations in their foliage, such as certain acacias, and those which accumulate very high foliar salt concentrations such as certain chenopods.

Supply of Germplasm

Seed supply has been the major constraint to the planting of the species listed in Table 1. Many of the species/provenances of interest are located in remote parts of Australia and only hold mature seed for a brief period. For those few species which hold mature seed over a longer period, e.g. *A. salicina*, it has been difficult to collect adequate quantities of seed because at any one time only a proportion of the crop is at a suitable stage for collection.

In 1986 the Tree Seed Centre DFR/CSIRO received funds from the National Biotechnology Program—Research Grants Scheme of the Australian Government's Department of Industry, Technology and Commerce to collect seed of useful salt-tolerant woody plants. This is part of a collaborative project with Alcoa of Australia Pty Ltd and other organisations, which aims to select and clone superior individuals. In September–November 1986 we are planning to collect seed and root symbionts of salt-tolerant woody plants from inland and northwestern Australia. The focus of these collections will be acacias, especially *A. ampliceps*. Seed of acacias from this and earlier collections will be available from the Tree Seed Centre for research purposes.

Recommendations for Future Research

With the exception of research by the Centre Technique Forestier Tropical (France) into the introduction of Australian acacias into dry, tropical Africa (Cossalter 1985), there has been limited research on acacias from Australia's subtropical dry zone. There is a need for considerably expanded research activity into the potential value of these species for a broad range of uses, especially fuelwood and fodder. Part of this field-orientated research program should be to evaluate the more promising species for saline, alkaline soils. Modes of establishment including direct seeding, coppicing and root suckering as well as site preparation techniques, especially mounding, require investigation. A significant component of this research could be usefully undertaken within Australia on salt-affected soils in northwestern Australia and the Northern Territory by organisations based in these areas.

Acknowledgments

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Tables 1 and 2 following pages

Table 1. Characteristics and potential uses of *Acacias*, from the subtropical and tropical (< 24°S), dry (< 500 mm) zone of Australia with potential for planting on saline, alkaline soils.

		Natural occurrence			Soil properties						Species characteristics				Potential uses and functions: Wood						Seed	Services			
Subgenus/section No. Species	Related species	Australian States	Latitudinal range (°S)	Rainfall range (mm/year-median)	Drainage lines	Climate zone	Frost incidence	Texture	pH	Soluble salts	Plant dimensions (height × width in m)	Growth rate	Longevity	Expected coppicing ability and root suckering habit	Fuelwood	Charcoal	Posts/small poles	Sawn timber	Stock fodder	Human food source	Aril character	Shade	Windbreak	Live fence	Soil stabilisation
Acacia																									
1. *A. farnesiana*		NSW, Qld, NT, SA, WA, (probably naturalised)	12-36	150-1300	*	1-3	*	SL-*C*	Ac-Al	—	2-7 × 3-9	2	2-3	3	2-3	3	3	3	1-2	3	3	3	2-3	1-2	2-3
2. *A. sutherlandii*		Qld, NT	16-24	350-900	*	2(N)	—	SL-*C*	Ac-Al	*	7-10 × 4-8	2-3	1-2	1	2-3	3	2	2	1-2 (C)	?	3	2	3	2	3
Phyllodineae																									
3. *A. ampliceps*	4,6 7,8	NT, WA	14-26	200-800	**	1	—	S-C	Al	**	3-9 × 6-12 0.2 × 10	1	2-3	1R	1	1	3	2-3	1	2	2-3	1	1	3	1
4. *A. bivenosa*	3,6 7,8	WA	15-27	200-700	—	1	—	S-CL	N-*Al*	*	2-4 × 4-6	2	?	1	1	3	3	3	2	3	2	3	1-2	3	1
5. *A. cuspidifolia*	10	WA	23-27	200-250	*	2(S)	*	SL-C	N-*Al*	*	3-6 × 4-9	2	1	2	1-2	1-2	3	3	1-2	2-3	3	2-3	1	2	1-2
6. *A. ligulata*	3,4,7,8	Vic, NSW, Qld, NT, SA, WA	14-38	100-700	—	1-3	**	S-SL	Ac-*Al*	**	2-5 × 4-9	1-2	2	1	1	2-3	3	3	2	3	1	3	1	2-3	1
7. *A. salicina*	3,4,6,8	Vic, NSW, Qld, NT, SA	18-37	100-1200	**	1-3	**	SL-C	Ac-*Al*	**	3-20 × 4-12	1	1	1R	1	1	1-2	1	1-2(T)	3	1	1	1-2	3	1
8. *A. sclerosperma*	3,4,6,7	WA	20-29	150-350	*	2(S)	*	S-CL	Ac-*Al*	**	2-6 × 3-8	2-3	1	1	1	2-3	3	3	2-3	3	3	2	1	3	1
9. *A. tetragonophylla*		NSW, Qld, NT, SA, WA	21-33	100-450	*	1-3	**	S-C	Ac-Al	*	2-7 × 1-8	3	1-2	1	2	3	3	3	2-3	3	1	3	2	1	2
10. *A. victoriae*	5	Vic, NSW, Qld, NT, SA, WA	14-36	100-1000	*	1-3	**	S-C	Ac-*Al*	**	2-10 × 5-15	1	2-3	1R	1	2	3	3	1	1-2	3	2-3	2	1	2
11. *A. wiseana*		NT, WA	20-28	200-300	*	1	*	S-CL	?	*	2-5 × 3-5	?	?	?	3	3	3	3	3	?	?	3	2	1	2
Plurinerves																									
12. *A. anaticeps*		WA	18-24	150-550	—	1	—	S	N-Al	*	3.5-5 × 2-4	1-2	2	1R	1-2	2-3	3	3	3	2	3	2-3	1-2	3	1-2
13. *A. cambagei*	14	NSW, Qld, NT, SA	17-32	150-700	*	1-3	*	SL-*C*	Ac-*Al*	*	4-15 × 3-12	3	1	2(R)	1	1-2	1-2	2-3	3	?	3	1	2-3	3	2
14. *A. harpophylla*	13	NSW, Qld	20-34	350-750	*	3(E)	**	L-*C*	Ac-Al	*	7-24 × 5-10	3	1	1R	1	1	2	1-2	2-3	3	3	1	2	3	1-2
15. *A. maconochieana*		NT, WA	18-21	250-400	**	1	*	S-*C*	N-AL	*	8-12 × 5-7	2	1	?	1	2	1	2	1-2	2	3	1	3	3	2
16. *A. microcephala*	13	Qld, NT	20-26	450-600	—	3(E)	—	L-C	Al	*	6-9 × ?	?	?	?	1	1-2	?	?	?	?	3	?	?	3	?
17. *A. oswaldii*		Vic, NSW, Qld, NT, SA, WA	20-36	100-700	*	3(S)	**	S-C	N-*Al*	*	2-8 × 3-7	3	1	1-2	1	2	3	3	2-3	2	1	2	1-2	3	1-2
18. *A. sibilans*		WA	22-28	200-250	*	3(S)	—	S-*L*	N-*Al*	**	3-12 × 5-15	3	1	2	1	1	2-3	2	3	?	3	1	3	3	2
19. *A. stenophylla*		Vic, NSW, Qld, NT, SA, WA	17-37	100-800	**	1-3	**	L-*C*	Ac-*Al*	**	4-15 × 5-12	2	1	1R	1	1	1	2	2	2	3	1	2-3	3	1

20. *A. translucens*	NT, WA	12-24	150-1100	—	1	—	S-*L*	Ac-Al	*	0.5-2 × 2-5	2	2	1-2	3	3	3	3	3	3	3	3	3	3	1
Juliflorae																								
21. *A. grasbyi*	WA	22-29	200-350	—	2(S)	*	S-C	N-*Al*	*	2.5-6 × 3-9	3	1-2	2	1	1-2	3	3	2-3	2	?	2	2-3	3	2-3
22. *A. hemsleyi*	Qld. NT, WA	12-22	350-1400	**	2(N)	—	*S*-CL	?	*	3-8 × 3-5	1	2-3	?	1	1-2	2-3	3	3(S)	?	3	2	2-3	3	2
23. *A. holosericea*	Qld, NT, WA	11-27	250-1600	*	1	—	S-L	Ac-Al	*	3-9 × 3-6	1	3	3	1	1	3	3	2-3	1	1	2	2	3	2
24. *A. intorta*	WA	23-27	200-250	*	2(S)	*	L-C	N-*Al*	*	2-4 × 4-6	3	1	?	1	1	3	3	?	?	3	2-3	2-3	2	2
25. *A. xiphophylla*	WA	20-27	200-350	*	2(S)	*	SL-*C*	N-*Al*	*	3-5 × 5-12	3	1	2	1	1	3	3	3	?	3	2	1-2	3	1-2

Notes on Table 1

Related species: Numbers indicate the most closely related species that occur in the subtropical dry zone.

Natural occurrence: (Drainage lines) ** species typically occurring in the lower parts of the landscape, in close association with drainage lines; * species which sometimes grow along drainage lines, especially in the drier parts of their range; — species not usually occurring in close proximity to drainage lines. (Climate zone) 1 species typically found in the subtropical dry zone; 2 species found frequently to infrequently in the subtropical dry zone; 3 species with a marginal occurrence in the subtropical dry zone; 1-3 species with very wide distributions; N,S & E denotes that distribution extends to the north, south and east of subtropical, dry zone. (Frost incidence) ** heavy frosts in most years over a substantial part of the range; * low incidence of frost in some parts of the range; — nil or very low incidence of frost throughout the range.

(Soil properties—italics indicates dominant category): *Texture* S = sand, SL = sandy loam, L = loam, CL = clay loam, C = clay; *pH* Ac = acid (pH < 6), N = neutral (pH 6-7.5), Al = alkaline (pH > 7.5); (Soluble salts) ** high levels of soluble salts (saturation extract EC > 4 mS cm^{-1}) in upper soil horizons in some locations; * high levels of soluble salts (saturation extract EC < 4 mS cm^{-1}) in lower soil horizons in some locations; — low levels of soluble salts in soil in most locations.

Species characteristics: Plant dimensions—the dimensions given are the range for fully-grown plants in their native habitat; Growth rate: 1 = fast; 2 = moderate; 3 = slow. Longevity: 1 = long-lived (> 50 years); 2 = moderate life-span (10-50 years); 3 = short lived (< 10 years). Expected coppicing ability and root suckering habit: 1 = high; 2 = moderate (i.e. variable); 3 = low; R = root suckering habit (brackets indicate low frequency of root suckering).

Potential uses and functions: Fuelwood & charcoal: 1 = highly suitable; 2 = occasionally suitable; 3 = unsuitable. Posts/small poles & sawn timber: 1 = suitable; 2 = occasionally suitable; 3 = unsuitable. Stock fodder: 1 = useful; 2 = limited usefulness (drought fodder value); 3 = nil or very limited usefulness. Potentially toxic compounds in foliage and legumes are indicated as follows: C = cyanogenic glycosides; S = saponins; T = tannins.

Seed (Source of food for humans): 1 high-yielding and easily harvested species whose seed is reported to have been utilised as a food source by aborigines; 2 species which have limited potential for food; 3 species which have nil or very limited potential for food; T indicates seed of this species may be toxic and should not be consumed. (Aril character): 1 expanded, oil-rich aril; 2 somewhat expanded aril of low to moderate oil content; 3 aril absent or little expanded and of low oil content.

Services (Shade, windbreak & live fence): 1 = useful; 2 = limited usefulness; 3 = nil or very limited usefulness. (Soil protection): 1 = very useful; 2 = useful; 3 = limited usefulness.

Table 2. Mineral composition of phyllodes and soil properties for natural stands of some *Acacia* species growing on apparently saline sites in Western Australia.

		Phyllode mineral composition[a]				Soil properties[b]							
Species	Location	Cl^- % DW	Na^+ % DW	K^+ % DW	Mg^{2+} % DW	Texture	pH	EC (mS cm^{-1})	Cl^- (in mmol l^{-1})	Na^+ (in mmol l^{-1})	K^+ (in mmol l^{-1})	Mg^+ (in mmol l^{-1})	Ca^{2+} (in mmol l^{-1})
A. ampliceps	Karratha township	1.5	1.42	0.91	0.45	Sandy clay	8.3	9.5	91	96	1.4	5.8	1.3
A. ampliceps	Eighty-Mile Beach (4 km NE of Wallal Downs Homestead)	2.5	0.12	1.31	0.53	Clay	8.3	24.0	209	258	9.2	4.2	0.47
A. sclerosperma	Murchison River, SE of Twin Peaks Homestead	1.2	0.06	1.01	0.65	Sandy clay	8.1	4.8	38	38	1.5	4.4	3.6
A. sclerosperma/ ligulata complex	4 km S of 26th Parallel (along Gt. NW Hwy)	1.8	0.05	0.57	0.58	Clay	8.2	8.0	55	4.1	3.5	6.1	23.3
A. victoriae	1.3 km E of Cue	1.1	0.34	0.84	0.96	Clay	8.2	2.1	13	6.4	0.72	3.1	5.2

[a] Fully expanded phyllodes were sampled from 5-10 plants in March/April 1986. Chemical analyses were performed on 10 mmol HNO_3 extracts.

[b] Soil samples were taken from 5-10 locations at 10 cm depth and bulked. Soil chemical properties were assessed on saturation extracts.

Salt Tolerance of Australian Tropical and Subtropical Acacias

N. Aswathappa, N. E. Marcar, and L. A. J. Thomson*

INCREASING world population growth will require efficient utilisation of marginal lands (Dudal 1982) that may be unsuitable for crop plants because of their aridity, high salinity, low fertility and/or extremes of pH. However, such lands can be useful for wood production (Midgley et al. 1986). Certain tree species, including nitrogen-fixing species such as acacias are known to establish well on marginal lands.

Australian acacias grow well on diverse soil types in their native habitat (Turnbull 1986) and are known to perform extremely well on non-saline soils of some Third World countries (Boland and Turnbull 1981). Some of these countries are also known to have vast areas of salt-affected lands (Ponnamperuma 1984) on which Australian native species might be planted. However, to date there has been no systematic screening of tropical and subtropical Australian tree species for salt tolerance. In this study seedlots of tropical and subtropical Australian tree species were evaluated for salt tolerance: only the data for *Acacia* are presented and discussed here.

Materials and Methods

The experiment was conducted in a glasshouse maintained at a day/night temperature of 25–30/20–25 °C. The seeds were provided by the Tree Seed Centre, Division of Forest Research, CSIRO. *Acacia* seed was pre-treated by immersion in boiling water (Doran and Gunn 1986) and germinated in vermiculite. Two-week-old seedlings were transplanted into plastic pots (2.2 l capacity) containing washed river sand and irrigated with ¼ strength Hoaglands No. 2 solution. Each pot contained 12 seedlings and there were 5 pots per species. The pots were arranged on glasshouse benches in blocks and were connected to an automated irrigation system consisting of a large tank, pump, timer, tubing and drippers (capacity: 8 l/hour). The pots were distributed randomly within each block. Salinity treatments were imposed on 2-month-old seedlings in step-wise increments of 25 mol m^{-3} every 2 days.

The salt solution comprised a mixture of NaCl, Na_2SO_4, $CaCl_2$ and $MgSO_4$ dissolved in the molar ratio of 65: 18: 8.5: 8.5 in ¼ strength Hoaglands No. 2 solution. The nutrient solution was maintained at a pH of 6.5 using NH_4OH. The pots were flushed 4 times daily with excess salt solution (2 to 3 l/day) and the drained solution was collected and recirculated after correcting for evapotranspiration. One pot of each species was maintained as a control on ¼ strength Hoaglands No. 2 solution. The treatment solutions were replaced with new solutions each fortnight.

Regular assessments were made of height growth, injury symptoms and mortality. Seedlings were considered dead when their foliage had permanently wilted. The salt concentration at which 50% of the plants died was defined as LD_{50}, and using this criterion species/provenances were classified as highly tolerant (> 1375 mol m^{-3}), moderately tolerant (975–1375 mol m^{-3}), less tolerant (500–975 mol m^{-3}) and least tolerant (< 500 mol m^{-3}). In order to examine the relationship between salt tolerance and tissue ion concentrations, two plants in each pot were harvested when the salt concentration reached about 850 mol m^{-3} (data not shown). The final harvest was made within 2 weeks of reaching 50% mortality. Plants were harvested and separated into foliage (phyllodes and leaves), stem and roots. Dry weights were determined after oven drying the samples at 85 °C for 4 days.

Results and Discussion

Injury Symptoms

Salt-treated plants were generally stunted, dull coloured and often had mildly chlorotic phyllodes particularly at higher salinity levels (> 1000 mol m^{-3}). The true pinnate or bipinnate leaves died in all species within about 4 weeks (or before the salt concentration reached about 400 mol m^{-3}), but in control plants these leaves were retained until

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harvest (20 weeks). Phyllodes also died prematurely at higher salinity levels, with the oldest phyllode senescing first. Within a phyllode, injury (browning/necrosis) started from the tip and extended towards the base along the margins.

In the less tolerant species (*A. difficilis, A. holosericea*) phyllode death progressed rapidly to the apex whereas in the highly tolerant species (*A. auriculiformis, A. stenophylla, A. maconochieana*) phyllodes died more slowly. Marked differences were observed in the appearance and growth of shoot apices in different species. At lower salinity levels (about 400 mol m^{-3}) the shoot apices of the tolerant species appeared unaffected and continued to grow (Fig. 1). The less tolerant species stopped growing at these concentrations and wilted early. However, at higher salinity levels (1300 mol m^{-3}), even the apices of the highly tolerant species turned reddish brown and wilted.

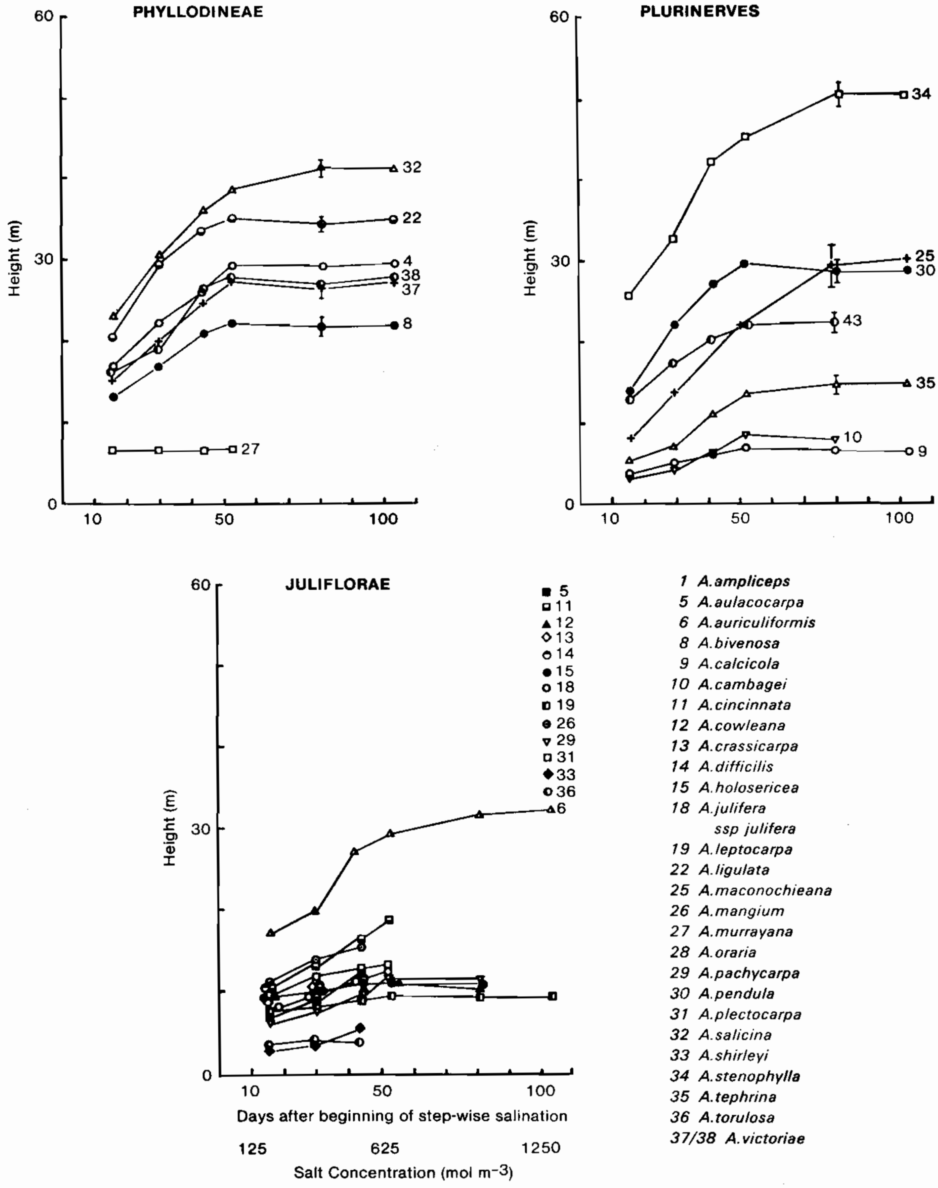

Fig. 1. Response of *Acacia* species to a step-wise increase in salinity. (Bars represent standard error of the mean; n = 5).

Table 1. Effect of salinity stress on survival, height and shoot weight of 37 *Acacia* species/provenances (ranked in order of LD_{50}). Salinity treatments were imposed in a step-wise order (25 mol m^{-3} every 2 days) and were continued until 50% mortality was reached. Salt solution comprised a mixture of NaCl, Na_2SO_4, $CaCl_2$, $MgSO_4$ in the molar ratio 65: 18: 8.5: 8.5, respectively.

Species +	Location	LD_{50} (*mol m^{-3}*)	Salt concentration around which height growth ceased (*mol m^{-3}*)	Maximum height for salt-treated plants (*cm*)	Control** Height (*cm*)	Shoot weight for salt-treated plants (*g*)
Highly Tolerant						
Acacia maconochieana (Pl)	Lake Gregory, WA	1850	1275	28.9	—	2.13
A. stenophylla (Pl)	Cow Creek, WA	1825	1025	50.0	71.9	3.96
A. auriculiformis (J)	Bula, PNG	1750	1275	28.6	48.4	2.71
A. oraria (Pl)	NW of Cairns, Qld	1725	1150	16.1	32.6	1.52
A. leptocarpa (J)	Starcke Holding, Qld	1675	650	9.5	—	1.08
A. salicina (Ph)	West of Banana, Qld	1625	1000	40.9	71.1	4.73
A. auriculiformis (J)	Balamuk, PNG	1550	1275	32.3	58.3	2.69
A. ligulata (Ph)	NW of Giles, WA	1400	650	35.6	72.6	3.27
A. ampliceps (Ph)	Wolfe Creek Crater, WA	1400	900	29.9	62.0	2.91
A. ampliceps (Ph)	Wave Hill, NT	1400	650	30.9	65.5	3.19
A. ampliceps (Ph)	Halls Creek, WA	1375	1275	27.8	77.1	3.17
A. ampliceps (Ph)	Lake Dora, WA	1375	650	29.8	80.0	4.91
A. bivenosa (Ph)	Barradale Road House, WA	1375	650	21.9	44.5	2.86
		***1563 ± 52**	**955 ± 77**	**29 ± 2.8**	**62 ± 4.5**	**3 ± 0.3**
Moderately Tolerant						
A. leptocarpa (J)	Musgrave, Qld	1300	650	10.7	58.2	1.13
A. cambagei (Pl)	West of Barcaldine, Qld	1300	650	8.3	13.9	0.70
A. ligulata (Ph)	Fitzroy River, WA	1275	650	20.9	47.7	1.80
A. tephrina (Pl)	NE Hughenden, Qld	1250	750	14.5	26.1	0.84
A. pendula (Pl)	Coollie Trangie dist., NSW	1200	650	28.6	48.1	1.20
A. ligulata (Ph)	Sturt Creek, WA	1150	650	28.4	67.0	2.20
A. victoriae (Ph)	Titree Station, NT	1100	650	26.1	48.7	1.56
A. victoriae (Ph)	Buronga/Gol Gol, NSW	1075	650	28.4	49.3	1.66
A. plectocarpa (J)	Kimberley Region, WA	1050	650	12.3	46.5	0.86
A. calcicola (Pl)	West of Uluru, NT	1050	650	6.2	21.1	0.77
A. holosericea (J)	Wolfe Creek Crater, WA	1000	650	14.1	55.4	0.93
A. holosericea (J)	Hooker Creek, NT	975	525	10.9	49.6	0.88
		144 ± 34	**648 ± 13.8**	**17.5 ± 2.4**	**44 ± 4.5**	**1.2 ± .14**
Less Tolerant						
A. pachycarpa (J)	Billiluna Station, WA	950	650	11.6	24.7	0.93
A. holosericea (J)	Turkey Creek, WA	925	525	10.2	58.7	0.85
A. crassicarpa (J)	Oriomo River, PNG	900	625	10.8	—	0.86
A. cincinnata (J)	Julatten Area, Qld	850	650	18.7	52.4	1.18
A. cowleana (J)	Wolf Creek Crater, WA	850	625	10.7	49.4	0.93
A. murrayana (Ph)	Alice Springs, NT	825	200	7.8	40.3	0.33
A. aulacocarpa (J)	Oriomo River, PNG	800	650	13.7	—	0.61
A. julifera ssp. *julifera* (J)	Hughenden, Qld	750	650	11.0	49.2	0.88
A. mangium (J)	Claudie River, Qld	725	525	15.3	—	1.07
A. difficilis (J)	Borroloola, NT	700	525	11.5	39.1	1.15
A. shirleyi (J)	Daly Waters, NT	650	550	5.1	23.7	0.42
		811 ± 29	**561 ± 40**	**11.5 ± 1.1**	**42.2 ± 4.5**	**0.83 ± .08**
Least Tolerant						
A. torulosa (J)	Weipa, Qld	350	200	3.9	8.7	0.33

* mean and standard error of the mean of each group. ** Measured at the time when most salt-treated plants ceased to grow (i.e. 11 weeks after beginning of salinity treatments).
+ Section to which each species belongs: J = Juliflorae, Ph = Phyllodineae, Pl = Plurinerves (Pedley 1978).
Qld: Queensland; NT: Northern Territory; PNG: Papua New Guinea; WA: Western Australia; Vic: Victoria; NSW: New South Wales.

Survival

For perennial species such as trees, survival may become more important during the dry season (when salinity levels increase), and the ability of a species to endure (rather than grow) under such situations, will decide its capability to persist on saline sites.

Large interspecific differences were observed for seedling mortality, with LD_{50} values ranging from 350 mol m^{-3} (*A. torulosa*) to 1850 mol m^{-3} (*A. maconochieana* and *A. stenophylla*) (Table 1). It is interesting to note that the members of the section Phyllodineae (except *A. murrayana*) and Plurinerves had higher survival than those of Juliflorae (except *A. auriculiformis* and *A. leptocarpa*). More than half the seedlots tolerated up to 1000 mol m^{-3}, and majority of them had LD_{50} of 1000–1400 mol m^{-3}. Only a limited number of provenances were examined and provenance differences were minimal.

The salt tolerances reported here (as measured by LD_{50}) are very high. However, they cannot be extrapolated directly to the field as they are based on short term exposures of seedlings and the experiments were conducted under conditions conducive to rapid growth. Nevertheless, they provide a satisfactory means of ranking species for salt tolerance on their relative survival.

Growth

The ability of a species to continue to grow under saline conditions is a vital attribute and can be measured through height increment. In this study height growth had a significant ($P < 0.01$) correlation with LD_{50} ($r = 0.62$) and shoot weight ($r = 0.65$).

The growth responses of acacias to a step-wise increase in salinity are shown in Fig. 1 and Table 1. Salinity reduced height growth in all species but the extent of reduction varied between species. Most species ceased height growth after the salt concentration reached about 650 mol m^{-3} or 50 days after the beginning of salinity treatments. However, the highly tolerant species continued to grow slowly up to about 950 mol m^{-3}, while less tolerant species ceased height growth at about 560 mol m^{-3}. Some species including *A. maconochieana, A. stenophylla, A. salicina* and *A. auriculiformis* were only slightly affected by salinity at lower concentrations, whereas others (*A. murrayana* and *A. leptocarpa*) had little or no height increment after addition of salt (Fig. 1).

Under salt treatment, the members of Phyllodineae and Plurinerves grew more rapidly than those of Juliflorae (except *A. auriculiformis*). These species accumulated more dry matter because they continued to grow at lower salinity levels (Fig. 1) and survived until high salt concentrations were reached. In contrast, the members of Juliflorae showed varied responses; some species grew rapidly and survived up to about 1600 mol m^{-3} (e.g. *A. auriculiformis*), some grew rapidly but died at lower salt concentrations (e.g. *A. cincinnata, A. mangium*) and others had little growth increment, yet survived very high levels of salinity (e.g. *A. leptocarpa*). Species which occur naturally on saline soils (*A. ampliceps, A. victoriae, A. ligulata, A. oraria, A. salicina* and *A. stenophylla*) typically exhibited above average salt tolerance (Turnbull 1986).

The importance of provenance variation for survival and growth under salinity appeared to vary with species. For example, the provenances of *A. holosericea, A. victoriae* and *A. auriculiformis* showed very little variation in LD_{50}, the salt concentration at which height growth ceased, and shoot weight (Table 1), but those of *A. ligulata* and *A. ampliceps* differed greatly. Although provenance differences observed in this experiment were generally smaller than the differences between species, the relatively large variation found for *A. ligulata* and *A. ampliceps* (35–45% in shoot weights) suggests that further exploitation of provenance variation for salt tolerance is needed.

Acknowledgments

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Selecting *Acacia* Species for Testing Outside Australia

Trevor H. Booth*

FINDING the best species for a particular site is an important problem facing many foresters. There are over 900 Australian wattle (*Acacia*) species, which are adapted to a wide range of environments, and many have great potential for fuelwood production and agroforestry (Boland and Turnbull 1981; Baumer 1983). How can foresters choose appropriate species to test?

Unlike eucalypts, only a few Australian acacias have been widely tested outside Australia, so selection of species for trials must depend to a large extent on matching climatic and soil conditions at introduced and natural sites. Matching soil conditions poses problems as many different soil classification systems are in use and soil conditions can change markedly within a few metres of any sampled point. On the other hand, standard climatic measurements are available from thousands of locations all around the world. These data can be analysed using recently developed interpolation methods to provide accurate estimates of mean climatic conditions for any location given its latitude, longitude and elevation (Hutchinson and Bischof 1983; Hutchinson et al. 1984). These new methods form the basis of the climatic analysis techniques described here.

Methods

Comparing Climate of Trial Site with Locations in Australia

The first method involves the comparison of a site outside Australia, where species are to be tested, with locations across Australia. The purpose of this preliminary analysis is to identify broad areas in Australia which experience similar climatic conditions and contain species which should be climatically suited to the trial site.

The information required to make these comparisons is very simple. Long term monthly mean values of daily maximum temperature, daily minimum temperature and precipitation are the only data needed. As an example, these values have been analysed for Ratchaburi, Thailand, which is about 85 km west-southwest of Bangkok. Ratchaburi is near an Australian Centre for International Agricultural Research (ACIAR) fuelwood species trial site. From the 36 monthly values, 18 climatic indices, such as annual mean temperature, coldest month minimum temperature and driest month mean precipitation, were calculated.

The same indices have been calculated for each of 2795 points in a half degree grid across Australia, so a climatic similarity computer program (CLIMSIM) can calculate the similarity between the trial site and the locations in the regular grid. Data from this program can then be used to produce maps which show those areas of Australia most climatically similar to Ratchaburi, for example. The location of areas with similar climates to the target location can be compared with *Acacia* (or other) species distributions and appropriate selections made for trials.

It is hoped that the CLIMSIM program will be implemented on a computer at the Tree Seed Centre at the Division of Forest Research in Canberra, so that it will be available to assist with routine enquiries.

Determining a Species' Climatic Requirements

In many studies there is interest in a particular species rather than a specific site.

A procedure for this type of analysis has been developed from climatic studies of eucalypts as part of ACIAR's project 8320 'Australian Hardwoods for Fuelwoods and Agroforestry.' The procedure involves four basic stages: (i) analysis of climatic requirements based on natural distribution; (ii) identification of suitable test sites and/or collection of data from existing trials; (iii) refinement of climatic requirements based on information from trials outside the range of natural occurrence; and (iv) identification of climatically suited sites within the region of interest.

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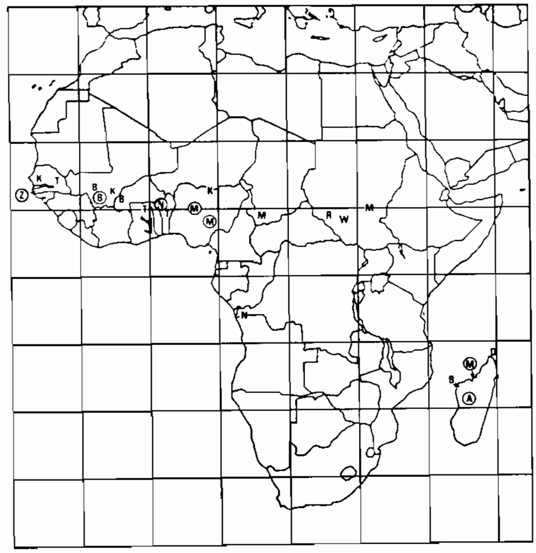
The first stage, involving the analysis of natural distribution, makes use of the Bioclimate Prediction System and the BIOCLIM program (Nix, in press; Nix, Busby and Hutchinson, in preparation). This procedure has been used to analyse the climatic requirements of *Eucalyptus citriodora* (Booth 1985). In an extension of this study the profiles of a further 12 eucalypt species have been determined and information from trials in Africa has been used to improve the climatic profiles. Mathematical relationships were developed to estimate mean monthly values of daily maximum and daily minimum temperature for any location in Africa.

The locations where particular species were successful were identified from a published review (Poynton 1979) and from routine questionnaires sent to researchers in Africa. Mean annual rainfall estimates were also obtained from these sources as insufficient data were available to analyse rainfall relationships for the whole continent. The proportional distribution of rainfall at the nearest meteorological station was used to estimate monthly precipitation at each trial site. Climatic conditions at the successful sites were then compared with values for climatic indices obtained from the analysis of the natural distribution. If more than one value from successful trial sites fell outside the profile limits for a particular factor then those limits were adjusted.

Revised descriptions of climatic requirements thus used data derived both from natural distribution information and trial results.

As a further part of the climatic analysis work being carried out for the ACIAR project on 'Australian hardwoods for fuelwoods and agroforestry' the climatic requirements of 10 non-eucalypt species are being analysed. A paper describing this work is being prepared by Booth and Jovanovic. *Acacia auriculiformis*, a species 'which merits large-scale testing as a fuelwood species' (National Academy of Sciences 1980), is used here to demonstrate the first two stages of the procedure outlined above. Figure 1 shows some locations in Africa which satisfy three important bioclimatic criteria determined from a BIOCLIM analysis of its natural distribution in Australia (but not including natural sites in Papua New Guinea and Irian Jaya).

The areas indicated provide only a provisional indication of climatic suitability, but the characteristics of the natural distribution can suggest useful locations for trial sites. However, some care should be taken in interpreting the results, as the species is often found in Australia along rivers and in other situations where moisture supply is increased by sources other than rainfall. The annual mean precipitation at the sites shown in Fig. 1 ranges from 780 to 1620 mm. Webb et al. (1984) suggested that *A. auriculiformis* plantations require annual mean precipitation in the range 1300–1700 mm. If so, the relatively high rainfall sites shown in Fig. 1 would be the most likely to be successful. Trials at lower rainfall sites would be more risky, especially in areas affected by any continuing sub-Sahelian drought. Still, these trials could determine the species ability to withstand seasonal drought without access to extra water and test if Australian provenances can produce reasonable growth with relatively low rainfall. Results could then be used to refine the description of *A. auriculiformis* climatic requirements.



A.auriculiformis characteristics derived from natural distribution in Australia

Annual mean temperature	26-28°C
Annual mean precipitation	760-1670mm (1300-1670mm locations circled)
Driest quarter precipitation	0-18mm

Locations indicated by first letter of name

Fig. 1. Locations in Africa which satisfy three main climatic characteristics of *A. auriculiformis* natural distribution in Australia.

Discussion

The methods described here are intended to assist the choice of species for trial. Other factors such as socioeconomic needs, soil conditions and pest/disease risks need to be considered, but climatic analysis can help to simplify the decision process.

The concept of trying to match climatic conditions has been used by foresters for many years.

However, the new interpolation methods can take much of the guesswork out of climatic analysis. The early results summarised here have been very encouraging, but much remains to be done to develop the methods.

For example, it would be highly desirable to improve the existing predictive relationships for Africa and to develop new relationships to cover areas in Asia. Cooperation from countries outside Australia will probably be required to develop these relationships. The resulting relationships would be useful not only for forestry, but for a whole range of agricultural, conservation and natural resource projects.

Although only work at the species level has been described here the methods may also be extended to assist the selection of provenances. Cooperative studies could involve the analysis of climatic effects in both *Eucalyptus* and *Acacia* trials

In conclusion, there are great opportunities for cooperative work both using and improving the methods outlined here.

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Growth Rates, Establishment Techniques, and Propagation of Some Central Australian Acacias

P. D. Kube*

ALICE Springs has an arid climate. The average rainfall is 283 mm yr^{-1} with a slight summer peak. Rainfall is unreliable and variable; the lowest and highest rainfalls on record are 60 mm yr^{-1} and 778 mm yr^{-1} respectively. Temperatures range between summer maxima above 40 °C and winter minima frequently below 0 °C. Frosts occur between May and August. Soils are generally of low fertility, although some more fertile soils occur on alluvial deposits. Major soil types include shallow skeletal soils, red earths, red clayey sands, and sands (Litchfield 1962). In arid Australia it is the *Acacia* woodlands and shrublands that dominate the vegetation. This is in contrast to most temperate and tropical areas of Australia where the eucalypts dominate. Arid Australia is floristically poor (Perry and Lazarides 1962) and contains only 116 species of *Acacia* (Jessop 1981), however there are many potentially useful species which have adapted to the harsh conditions of this region.

The major problem with plant establishment in Central Australia is water supply. Average rainfall statistics do not give the complete picture of water requirements of Central Australian plants; there are two complicating factors. Firstly, the rainfall is extremely variable. Approximately every 50 years massive rainfall events occur. The last occurred during the mid 1970s when for 3 successive years annual rainfall was over 550 mm. A large amount of plant regeneration occurs during these events and, for some communities, these events appear essential to their self perpetuation. Secondly, 'water harvesting' occurs on some sites. The lush vegetation beside streams is the most obvious extreme, however other sites may benefit from less obvious catchments, underground seepage from nearby ranges, or groundwater. Plants which exist in such places are dependent on these water sources to supplement their water supply.

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When considering plant establishment and species selection water supply is always the primary consideration. The water needed for successful establishment and the quantity of water the site is likely to receive in later years must both be considered. The following notes on growing Central Australian acacias focus on the water requirements. The notes are limited to those species for which reasonable information is available. They are based on observations of amenity planting and species trials on a variety of sites near Alice Springs. Some of these trials are described in detail in Sandell et al. (1985).

Growing Central Australian Acacias

All the Central Australian *Acacia* species listed here grow quickly from seed. The seeds are soaked in hot water (approximately 80 °C), sown in germination trays, and covered with a thin layer (2–3 mm) of vermiculite or fine sand. They are transplanted when they have cotyledon leaves and most are ready for transplanting 2–3 days after sowing. The roots grow very quickly and if transplanting is delayed, it becomes very difficult. The seedlings are transplanted into tubes 5 cm in diameter and 15 cm deep. The potting mix needs to be free-draining with good moisture-holding capacity. Successful mixes have been 1:1:1 of coarse sand, fine sand, and peat moss, or 1:1:1 of coarse sand, sandy loam, and peat moss. Approximately 4 kg m^{-3} of slow-release fertiliser is also added. Excessive humidity needs to be avoided and seedlings are moved into a well-ventilated area under 80% shade 1–5 days after transplanting. Regular applications of a fungicide are usually necessary. The seedlings are exposed to increasing amounts of sunlight as they grow and are usually at a plantable size 3 months after sowing in temperatures of 25–30 °C.

Given the vagaries of rainfall in Central Australia plant establishment needs to be done with the help of irrigation. Plants are irrigated from 6 to 24 months depending on rainfall. No mycorrhizal associations have been reported for Central Australian *Acacia* spp., however it is unlikely that many serious attempts have been made to identify them. All species described here grow well without mycorrhizal inoculation, and grow without fertiliser and no trials have been done to quantify any responses to fertiliser. Growth of seedlings is best when a large planting pit is used. Where possible a hole 30 cm wide and 60 cm deep is drilled with a posthole borer. Holes this size have given consistently better results than holes large enough for the seedling container only. The use of hydrogels (artificial water storers) is not recommended. Although no data are available for the effects of these substances on *Acacia* spp. they have been found to hinder eucalypt survival in periods of water stress, presumably because they inhibit extensive root development (Kube 1985).

Most Central Australian *Acacia* spp. naturally regenerate with stockings of up to 5000 stems ha^{-1}, including the tree species such as *A. aneura* and *A. estrophiolata*. However, these dense stands occur only after exceptionally high rainfall. A period of severe thinning then occurs which may reduce stands to 100–400 stems ha^{-1}. Fires and drought are probably the main factors causing this thinning. The optimal spacing for planted species of Central Australian acacias is debatable, however initial stockings of 1000 trees ha^{-1} followed by thinning as the stand matures is one possibility. This would only be recommended if there is a use for small diameter thinnings or a need for rapid site cover. If not, stockings of approximately 400 trees ha^{-1} would probably be preferable.

Acacia aneura (Mulga)

Acacia aneura grows into a small tree up to 10 m tall. In Central Australia the *A. aneura* woodlands are best developed on the plains adjacent to mountains and hills where they would receive some storm-water runoff. *Acacia aneura* often occurs in groves up to 50 m wide and up to 400 m long with intergrove areas (of similar size) acting as a water catchment. *Acacia aneura* generally occurs on medium-textured red-earths and sometimes on rocky hillsides and clayey-sands. *Acacia aneura* can live for greater than 50 years but is very fire-sensitive. Although normally drought-tolerant, it will die in a severe drought.

Planted specimens receiving little supplementary water runoff and above-average rainfall (370 mm yr^{-1}) have, in 10 years, grown into a healthy multi-stemmed tree 3 m tall with a diameter at breast height (dbh) of 2–4 cm and a crown radius of 1 m. These trees were grown on a loam soil. With a good water supply, *A. aneura* can grow 1 m in height per year. Cultivated specimens receiving regular irrigation have grown into multi-stemmed trees 10 m tall and with dbh of 10 cm in 10 years. The wood density of 10-year-old *A. aneura* (a tree 6 m tall) was measured as 850 kg m^{-3} and the heartwood was well developed. Although slow-growing without a good water supply, *A. aneura* has proven to be drought-tolerant and will remain healthy under cultivation long after other species (such as some eucalypts) decline.

Acacia aneura is an excellent fuelwood. It is generally palatable to stock and has moderate nutritive value (Askew and Mitchell 1978). Because *A. aneura* is drought-tolerant it is useful drought fodder for stock. The seeds of *A. aneura* can be eaten by humans.

Acacia estrophiolata (Ironwood)

Acacia estrophiolata grows to a medium-sized tree up to 15 m tall. It usually occurs on plains or flood plains and sometimes on undulating country with fairly shallow soils. It occurs on coarse- to medium-textured soils and is fire-sensitive. *Acacia estrophiolata* is a long-lived species which will survive droughts.

Planted specimens growing on a site receiving little supplementary water and above-average rainfall (370 mm yr^{-1}) grew very slowly; at 7 years they were just over 1 m tall and at 10 years 2 m tall. With a regular water supply growth is faster; 6 years after planting heights of 4 m have been recorded. A 5 m tall tree with a good water supply was observed to double in height in 10 years and its habit changed from the erect form of a young tree to the weeping habit of a mature tree. *Acacia estrophiolata* has proven to be difficult to establish. The reasons for this are not fully understood, however it could be due to constricted root development in seedling containers, the need for a weed-free environment for a number of years, or a need for very well drained soils. The wood density of a young tree (5 m tall) was 840 kg m^{-3} and heartwood formation had commenced. The wood density of a mature tree was 1040 kg m^{-3}.

Although slow-growing, *A. estrophiolata* is very drought-tolerant and is an excellent fuelwood. It is very palatable to stock, moderately nutritious and an excellent source of drought fodder (Askew and Mitchell 1978).

Acacia murrayana (Murray's wattle or Colony wattle)

Acacia murrayana is a small multi-stemmed shrub or tree, usually no more than 6 m tall. It normally occurs on soils ranging from deep sands to sandy loams, and tends to occur on sites receiving some supplementary water. It tends to be short-lived and not very drought-tolerant.

Planted specimens of *A. murrayana* grew reasonably quickly while rainfall was above average (390 mm yr^{-1}), but their health declined quickly during a dry period (< 150 mm yr^{-1}). Seven years after planting *A. murrayana* grew into a 3-4-stemmed tree a little over 4 m tall and with a dbh of 6 cm. On a site receiving additional water the growth rate was not much quicker, however it survived for a longer period of time; at 10 years *A. murrayana* had grown into a multi-stemmed tree 6 m tall with 3–4 stems approximately 10 cm in diameter. This species coppices vigorously and produces numerous root-suckers which can form a dense colony. The wood density of a 7-year-old tree (6 m tall) was measured as 480 kg m^{-3} and no heartwood was present.

Acacia kempeana (Witchety bush)

Acacia kempeana is a multi-stemmed shrub usually no more than 3 m tall. It naturally occurs on calcareous, stony skeletal, and red earth soils as well as rocky mountain ranges. *Acacia kempeana* is not fire-tolerant but is long-lived, drought-tolerant, and naturally occurs on sites not receiving supplementary water.

Planted specimens of *A. kempeana* receiving above average rainfall (370 mm yr^{-1}) grew into dense healthy shrubs 2 m tall with a crown spread of 3 m at age 7 years. They survived 2 non-consecutive years where rainfall was below 170 mm yr^{-1} with no decline in health. Growth is only slightly accelerated with a better water supply; 4 years after planting cultivated specimens of *A. kempeana* have grown into dense shrubs 2 m tall and with a crown spread of 2 m.

There is little useful wood on this species. However, it is a useful screening plant and is very hardy. *Acacia kempeana* is palatable to stock but has low nutritive value (Askew and Mitchell 1978).

Acacia peuce (Waddy wood)

Acacia peuce is an erect single-stemmed tree growing up to 15 m tall. Only three small stands exist, all occurring on gravelly sandy-clay soils on the edge of the Simpson Desert. Average rainfall in these areas is approximately 150 mm yr^{-1}. *Acacia peuce* is very drought-tolerant and long-lived; some trees may be over 500 years old (Chuk 1982).

Both planted specimens and natural trees grow very slowly. Mature trees in the natural stand have changed little in 50 years and a seedling grew from 0.8 to 3.0 m tall in 14 years (years with very good rainfall). With regular irrigation planted specimens grow more quickly, although over-watering needs to be avoided. Seven years after planting heights of 2 m were observed and 11 years after planting *A. peuce* was a single-stemmed tree nearly 4 m tall with a dbh of 8 cm. Planted specimens have proven to be extremely drought-tolerant and hardy. Some trees in the natural stands have been observed to coppice although dead cut stumps in the same stands suggest this is not always the case. The wood of small-diameter timber had a measured basic density of 1400 kg m^{-3}.

Acacia victoriae (Prickly wattle or Bramble wattle)

Acacia victoriae is a shrub or small tree which grows up to 7 m tall and often has thorny branches. It grows on a wide range of soil types but is usually found near drainage lines, on flood-outs, or on sites receiving reasonable amounts of water. *Acacia victoriae* dies out during severe droughts but in good years regenerates quickly and forms dense thickets.

Acacia victoriae planted at Alice Springs will grow quickly if it receives a good water supply. Three years after planting (when rainfall was always greater than 500 mm yr^{-1}) heights of 2 m were obtained and all trees were healthy and vigorous. At age 10 years (when average rainfall between years 3–7 had been 350 mm yr^{-1}, with 2 non-consecutive years below 170 mm) only the trees on sites receiving additional runoff water or close to drainage lines remained healthy and vigorous. They had grown into multi-stemmed trees 5–7 m tall with 3–4 stems with a dbh of approximately 10 cm. The wood density of a 5-year-old tree was 670 kg m^{-3} and heartwood formation had commenced.

Acacia victoriae is suitable as fuelwood. The foliage is grazed by cattle and has moderate nutritive value (Askew and Mitchell 1978). *Acacia victoriae* seeds extremely heavily and the seeds are edible by stock and humans.

Acacia salicina (Willow wattle or Cooba)

Acacia salicina is a shrub or tree up to 13 m tall. In Central Australia it is confined to water courses. Planted specimens will only grow on sites receiving considerable amounts of additional water. When planted close to a stream line in Central Australia and receiving no artificial irrigation it grew into a small tree 5 m tall in 10 years. When receiving regular irrigation it has grown 1 m in height per year for at least 5 years. Under cultivation it has developed into a large tree with considerable wood volume, reaching heights of 10 m in 15 years.

Acacia cowleana

Acacia cowleana is a spindly shrub growing up to 4 m tall. It usually occurs along drainage lines and floodouts on sandy or stony soils. *Acacia cowleana* grows quickly in seasons of good rainfall but declines rapidly in a drought. Planted specimens grow quickly and reach heights of 2–3 m in 2 years, and may live for up to 10 years.

Acacia holosericea

Acacia holosericea is a spreading shrub, or sometimes a small tree up to 8 m tall. It occurs in the northern region of Central Australia, usually along the banks of seasonally dry streams. It has been grown on well-irrigated sites in Central Australia. It usually grows to about 3 m tall in 3 years after which the growth rate slows down. Best growth recorded is 4 m tall 18 months after planting. It prefers well-drained soils and will tolerate frosts.

Acacia ligulata (Small Cooba or Umbrella bush)

Acacia ligulata is a bushy shrub or occasionally a small tree up to 5 m tall. It is usually found on sandhills and sandy soils on sites not benefiting from supplementary water. This species has not been cultivated extensively, however it appears to be potentially useful. It grows quickly and with some additional irrigation (during years of below average rainfall) grew into a bush nearly 2 m tall and 3 m wide in 4 years. It would probably be drought-tolerant, and although it naturally occurs in sandy soils it has been grown in sandy-loams.

Future Directions

The conditions in Central Australia are very harsh and more research is needed to identify suitable species, provenances and techniques for the various sites and purposes in the arid zone. The major need is seen as matching the long-term water availability on a site (including rainfall, storm-water and groundwater) with the water requirements of individual species. Other research needs are identified as nursery practices, fertiliser responses, and the use of microsymbionts in an arid climate, and the identification and protection of potentially valuable populations. Such information should be of importance to areas elsewhere in the world with similar conditions.

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Acacia Species Trials in Southeast Queensland, Australia

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INDIGENOUS forests in many developing countries are heavily utilised for a wide variety of products. The pressure on forests for the supply of essential commodities is resulting increasingly in declining resources and environmental degradation. Thus there is a need to locate species, particularly with multipurpose characteristics, to supplement production from indigenous forests.

Many Australian species have characteristics that make them highly suitable for introduction into tropical and subtropical countries, particularly in situations of low soil fertility and aridity (Boland and Turnbull 1981). However, while a variety of genera have been established successfully outside Australia, the range of species in cultivation is limited.

The Australian Centre for International Agricultural Research (ACIAR) is sponsoring projects to study a wide but selected range of Australian tropical and subtropical species, including acacias, from wet through to arid environments. One of these projects is being conducted by the Queensland Department of Forestry to develop information on nursery production techniques, field performance and biology of these species.

A basic premise in the conduct of the trials is that constraints to productivity should be minimised to enable valid evaluation of potential performance. Thus the trials have had reasonably high levels of management inputs: cultivation, good weed control, fertiliser and insect control. The effects of various degrees of cultural inputs can be determined subsequently for the more promising species once base performance data from this initial screening process has been obtained.

This paper describes briefly the techniques that have been used with some comment on general observations of acacias in the trials.

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Location of Study

The study is centred at Gympie in southeast Queensland, Australia, which has a subtropical climate of warm wet summers and cool mainly dry winters.

Plants are raised at the Queensland Department of Forestry nursery at Toolara while the field trials have been established at Tuan and Wongi State Forests (Table 1).

Table 1. *Acacia* species showing best growth at age 1–2 years.

Species	Origin*	Climatic distribution
aulacocarpa	PNG, NQ	tropical-subtropical; humid-subhumid
auriculiformis	PNG, NQ, NT	tropical; humid-subhumid
cincinnata	NQ	tropical-subtropical; wet-subhumid
crassicarpa	PNG, NQ	tropical; wet-humid
elata	NSW	warm; humid-subhumid
flavescens	NQ	tropical-subtropical; wet-subhumid
holosericea	NQ, NT	tropical; humid-subhumid
hylonoma	NQ	tropical; wet-subhumid
leptocarpa	PNG, NQ	tropical-subtropical; humid-subhumid
mangium	PNG, NQ	tropical; wet-humid
melanoxylon	SQ, NQ, Vic	cool temperate-tropical; humid-subhumid
plectocarpa	WA	tropical; subhumid-semi arid
podalyriifolia	SQ	subtropical; humid-semi arid
saligna (syn *cyanophylla*)	WA	warm, humid-subhumid
simsii	PNG, NQ	tropical; wet-semi arid
torulosa	NQ	tropical; subhumid-semi arid
tumida	WA	tropical; humid-arid

* PNG—Papua New Guinea; NQ—Northern Queensland; NT—Northern Territory; NSW—New South Wales; SQ—Southern Queensland; Vic—Victoria; WA—Western Australia.

Climate for the two field sites is comparable: At Wongi (Bruce and Harwood sites) the mean minimum is ~10 °C, and mean maximum ~29 °C, with annual rainfall ~1100 mm, range of ~140 mm and ~35 mm in the driest month; comparable figures for Tuan (Dinne site) are ~10 and 29 °C, ~1360 mm, range of ~170 mm, and ~50 mm in the driest month.

Soils on each site are of low fertility, loamy sands in the upper horizons increasing in texture to sandy clay loam with depth. The soils at the Tuan sites are deeper with generally better drainage than those at the Wongi sites though seasonal saturation to the soil surface may occur at both locations.

The Tuan sites originally carried tall open forest while the vegetation at the Wongi sites was woodland (Specht et al. 1974). Vegetation on both sites was dominated by an overstorey of *Eucalyptus* species.

Nursery

No detailed trial work on nursery techniques has been undertaken. Observation and monitoring of nursery performance has been used as a basis for changes in techniques. While much of the assessment has been qualitative, it has also given an indication of the type of work required to produce information on the underlying principles for raising *Acacia* seedlings.

Germination Procedure

Seeds for most *Acacias* require seed coat pretreatment to facilitate germination. While a variety of methods are advocated, we have found that the simplest and most efficient method is to pour boiling water onto the seeds, allowing them to cool and soak for 24 hours before sowing.

Initially sowing was directly into pots but this was changed to sowing into germinating trays and transplanting germinants into tubes. This has provided benefits in stock management. However, care is required to ensure that sowing is not too dense or problems in transplanting can result, particularly if germinants develop quickly (preferred transplanting size is about the two-leaf stage).

Potting Medium

The potting medium used for all sowings consists of a mix of 1 part peat moss and 2 parts vermiculite. This mix has the advantage of being sterile, uniform and with generally good physical properties. However it can be difficult to rewet when dry. It has also been suggested that it may lose moisture rapidly and shrink differentially in clay soils under dry conditions (D. West, Queensland Dept of Forestry; Dalby, pers. comm.).

Pot Types

Three types of pots have been used to raise stock (Fig. 1). All of these pots have design features to minimise root curl within the pot and to enable air pruning of roots to maintain a compact root system.

A biodegradable net pot (BNP) was used initially. While compact and easy to handle and plant (seedlings are planted without removing the pot), the BNP is shallow and seedlings are susceptible to rapid moisture loss as the surface soil dries. It seems also that the retention of the pot at planting may result in physical damage to the root collar as the seedling develops resulting in some susceptibility to pathogen and insect attack.

The Hawaiian Dibbling Tube (HDT) appears to be superior to the BNP. Though having a smaller volume (50 cc compared with 70 cc), its greater

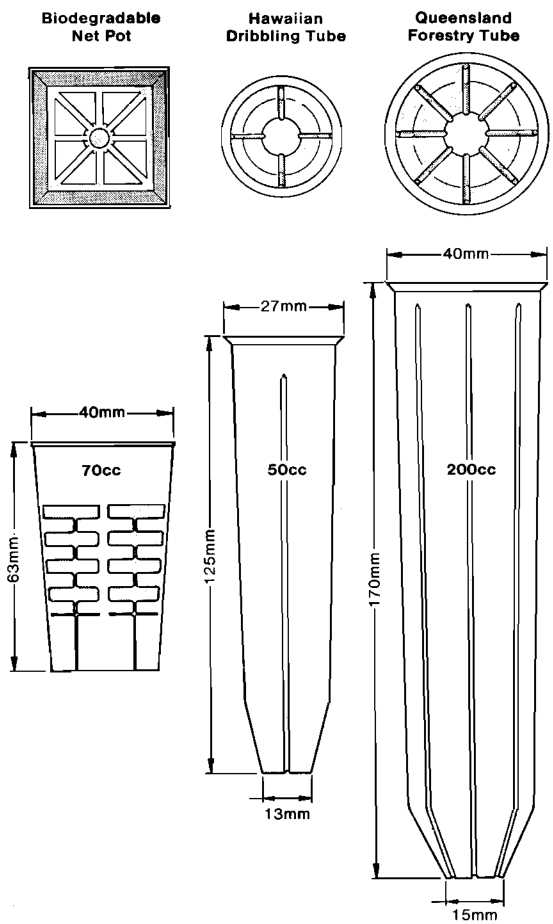

Fig. 1. Seedling containers used in ACIAR trials in South Queensland.

depth seems to provide a greater capacity to withstand drying of the soil after planting.

Stock raised in the larger Queensland Forestry Tube (QFT) generally develop more quickly and are more robust than those raised in the HDT but are not as easy to transport or handle. The use of the QFT also allows for greater flexibility in the timing of planting.

Fertilising

Fertilisers for the first sowing were a combination of slow release fertilisers incorporated into the sowing mix, and foliar applications via the watering system to supply a total of 16N, 8P, 15K mg/plant plus traces.

For subsequent sowings, only slow-release fertilisers (to supply macro- and micronutrients) have been used to supply a total of 18N, 3P, 10K mg/plant (four times this rate for stock raised in the QFT).

The major disadvantage of foliar applications of fertiliser is the difficulty of adding sufficient nutrient at a concentration low enough to avoid foliage burn. Increased susceptibility to pathogens appears to be an additional unfavourable side effect of fertiliser damage to foliage.

In all cases, the potting mix has been amended by the use of lime or dolomite to maintain a favourable pH level.

Watering and Conditioning

From germination through to about the 4- to 6-leaf stage, seedlings are maintained in a greenhouse and watered three times per day for 1 min by overhead sprinklers.

After removal from the greenhouse, they are kept under 50% shade for 3–4 days before exposure to full sun (it has been found that some plants, e.g. *Eucalyptus cloeziana*, require up to about 15 days under the intermediate shading treatment).

Watering after removal from the shade house is three times per day for 2 min. The frequency of watering is tapered to once per day as a drought-conditioning process. Some supplementary watering of individual plants may be carried out initially where wilting is in excess of 2 hours. The volume of water, however, is increased to ensure thorough wetting of the potting medium.

Insect Control

Spraying to control insect attack is prescribed on an 'as required' basis. However no control measures have been necessary.

Disease Control

A fungicidal drench is applied at sowing to prevent damping off. Thereafter disease control is largely on an 'as required' basis. However, under hot, humid conditions prophylactic applications of fungicide are carried out to prevent the buildup of *Colletotrichum acutatum*, a fungus associated with dieback, root rot, leaf spot and seedling blight of a wide range of hosts.

General Results and Discussion

Sufficient stock were raised in the nursery to establish at least one plot in the field for all but a few of the species under test.

However, it has been noted from the first sowing that a significant number of *Acacia* species, though initially healthy and vigorous, begin to decline when about 8 cm high, with varying degrees of mortality.

This syndrome seemed to affect predominantly those species derived from the arid zones, and it was thought initially that the high humidity of the coastal Toolara nursery may have been responsible. However, the same stock raised under the drier environment of a more inland nursery showed the same pattern of decline.

Seedlings of affected species, however, when transplanted into larger (250 cc) pots maintained vigorous and healthy growth. An examination of nursery data for all sowings has shown that, though a higher proportion of species from dry zones are affected (17 out of 41 showing decline), marked declines (11 of 35 species) have occurred also in species derived from relatively wet regions. It is possible that restrained root development or loss of functional roots may be responsible for this syndrome. Roots of *Acacia podalyrifolia*, a wet zone species which has shown symptoms of decline in the nursery, have developed to a depth of greater than 30 cm within 7 weeks of sowing while stem height was only 5 cm (Ryan, unpublished data). Root wrenching of acacias in Zimbabwe has resulted in seedling mortality (D. P. Gwaze, Zimbabwe Forestry Commission, Harare, pers. comm.).

Other factors, including nutrition, watering and potting medium characteristics may also be involved.

Field

The field trials consisted of two replicate growth study plots and a single replicate coppice study plot at each site for each species. The growth study plots consist of 36 trees planted at 3 m × 2 m, the middle 16 trees being measured. The coppice study plots are 20 tree line plots with 1.5 m spacing between trees and 3 m spacing between plots.

Site Preparation

Standing vegetation was cleared by pushing with crawler tractors, heaped into windrows and burnt. The site was ploughed to about 30 cm depth and reploughed prior to planting for the first 2 years. The second ploughing has been replaced by the construction of small mounds to overcome drainage problems resulting from depressions created by ploughing.

Plots established for the growth trials avoided the ash heaps left from burning.

Establishment

Planting in all cases has been by the use of bars designed to punch holes in the ground of identical dimensions to the seedling root ball.

Plots have been fenced to exclude cattle while net fencing has been erected around some sites to exclude small herbivores after considerable browsing damage in the first year's planting.

Weed Control

Weed control has aimed at maintaining a 1 m radius around each tree free of weeds for about the first 18 months.

Initially this was difficult to achieve satisfactorily as all weed control was by chipping with hoes. This is slow and expensive, damaging to the fine roots of trees, creates depressions around the trees and removes fertilised soil from the immediate vicinity of the trees. More recently, a technique of a guarded application of glyphosate has been developed and is now the major method used with some hand weeding around the base of the plant.

Some preliminary trial work has been carried out on the use of selective herbicides. 'Fusilade' (fluazifopbutyl) has proved to be effective in controlling grasses without apparent ill-effects on the trees, while 'Goal' (oxyfluorfen) and 'Casaron' (dichlorobenil) show promise as selective pre-emergent herbicides.

A more comprehensive trial has been established recently to test the selectivity of a range of herbicides (contact and residual) against a range of hardwood species.

Fertilising

Fertilising at 57 g/tree of double superphosphate (19.2P, 1.68S, 16Ca) and 95 g/tree ammonium sulphate (20.5N, 24S) was carried out soon after planting. Additional fertiliser applications were made in early summer of the first year (double superphosphate and ammonium sulphate) and at the end of the second year (double superphosphate and ammonium nitrate). Total fertiliser application is equal to 150 kg/ha P and 300 kg/ha N.

Insect Control

Insect control on one replication per site using Orthene (acephate) has been carried out on a regular basis (approximately monthly) since planting. So far there has been little indication that insect control has resulted in overall growth improvement though a few species have suffered significant insect damage.

Potentially damaging insect pests recorded on acacias in the trials include: *Monolepta australis, Rhyparida limbatipennis, Repsimus aeneus*, and *Anoplognathus* sp.—polyphagous leaf-eating beetles; *Platyomopsis albocincta*—a ring-barking weevil, and *Chrysolopus spectabalis*—a stem-girdling weevil (F. R. Wylie, Queensland Department of Forestry, Biology Laboratory, Indooroopilly, pers. comm.).

Pathogens

A number of pathogenic fungi have been isolated from various *Acacia* species in the trial. These include: *Glomerella cingulata*—a leaf spotting disease (on *A. simsii*); *Uromycladium robinsonii*—a phyllode rust (on *A. melanoxylon*); and *Oidium* sp.—a powdery mildew (on *A. holosericia, A. mangium, A. polystachya*). The *Glomerella* leaf spot and the powdery mildew have been recorded on a variety of acacias in the nursery (J. W. Tierney, Queensland Department of Forestry, Biology Laboratory, Indooroopilly, pers. comm.).

No disease control measures have been applied in the field as health and vigour of affected plants do not appear to have been unduly affected with the possible exception of *A. holosericea* from Jabiru in the Northern Territory.

Assessments

Annual measures of height and diameter at ground level are the major growth parameters measured. Diameter at breast height ('tree' form species only) and crown width are measured and an assessment of health is made.

Annual observations of general characteristics of individual species are carried out to provide some information on such things as foliage density, presence and abundance of thorns and spines, effects on understorey growth and the occurrence of natural regeneration. It is intended to include characterisation of growth habit also. However no satisfactory classification system has been arrived at as yet.

Monthly inspections are carried out to record general observations on the phenological patterns of individual species and any damage that may have occurred due to insects, disease, wind, frost or animals.

General Results and Discussion

The majority of species in the trials are being tested under environmental conditions markedly different from those operating in their natural habitat. Good performances by these species may indicate that they possess some degree of environmental adaptability, a very useful trait for broadscale species introductions.

Species from the tropics and subtropics in the humid to subhumid zones are dominant among the better performers (Table 1). In general, species from these regions have had high survival and growth rates.

Those derived from semi-arid to arid areas are not performing well—survival rates tend to be low while growth is slow. However, a number of species (e.g. *A. aneura*) show a considerable degree of variation in productivity with some individuals growing quite well. In these cases, most survivors appear to be quite healthy.

Growth rates of species from temperate regions have ranged from poor to good, frequently with a high degree of variation within individual provenances. Survival rates in many cases have been moderate to low.

In general it would appear that species from tropical habitats have performed better under subtropical conditions than those from temperate habitats. It is particularly interesting to note that Papua New Guinea provenances appear generally to be performing better than their North Queensland counterparts.

However, it is noticeable also that though growth is good, most of the species which are single-stemmed in their natural habitat are multi-stemmed in these trials. It is not known whether this is environmentally or culturally induced.

Differences in environmental tolerances have been noted for different species from the same general region. For example, *A. mangium* from the Papua New Guinea lowlands was affected severely by frosts in 1984 while the other Papua New Guinea acacias from similar environments showed only occasional leaf discoloration.

Overall results to date indicate that a number of species show potential for use in sub-humid to wet environments in the subtropics and tropics. While species from semi-arid to arid areas have not performed well as a group, there are some species which do show promise.

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Growth Rate of Selected *Acacia* Species in North and Southeast Queensland, Australia

G. B. Applegate and D. I. Nicholson*

THE genus *Acacia* is represented in Australia by over 700 species (Boland et al. 1984), many of which have the potential to be managed for a number of purposes in overseas countries. Some of them have already proved their usefulness. One example is *Acacia mangium*, a species native to the wetter tropical regions of northeast Australia and parts of Indonesia and Papua New Guinea. It was introduced into Sabah in 1966 and is now grown in major plantations in South and Southeast Asian countries where it forms the basis of sawmilling industries and community forestry programs (National Academy of Science 1983).

Other *Acacia* species native to Australia which have the potential for providing a range of products and benefits in overseas countries are being tested in Queensland in a project funded by ACIAR and managed by the Queensland Department of Forestry. This project is designed to investigate suitable nursery techniques, monitor survival and growth, phenology and seed production, and determine silvicultural characteristics of a range of Australian native species. Although the project involves many genera, this paper reports on the height growth at age 12 months of 13 seedlots of *Acacia* grown in north and southeast Queensland.

Acacia Studies

Site Characteristics

Trial sites are located at Tuan in southeast Queensland, latitude 25°47′S and longitude 152°50′E, and at Kuranda in north Queensland, latitude 16°45′N and longitude 145°33′E.

The Tuan site has a northerly aspect with gentle slope and a sandy lateritic podzolic soil. The site is located at an altitude of 50 m and receives an annual rainfall of 1400 mm/annum (M. Podberscek pers. comm.). February is the hottest month with a mean of 24°C, and July, the coldest month, a mean of 13°C. The original vegetation was a woodland containing *Eucalyptus signata, E. intermedia, Casuarina torulosa* and an understorey dominated by *Xanthorrhoea media* and *Themeda australis.*

The site at Kuranda is gently sloping (5°) with a western aspect at an altitude of 445 m. The shallow soils are almost skeletal and have developed from schist contained in the Barron River metamorphics (Fardon and de Keyser 1964). No long-term climatic data are available from the site, but the Forest Office nearby receives 1800 mm of rain per annum (Queensland Department of Forestry 1986), with a dry season in August and September. Temperature records indicate that the site would average a maximum of 30°C and an average minimum of 17°C. Prior to clearing, woodland (Specht 1970) dominated by *Eucalyptus acmenoides, E. intermedia, E. polycarpa, E. tereticornis, Allocasuarina littoralis* and *Themeda australis* covered the site.

Site Preparation

Following clearing of the Tuan site, the area was broadcast-ploughed to a depth of 25 cm and then disced with John Shearer Tandem discs. Prior to planting, the area was sprayed with Roundup herbicide (active ingredient glyphosate) and fenced with hare-proof netting.

At Kuranda, the site was cleared and mounded (initially for routine planting) and then reploughed using a Wasp four-disc plough. Due to the rough planting surface the area was reploughed 9 days prior to planting with the disc plough. Fencing was erected using 1-inch mesh wire. No herbicides were applied prior to planting.

Design and Layout

The plantings at Tuan were a replicated randomised complete block with each net plot containing a single seedlot of four rows by four trees planted at a spacing of 3 × 2 m.

At Kuranda an unreplicated series of single line plots each of four plants per seedlot were established. Plot positions were randomly located on the site. Planting espacement was 3 × 2 m.

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Stock Details

Details of the *Acacia* seedlots planted at Tuan and Kuranda are listed in Table 1. All stock was raised in the Toolara nursery, located just south of Tuan.

Planting

Following good rain, at both sites in early 1985, planting was carried out during February at Tuan, and in early March at Kuranda.

Fertiliser Application

The fertiliser regime prescribed for both sites was 50 kg/ha P and 100 kg/ha N applied as a split dressing as follows:

Tuan: At planting an individual tree application (ITA): 52 g/tree Superking (16.5 kg/ha P); 98 g/tree ammonium sulphate (33.0 kg/ha N).

At age 9 months (ITA): 104 g/tree Superking (33.5 kg/ha P); 196 g/tree ammonium sulphate (67.0 kg/ha N).

Kuranda: At planting (ITA): 111 g/tree Superphosphate (16.5 kg/ha P); 98 g/tree ammonium sulphate (33.0 kg/ha N).

At age 13 months (ITA): 222 g/tree superphosphate (33.5 kg/ha P); 196 g/tree ammonium sulphate (67.0 kg/ha N).

Insect Control

Orthene 75, a wettable powder, was mixed with water at the rate 1 kg Orthene 75/1000 l and sprayed on trees when insects were prevalent.

Results and Discussion

It is evident from the descriptions of the layout and design of the planting at the Kuranda site, that statistical comparisons between the height growth of seedlots at both sites would be quite misleading and unacceptable. It is always tempting to readily accept data without taking account of how it was obtained and the associated limitations.

Nevertheless the small unreplicated plantings at Kuranda do provide a guide to the early growth rates in addition to providing an empirical comparison for the same seedlots grown at Tuan. Figure 1 shows the height developments at age 12 months of the *Acacia* seedlots growing at both Tuan and Kuranda.

Acacia melanoxylon, seedlot no. 13944 from south Queensland, shows the best growth of the 13 *Acacia* seedlots grown at either Tuan or Kuranda. The seed of this particular provenance comes from an area 26 °S latitude at an altitude of 140 m which receives approximately 1800 mm of rain per annum. The data in Fig. 1 suggest that this seedlot grows equally well at both Kuranda and Tuan. *Acacia melanoxylon*, seedlot no. 14176 from Atherton, grows equally well on both sites although it did not perform as well as seedlot 13944. The comparison from the two sites gives an indication of the plasticity of the species and of the importance of provenance selection in matching site with a particular seedlot.

Both provenances of *A. plectocarpa* (14003 and 14004) grew better in the first year at Kuranda than

Table 1. Details of *Acacia* seedlots planted at Kuranda and Tuan.

Species	Seedlot No.	Origin[a]	Altitude *(m)*
melanoxylon	13944	Nambour Q	140
plectocarpa	14004	Packsaddle Springs WA	50
podalyrifolia	12055	Bundaberg Q	100
flavescens	14175	Mt Molloy Q	167
plectocarpa	14003	Middle Springs WA	50
melanoxylon	14176	Atherton Q	1003
pendula	13482	Charleville Q	380
torulosa	14183	Chillagoe Q	275
cambagei	13487	Longreach Q	210
rothii	14160	Weipa	10
victoriae	14489	Titree Stn NT	552
hylonoma	14197	Gordonvale Q	167
simsii	13690	Rouku PNG	30

[a] Q—Queensland; WA—Western Australia; NT—Northern Territory; PNG—Papua New Guinea.

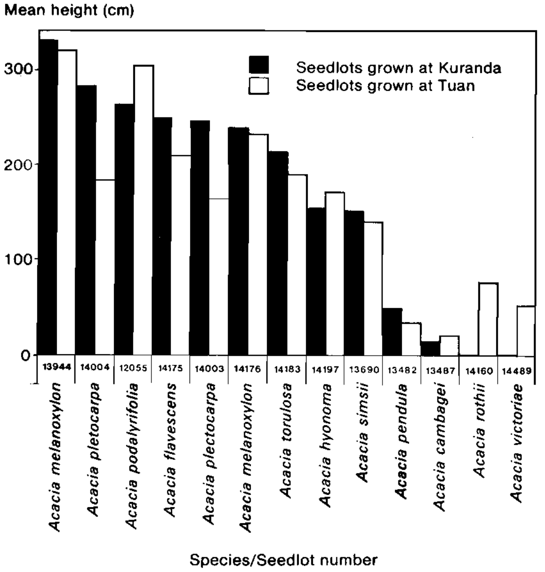

Fig. 1. Height growth at age 12 months of the *Acacia* seedlots growing at Tuan and Kuranda.

on the coastal lowlands at Tuan. Although the performance of *A. podalyrifolia* (12055) from Bundaberg was good on both sites, it grew better at Tuan than at Kuranda. Figure 1 also shows that in all but two cases, *A. podalyrifolia* from Bundaberg and *A. hylonoma* from near Gordonvale, the height growth at Kuranda by age 12 months is superior to that at Tuan. The growth of most seedlots at Kuranda is relatively good given the fact that the Kuranda site had received only one-third of the prescribed fertiliser by age 12 months, whereas the Tuan site had received the prescribed 50 kg/ha P and 100 kg/ha N. If the Kuranda site had received the second application of fertiliser before the measure at 12 months, the growth differentials between the two sites could be even greater. Although this may be the case the soil analysis data from Kuranda when available would need to be compared with that from Tuan to identify whether soils could have influenced relative growth on the sites.

The height growth data from both sites give only the most rudimentary trends, and many exceptions, which are difficult to explain, are evident. For example, the data suggests that *A. plectocarpa* 14004 grows better at Kuranda than 14003. The differences in height growth of these two seedlots suggested in Fig. 1 seems large when it is apparent that the seedlots originate from localities with similar site characteristics (altitude 50 m, longitude 128°40'E for both seedlots and latitude 15°50'S and 15°45'S for 14004 and 14003 respectively). As these plantings become older and the difference in growth habits continues, more details on the biotic and abiotic site characteristics would be required to explain these differences.

None of *A. rothii* 14160 from Weipa survived at Kuranda. This is not an indication of the potential of this seedlot to grow in this locality as the seedlings at planting were not healthy and quite small. This seedlot should be planted in any future trials.

Concluding Comments

Human populations of many tropical countries are dominated by rural dwellers who require fast-growing, multipurpose species for their subsistence. The comparisons of the height data of the *Acacia* species grown at Kuranda with those at Tuan do provide some information which might be useful for selecting seedlots suitable for these countries.

Apart from the Nambour seedlot of *A. melanoxylon* 13944 the tallest nine seedlots growing at Kuranda are from the north and perform better in their early growth stages at the low latitude (16°45'S) than further south. Even at this young age, latitude appears to be an important consideration when matching seedlots to planting sites. These even tenuous findings are worth pursuing by testing some seedlots further in well-designed trials. If the results from these properly constituted trials involving the genus *Acacia* are to be used to assist in the determination of suitable species and provenances for tropical countries, it would be sound practice to undertake some of the testing of the most useful seedlots (from a user viewpoint) in far north Queensland, which offers a number of different altitudes, soil types and rainfall regimes.

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Australian Acacias for Pulpwood

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ORIGINALLY, Australian eucalypts were considered unsatisfactory for pulp and paper manufacture. However, extensive research has led to the acceptance of many of these species for commercial utilisation in: groundwood for newsprint; cold soda semichemical pulp as a component of newsprint and magazine grades; soda, soda-anthraquinone (soda-AQ) and kraft pulp for writing and printing papers and packaging papers; and neutral sulfite semichemical (NSSC) pulp for corrugating medium and higher quality packaging-type products. Eucalypts from plantations are now being used commercially for pulp production in overseas countries such as Spain, Portugal, Brazil and South Africa.

Likewise, results of pulping studies at the CSIRO Division of Chemical and Wood Technology laboratories on fast-growing reforestation hardwoods from developing countries have shown that there are Australian acacias with very promising pulping characteristics (Phillips and Logan 1976; Phillips et al. 1979; Logan 1981; Logan and Balodis 1982; Logan et al. 1984). In particular, *Acacia auriculiformis* from Papua New Guinea (PNG) and *A. mangium* from Sabah, Malaysia, exhibited excellent pulpwood potential, at least as good as some of the commercially accepted high-quality eucalypts.

This paper describes advantages of Australian acacias for possible pulpwood plantations and discusses further areas of research which need to be pursued in order to promote the future benefits of these species to developing countries.

Silvicultural Considerations

Acacias are members of the family Leguminosae which have the special capacity to provide their own nitrogenous fertiliser through nitrogen-fixing bacteria living in nodules in their roots. Thus, for average growth, leguminous plants usually require no nitrogen fertiliser (National Academy Press 1983). Leguminous trees are often among the first to colonise newly cleared land and, apart from their nitrogen-fixing ability, their advantages for plantation cultivation generally include: (i) rapid growth that enables them to overtop potential competitors; (ii) adaptability to a wide range of sites and soils, particularly nutrient-deficient soils and marginal sites unsuited to food crops; (iii) copious seeding at an early age; (iv) ability to coppice; (v) light-coloured wood; and (vi) a robust, irrepressible character (National Academy of Sciences 1979).

The acacias are the largest genus of flowering plants in Australia with more than 700 species spread over a geographical range as large as the eucalypts (Connell 1980). Hence, coupled with the above attributes the opportunity exists for testing the plantation potential of various Australian acacias in different developing countries covering a range of climatic zones such as the humid tropics, cool tropical highlands and arid or semi-arid regions.

However, no matter how good the silvicultural characteristics of a particular species may be, when plantations are established for pulpwood purposes, it is essential also to have a knowledge of the potential pulping quality of the species. There is no point in planting a species for pulpwood if it has excellent growth properties but poor pulping properties, or vice versa. For a successful venture both satisfactory silvicultural and pulping characteristics are necessary.

Pulping and Papermaking Characteristics

Kraft (Sulfate) Pulping

Examples of the pulping and papermaking properties of six Australian acacias are given in Table 1. For comparison, the results for two commercial plantation pulpwoods from the tropics, *Eucalyptus deglupta* and *Gmelina arborea* are included. The acacias have a basic density which is generally higher than that of fast-growing hardwoods, especially common tropical species such as *E. deglupta* and *G. arborea*. Provided that satisfactory

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Table 1. Kraft pulping data on some Australian acacias.

Pulping properties

Species	Age (yr)	Basic density (kg/m^3)	Active alkali[a] (% as Na_2O)	Screened yield[a] (%)	Screen rejects[a] (%)	Kappa No.
auriculiformis	10	517	13.0	55.0	0.3	19.9
dealbata	mature	553	13.5	52.8	0.7	20.7
decurrens[b]	9	457	15.0	55.9[c]	—	18.7
mangium	9	420	14.0	52.3	0.1	21.0
mearnsii	10	598	13.0	52.4	1.7	21.0
elata	c.15	672	13.0	58.7	0.1	13.1
Eucalyptus deglupta (commercial chips)	8	337	14.0	49.3	0.2	20.7
Gmelina arborea (commercial chips)	c.6	366	14.0	50.6	0.5	22.2

Papermaking properties (unbleached pulps)

Species	Freeness (CSF)	Beating rev. (PFI)	Bulk (cm^3/g)	Burst index (kPa.m^2/g)	Tensile index (N.m/g)	Tear index (mN.m^2/g)
auriculiformis	250	4600	1.34	7.4	111	11.6
dealbata	250	4800	1.37	7.2	90	9.7
decurrens[d]	350	—	1.26	6.6	95	10.0
mangium	250	3830	1.27	8.7	119	9.8
mearnsii	250	4000	1.38	7.0	88	9.6
elata	364	6000	1.50	6.1	84	8.9
Eucalyptus deglupta	250	3300	1.33	8.6	105	10.4
Gmelina arborea	250	4600	1.20	8.6	106	10.1

[a] Based on oven dried wood.
[b] Source of data: Hannah et al. 1977.
[c] Total yield, screened yield unavailable.
[d] Data for DcEHD bleached pulp.

pulping and papermaking properties can be achieved, higher basic density is an advantage for a good quality pulpwood because (i) a higher weight of chips can be accommodated in the digester which increases digester production efficiency during batch digester pulping and (ii) if considered for woodchip export, shipping freight costs will be reduced because these charges are usually made on a volume basis.

The acacias were pulped readily with moderate amounts of alkali to Kappa numbers in the bleachable range and high yields of pulp (> 50%) were obtained. In particular, *Acacia elata* produced an excellent yield of pulp at a low Kappa number. However, the pulping tests on *A. elata* were done on a small sample of wood from a single tree and these results will need to be confirmed on a more representative wood sample.

Paper handsheets prepared from all of the *Acacia* pulps exhibited very good strength properties (Table 1). The level of tearing strength was particularly satisfactory for hardwood pulp and generally the bonding properties of the pulps (burst and tensile indices) attained high levels on beating. Handsheet bulk is sufficiently high to indicate favourable conditions for the production of printing papers from these species.

Pulps from *A. mangium* and *A. decurrens* were readily bleached to high brightness levels and the bleached pulp properties would be suitable for a variety of end products such as writing and printing papers (Logan and Balodis 1982; Hannah et al. 1977). These results indicate that no difficulties should be encountered in preparing bleached pulps with satisfactory properties from the other four species.

Kraft pulping of 9-year-old *A. mangium* from Sabah has shown that unbarked wood of this species can also be pulped satisfactorily (Logan and Balodis 1982). Compared with the pulping of wood alone, the inclusion of bark gave a screened yield of pulp above 50% at Kappa number about 20 and there was no obvious difference in strength properties between the wood and wood plus bark pulps. The wood plus bark pulp was bleached by a CEHD sequence to an acceptable brightness level and bleached pulp handsheets had satisfactory optical, physical and surface properties.

Overall, the kraft pulping and papermaking properties of the *Acacia* species compare very favourably with those of the commercial chip samples of plantation-grown *E. deglupta* and *G. arborea* and therefore they should be suitable for utilisation in a wide range of paper and paperboard products such as linerboards, bag and wrapping papers, white boards and writing and printing papers. Plantation-grown *Acacia mearnsii* is currently being used commercially in South Africa as a component of a wood furnish for kraft and soda-AQ pulp production, and *A. mearnsii* woodchips are exported from that country to Japan for use in the manufacture of kraft pulps. *Acacia dealbata*, an understorey species in Tasmanian forests, is recognised as a very good quality pulpwood by APPM (North Broken Hill Ltd) (Batchelor et al. 1970) and, when available, is included as a minor species in the wood intake to its formerly soda and now soda-AQ pulping plant.

NSSC Pulping

Eucalypts are generally considered to be very suitable for NSSC pulp production. Overmature eucalypts produce excellent pulp for corrugating medium and NSSC pulp from regrowth ash eucalypts has been used as a replacement for kraft pulp in some packaging materials (Phillips 1984). An indication of the NSSC pulping potential of acacias can be gained from the properties of young *A. mangium* and *A. auriculiformis* given in Table 2 and compared with *Eucalyptus regnans*, a high quality pulpwood, and a commercial sample of mixed eucalypts.

Two sets of pulping conditions were used to assess properties at different levels of pulp yield and Kappa number. Under condition (i) the acacias gave a similar yield of pulp to *E. regnans* and a much higher yield (approx. 10 percentage points) than the mixed eucalypts. Tear index and crush resistance of the *Acacia* spp. pulps were similar to or higher than those of the two eucalypt samples and tensile index values were much higher, especially in the case of the *A. auriculiformis* pulp. On the basis of these results the acacias should be highly suitable for use in the manufacture of corrugating medium.

With condition (ii) the strength properties of the *Acacia* pulps reached a level expected from a good quality hardwood kraft pulp. Hence, the NSSC pulps from these species could be used as a substitute for unbleached kraft pulps in end products such as linerboards with the added advantage of a substantially higher pulp yield compared with kraft pulps.

Mechanical Pulping

There is little reported information on mechanical pulping studies on *Acacia* species. Following the laboratory preparation of groundwood from impregnated billets (GIB), cold soda semichemical (CSSC) pulp, refiner mechanical pulp (RMP) and chemithermomechanical pulp (CTMP) from 10-year-old plantation samples of *A. auriculiformis* from PNG, Logan et al. (1984) concluded that this species would have limited uses for mechanical pulp production.

Table 2. Properties of NSSC pulps.

Species	Age (yr)	Pulping conditions	Screened pulp yield[b] (%)	Kappa No.	Tear index[c] ($mN.m^2/g$)	Tensile index[c] (N.m/g)	Crush resistance[c] (CMT) (N)
A. auriculiformis	10	(i)[a]	76.2	119	9.1	90	345
		(ii)	65.6	78	10.2	105	395
A. mangium	9	(i)	75.3	143	8.2	75	326
		(ii)	64.8	104	8.6	100	350
E. regnans	32	(i)	75.3	127	9.0	73	370
Commercial overmature mixed eucalypts		(i)	64.3	121	7.9	60	340

[a] (i) 15% Na_2SO_3, 3.5% Na_2CO_3, 2 h at 170°C.
(ii) 25% Na_2SO_3, 5.8% Na_2CO_3, 3 h at 180°C.
[b] Based on oven-dried wood.
[c] At 250 CSF.

However, recent high-yield pulping tests (CSSC and CTMP) at the CSIRO laboratories showed that acceptable pulp yields were obtained from the lower density *A. mangium* plantation samples from Sabah. Papers produced from these pulps possessed high opacity and excellent surface smoothness, but brightness was low. The pulp strength properties were satisfactory and at a level adequate for inclusion in a furnish for newsprint production.

Pulping Quality Variability

Some kraft pulping properties of *A. auriculiformis* from various regions have been tabulated (Table 3) to illustrate the variability in pulpwood quality which can arise when different samples of the same species are examined. The four wood samples from PNG (three regions) and Taiwan all showed generally similar good pulpwood quality, whereas other samples from Sarawak, Thailand and India had considerably inferior pulping and papermaking properties (e.g. substantially lower pulp yield and poorer pulp strength properties). This wide variation in pulping quality which can exist between samples of the same species collected from different locations is probably due to site factors and/or the different seed sources of the trees. Turner et al. (1983) found a large variation in pulping properties between different provenances of *Eucalyptus globulus* from Tasmania.

Acacia auriculiformis is renowned for its relatively poor form and multiple leader habit and this is probably the major drawback to its utilisation as a plantation pulpwood. The 10-year-old sample from the East Sepik Province, PNG (Table 3), was pulped by CSIRO some years ago. The wood samples were taken from trial plantations which were well managed and the form of the *A. auriculiformis* trees was reasonably good for this species. On the basis of the excellent pulping properties of this sample, plantings of *A. auriculiformis* were undertaken in clear-felled areas in the Gogol timber area, PNG. The pulping quality of 5-year-old trees from these plantations was also very good, but unfortunately the trees had poor form. In a search for an alternative provenance with better form, 13-year-old trees with acceptable form from the Milne Bay Province, PNG were tested and found to have similar pulping and papermaking characteristics to other samples of *A. auriculiformis* with poorer form. Hence, the opportunity exists to collect seed from the Milne Bay trees for reforestation trials in the Gogol area. This exercise is an example of the usefulness of pulping research to forestry departments in developing countries.

Recommendations for Future Research

The foregoing demonstrates the silvicultural and pulping attributes of Australian acacias. These species provide a relatively untapped source of high-quality fibre for papermaking, and the potential for

Table 3. Kraft pulping properties of plantation-grown *A. auriculiformis* from different locations.

Origin	Age (yr)	Basic density (kg/m^3)	Active alkali[a] (% as Na_2O)	Screened pulp yield[a] (%)	Kappa No.	Handsheet properties: Freeness (CSF)	Tensile index (N.m/g)	Tear index (mN.m^2/g)
Madang Province, PNG	5	540	13.0	53.8	20.3	250	112	10.4
East Sepik Province, PNG	10	517	13.0	55.0	19.9	250	111	11.6
Milne Bay Province, PNG	13	516	13.0	53.1	19.3	250	118	9.6
Sibu area, Sarawak	12	635	17.0	45.8	21.9	250	77	9.2
Taiwan[b]	4	580	15.0	51.3	18.0	395	75	10.9
Thailand[c]	3	—	12.0	42.2	20.6	300	43	4.9
India[d]	—	—	18.6	44.4	—	300	46	5.6

[a] Based on oven-dried wood.

Source of data: [b] Ku and Chen 1985.
[c] Niyomwan et al. 1983.
[d] FAO 1975.

their successful use in developing countries in pulpwood reforestation schemes appears substantial.

However, in order to achieve the maximum benefits from such utilisation a great deal of work still needs to be done. With respect to this, the following are some recommendations for cooperation between different organisations and possible future research tasks.

1. When reforestation is considered for pulpwood purposes, close liaison between forestry authorities and pulping research establishments is essential to ensure that species selected for planting are suitable from both a silvicultural and pulping viewpoint. If possible, the most likely end use of the pulpwood should be ascertained. Certain species may be suitable for one pulping process but may produce poor quality pulps from another process. This calls for cooperation and consultation between forest departments and pulping technologists before wide scale planting programs are undertaken.

An example where an apparent lack of communication has arisen is with *Eucalyptus tereticornis*. This species grows well in many tropical areas, and is widely planted, especially in India. Early plantings in PNG were promising and it was assumed that the *E. tereticornis* provided good pulpwood. However, subsequent pulping tests at CSIRO have shown that it has poor pulping and papermaking properties for a range of processes, and it cannot be recommended for commercial operations, especially since there are other species available with superior properties.

It is suggested that developing countries undertake trial plantings of a range of *Acacia* species and those species which show promising growth performance should be tested for pulp quality as early as age 3–4 years. If a forestry department does not have access to pulp testing facilities, funds should be sought from overseas aid agencies, which assist developing countries, so that pulping studies can be carried out at an appropriate pulping research laboratory.

2. Pulping investigations on a wider range of Acacia *species need to be carried out.* For example, *A. auriculiformis* has shown excellent pulping potential, therefore related species such as *Acacia aulacocarpa* and *Acacia crassicarpa* should be examined. Further samples of *A. elata* need to be pulped to verify the extremely promising pulping results already obtained on a non-representative sample.

Acacia species known by Australian forestry organisations to be showing promise with respect to growth and form, either in plantations or in natural forests, should be tested for pulping potential. The Department of Forestry, Queensland, has hardwood plantation trials (including the ACIAR trials) in progress which include a number of acacias. Pulping studies should be done on those species which show good silvicultural properties. Even if plantation material is not always available, older natural growth trees can provide a guide to pulping quality.

3. Species with established good pulping characteristics and with poor form such as A. auriculiformis should be subjected to provenance trials in an attempt to improve tree form, and possibly pulping quality and growth rate. Apparently, *A. auriculiformis* readily hybridises with *A. mangium* which has good pulping and papermaking properties and much better form. Hence, the possibility exists that, by crossing these two species, a hybrid could be produced with acceptable form and good pulping characteristics.

4. Through recent efforts in intensive forest management and genetic improvement established by means of rooted cuttings Aracruz Celulose SA of Brazil have vastly improved the pulpwood characteristics and forest productivity of Eucalyptus grandis. Surpassing these results with *Acacia* species may not be beyond the realm of possibility. Some *Acacia* species already possess superior pulping properties to *E. grandis*. The challenge is there to be taken up.

5. Little work has been done on the pulping of acacias by processes other than kraft or NSSC. Attention needs to be turned to mechanical pulping studies and recently developed chemical processes such as the soda-AQ process in an attempt to extend the potential utilisation of *Acacia* species for a wider range of pulp and paper products.

There is an increasing need for raw materials for use in newsprint manufacture. Hardwood pulps, especially hardwood mechanical pulps, can make a significant contribution to the range of pulps which can be used as part of the furnish to make newsprint of various qualities. Mechanical pulp mills can be established on a smaller scale and at a lower cost per tonne than chemical pulp mills. This is of significance to developing countries considering the establishment of a pulp and paper industry.

The soda-AQ process can produce high quality pulp without the environmentally unacceptable sulfur compound emissions which are present in some current commercial kraft pulping operations. Smaller scale operations are also a possibility with the soda-AQ process. Pulping studies using this process could therefore lead to the setting up of smaller, less capital-intensive, less polluting pulp mills, compared with commonly established kraft mills in developed countries.

6. *Apart from the pulping and papermaking characteristics of Acacia species already discussed, there are some other specific properties affecting utilisation which need further investigation.* These include: (i) a study of the properties of black liquors resulting from the chemical pulping of acacias as a guide to processing characteristics in a pulp mill recovery system; and (ii) the determination of the effect of vessel-picking tendency of *Acacia* pulps on their use in the production of offset printing papers.

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Fodder Potential of Selected Australian Tree Species

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THE use of trees and shrubs as fodder for livestock offers several advantages relative to pastures in some environments. They are less susceptible than pastures to seasonal variation in moisture availability, temperature (frosts and desiccation) and fire. Also, there is a range of other products and benefits which may be gained by planting trees. They may be more readily established and maintained in dry environments than pastures and they are capable of providing vital food supplies to stock at critical times during the year.

In areas suitable for pasture production, browse material may provide a useful supplement to pasture in terms of minerals, energy and, at certain times of the year, protein. Areas where good pasture growth is difficult to achieve, particularly the arid and semi-arid zones of the world (< 180 days/year for pasture growth), will be the areas with greatest interest in fodder trees. For example, 59% of the total meat production and 72% of the total milk production of Africa comes from arid and semi-arid zones and it is in these areas that pastures are severely degraded (Mahadevan 1981). Acacias and other genera from the dry tropics of Australia have potential in these areas for fuelwood and erosion control, and, if their usefulness as fodder can be established, their value would be enhanced.

The value of some of the Australian dry-zone trees and shrubs as drought reserve feed in this country is well known by graziers and has been documented by Chippendale and Jephcott (1963) and Everist (1969). Studies on the nutritive value of trees and shrubs (particularly acacias) to livestock in Australia have been limited to the more widespread and better known fodder species such as *Acacia aneura* and *Brachychiton populneus* (Everist 1969; McLeod 1973; Wilson 1977).

This study is a preliminary screening for fodder potential of a number of species being evaluated under ACIAR project 8320—Australian Hardwoods for Fuelwood and Agroforestry. In this project about 100 species were identified as having potential for fuelwood and agroforestry in tropical and subtropical developing countries. Twenty-two of these species were selected for fodder study due mainly to their accessibility from Brisbane.

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Materials and Methods

Trees and shrubs were selected from natural stands in southern Queensland (one site per species).

Foliage samples (in situ on branchlets up to 6 mm diameter) were collected from 6 trees per species. Four samples per tree were taken to cover possible variation in nutrient content due to aspect and shading. Foliage samples were bulked and frozen in the field over dry ice, then transferred to freezer storage (-10°C) on return to the laboratory. The samples were dried in a forced air oven at 80°C to avoid chemical degradation and dry matter losses due to respiration (McLeod 1973; and Johnson et al. 1985). Leaves and twigs were separated after drying and ground to pass through a 1 mm sieve in a Christy and Norris 20 cm mill. Fruit was also collected from three species and this was separated and prepared in the same way.

The concentrations of nitrogen, phosphorus, potassium, calcium, sulfur, sodium, magnesium, copper, zinc, manganese, aluminium, boron, and titanium were determined using a Quantometer for multi-element analysis (Johnson et al. 1985). Dry matter digestibility was estimated using the in vitro method of Minson and McLeod (1978).

Samples of tree species with known in vivo digestibilities could not be obtained and two grasses, kikuyu (*Pennisetum clandestinum*) and buffel (*Cenchrus ciliaris*) were selected as standards for the in vivo digestibility estimates.

Results and Discussion

Results of the analyses of digestibility and major nutrient analyses of leaves, twigs and fruit are given in Tables 1 and 2.

Table 1. Digestibility and major nutrient analysis—Foliage.

Species	(IVDMD)[a]	Predicted *in vivo*	Crude protein[b]	P	K	Ca	S	Na	Mg	Ca/P ratio	S/N ratio
		%	%	%	%	%	%	%	%		
Melia azedarach	(66.9)	73.1	20.3	0.18	1.78	2.41	0.28	0.02*	0.27	13.4+	0.13
Cassia brewsteri	(54.4)	61.6	11.9	0.09*	0.62*	2.38	0.23	0.08	0.52	26.4+	0.12
Albizia lebbeck	(54.0)	61.3	22.6	0.15	0.79	2.59	0.27	0.04*	0.46	17.3+	0.07
Acacia shirleyi	(52.2)	59.6	8.9	0.06*	0.66*	0.40	0.13	<0.01*	0.26	6.7	0.09
A. bidwillii	(48.7)	56.5	11.4	0.09*	0.89	2.43	0.21	0.06*	0.24	27.0+	0.12
A. salicina	(42.3)	50.6	12.4	0.11*	1.17	3.52	1.13	0.02*	0.29	32.0+	0.57
A. leptocarpa	(42.3)	50.6	13.7	0.06*	0.76	0.97	0.18	0.25	0.37	16.2+	0.08
A. aneura	(36.4)	45.2	11.1	0.07*	0.89	1.39	0.17	<0.01*	0.26	19.9+	0.10
A. melanoxylon	(36.4)	45.2	13.8	0.09*	0.89	0.81	0.16	0.16	0.28	9.0	0.07
A. deanei	(35.2)	44.1	14.3	0.09*	0.46*	0.70	0.15	0.09	0.27	7.8	0.07
A. concurrens	(34.7)	43.7	12.1	0.05*	0.62*	0.97	0.18	0.25	0.26	19.4+	0.09
A. stenophylla	(34.4)	43.4	11.3	0.10*	1.07	2.08	0.58	0.16	0.35	20.8+	0.32
A. glaucocarpa	(34.1)	43.2	12.4	0.05*	0.59*	1.01	0.14	0.08	0.23	20.2+	0.07
A. fimbriata	(32.8)	41.9	14.4	0.06*	0.49*	0.30	0.12	0.13	0.25	5.0	0.05*
A. holosericea	(31.6)	40.8	13.6	0.07*	0.76	0.51	0.14	0.18	0.21	7.3	0.06*
A. irrorata	(28.9)	38.4	13.3	0.05*	0.56*	0.34	0.14	0.20	0.31	6.8	0.07
Eucalyptus argophloia	(28.7)	38.2	8.6	0.10*	1.13	0.70	0.13	0.02*	0.42	7.0	0.09
Brachychiton populneus	(27.4)	37.0	12.3	0.22	1.16	1.81	0.18	<0.01*	0.62	8.2	0.09
Alphitonia petriei	(25.3)	35.1	11.0	0.08*	0.87	0.33	0.14	0.02*	0.33	4.1	0.08
Commersonia bartramia	(25.2)	35.0	14.3	0.12*	1.25	0.96	0.45	0.12	0.44	8.0	0.20
Acacia aulacocarpa	(22.9)	32.9	13.7	0.09*	0.74	0.43	0.31	0.33	0.26	4.8	0.14
A. flavescens	(16.9)	27.5	13.9	0.06*	0.41*	0.29	0.20	0.41	0.33	4.8	0.09
Preferred value			>7.2[c]	>0.15[d]	>0.70[d]	>0.18[d]	>0.10[e]	>0.08[d]	>0.07[d]	>10.0[d]	>0.07[e]

[a] In vitro dry matter digestibility.
[b] Calculated as N × 6.25.
[c] Value from Milford and Haydock in McLeod 1973.
[d] Value from Underwood 1981.
[e] Value from ARC 1980.
* Inadequate for maintenance of sheep and cattle.
\+ Excessive for sheep and cattle.

Table 2. Digestibility and major nutrient analysis—Twigs and fruit.

Species	(IVDMD)[a]	Predicted in vivo	Crude protein[b]	P	K	Ca	S	Na	Mg	Ca/P ratio	S/N ratio
		%	%	%	%	%	%	%	%		
Twigs											
Melia azedarach	(52.4)	59.8	7.8	0.12*	2.20	1.86	0.16	0.05*	0.20	15.5+	0.09
Albizia lebbeck	(41.3)	49.7	10.9	0.13*	0.86	2.17	0.16	0.04*	0.44	16.7+	0.09
Cassia brewsteri	(28.7)	38.2	4.8*	0.08*	0.39*	2.00	0.15	0.04*	0.29	25.0+	0.20
Acacia bidwillii	(28.5)	38.0	5.3*	0.05*	0.47*	2.45	0.16	0.02*	0.11	49.0+	0.19
Brachychiton populneus	(25.4)	35.2	4.1*	0.21	0.95	3.63	0.13	0.01*	0.39	17.3+	0.20
A. deanei	(24.7)	34.6	7.3	0.04*	0.25*	0.58	0.09*	0.11	0.27	14.5+	0.08
A. melanoxylon	(23.6)	33.5	6.7*	0.06*	0.60*	1.42	0.03*	0.12	0.27	23.7+	0.12
A. salicina	(22.8)	32.8	6.6*	0.06*	0.95	1.95	0.63	0.01*	0.21	32.5+	0.60
Alphitonia petriei	(22.4)	32.4	7.1*	0.09*	0.97	0.37	0.08*	0.07*	0.27	4.1	0.07
Acacia glaucocarpa	(22.1)	32.1	6.1*	0.02*	0.44*	1.01	0.09*	0.07*	0.15	50.5+	0.09
A. concurrens	(20.8)	31.0	5.4*	0.02*	0.41*	0.98	0.10	0.12	0.15	49.0+	0.12
A. shirleyi	(20.6)	30.8	6.4*	0.03*	0.30*	0.26	0.09*	<0.01*	0.09	8.7	0.09
A. holosericea	(20.3)	30.5	6.0*	0.03*	0.45*	0.52	0.09*	0.15	0.19	17.3+	0.09
A. leptocarpa	(19.9)	30.1	5.8*	0.03*	0.33*	0.97	0.11	0.12	0.15	32.3+	0.12
A. irrorata	(19.4)	29.8	6.7*	0.05*	0.38*	0.19	0.10	0.18	0.23	3.8	0.09
Commersonia bartramia	(18.9)	29.2	5.3*	0.09*	1.23	0.73	0.23	0.06*	0.33	8.1	0.27
A. aneura	(18.4)	28.8	7.5	0.06*	0.33*	1.84	0.14	<0.01*	0.10	30.7+	0.12
A. aulacocarpa	(16.9)	27.5	7.8	0.08*	0.51*	0.95	0.20	0.13	0.15	11.9+	0.16
A. stenophylla	(16.8)	27.3	6.1*	0.05*	0.52*	1.53	0.21	0.07*	0.14	30.6+	0.21
Eucalyptus argophloia	(16.3)	26.8	4.1*	0.06*	0.62*	1.21	0.08*	0.01*	0.34	20.2+	0.12
A. fimbriata	(15.6)	26.3	5.9*	0.05*	0.41*	0.25	0.07*	0.09	0.11	5.0	0.07
A. flavescens	(14.9)	25.6	7.2	0.04*	0.39*	0.48	0.14	0.35	0.26	12.0+	0.12
Fruit											
Melia azedarach	(22.7)	32.7	4.4	0.08*	0.80	1.25	0.09	0.01*	0.09	15.6+	0.13
Commersonia bartramia	(11.2)	22.2	4.8	0.09*	1.24	0.24	0.12	0.02*	0.18	2.7	0.16
Alphitonia petriei	(9.6)	20.8	5.0	0.09*	0.97	0.37	0.08	0.07*	0.16	4.1	0.08
Preferred value			>7.2[c]	>0.15[d]	>0.70[d]	>0.18[d]	>0.10[e]	>0.08[d]	>0.07[d]	>10.0[d]	>0.07[e]

a In vitro dry matter digestibility.
b Calculated as N × 6.25.
c Value from Milford and Haydock in McLeod 1973.
d Value from Underwood 1981.
e Value from ARC 1980.
* Inadequate for maintenance of sheep and cattle.
\+ Excessive for sheep and cattle.

The predicted in vivo digestibilities are high compared to values obtained by McLeod (1973) and McDonald and Ternouth (1979). This may be due to the use of kikuyu and buffel grass as digestibility standards. Newman and McLeod (1973) compared the in vitro technique with known in vivo values and found very small differences between values for browse forage when using rumen fluid.

Crude protein levels in leaves ranged from 8.6 to 22.6% but were fairly similar across the acacias. The digestibility values, however, cover a large range. This could be a reflection of variation in the levels of tannins which have a binding effect on protein.

Requirements for calcium (>0.18%, Underwood 1981) and sulfur (>0.10%, Agricultural Research Council 1980) appear to be met by all species although each species tested was found to have low concentrations of at least one of the minerals required for animal growth. In 86% of the species tested, foliar phosphorus levels were below 0.15%, the estimated maintenance requirement for sheep and cattle (Underwood 1981). The high phosphorus level (0.21%) given for the twigs of *Brachychiton populneus* (kurrajong) is of particular interest.

Minor nutrient concentrations are given in Table 3. Of note are the copper levels in the leaves of some species which are abnormally high. Copper levels in tree species have not been reported to exceed 40 ppm (10 ppm in acacias) and the figures here indicate possible contamination of the samples (Snowdon, pers. comm.). According to Underwood (1981), copper levels as low as 40 ppm can cause poisoning in sheep if levels of molybdenum and sulfur are low, but cattle are more tolerant of high copper concentrations.

The samples used in this study were collected from plants growing in a variety of soil types and environments. This will have an effect on their relative foliar mineral composition, and possibly their digestibility, particularly when making direct comparisons between species. For example the sodium content varies quite markedly between species which may be a result of different soil types. However some of the minor concentration figures (particularly Mn and Zn) may be due to species differences in accumulation.

Other Considerations

Palatability and Intake

Intake, of which palatability is a component, was not investigated in this study, and without this information, no definite conclusions can be drawn about the relative nutritional value of these species as fodder. Observations on palatability for some species in this study are given by Squires (1980),

Table 3. Minor nutrient concentrations (ppm)—Foliage.

Species	Cu	Zn	Mn	Al	B	Ti
Acacia stenophylla	152+	123	42	68	40	2
A. holosericea	125+	94	115	26	19	2
A. melanoxylon	78+	64	457	325	20	2
A. aneura	67+	76	863	130	37	1
A. shirleyi	59+	69	79	45	32	2
A. fimbriata	51+	33	83	97	16	5
A. salicina	50+	55	30	70	45	4
A. leptocarpa	46+	75	622	40	24	1
A. concurrens	41+	47	917	78	23	2
A. bidwillii	31	37	49	99	50	7
Brachychiton populneus	26	70	53	123	39	9
A. irrorata	24	43	99	116	20	6
A. flavescens	23	59	64	58	26	1
A. glaucocarpa	20	45	53	147	30	2
A. aulacocarpa	19	45	281	81	23	2
Commersonia bartramia	13	46	696	42	35	1
A. deanei	12	37	64	223	33	2
Eucalyptus angophloia	6	26	477	117	42	0
Melia azedarach	6	42	31	39	59	2
Alphitonia petriei	5	20	660	37	25	1
Albizia lebbeck	4	22	54	70	77	3
Cassia brewsteri	4	42	123	72	40	3

+ May be toxic depending on Mo levels.

Wilson (1977) and Everist (1969) who also reported provenance variations in palatability for two *Acacia* species in the present study (*A. aneura, A. shirleyi*).

There are no reliable indicators of intake for browse material from laboratory analyses alone—even high digestibility and protein levels do not necessarily correlate with high intake. Intake of browse can sometimes be stimulated by supplementation with nitrogen, sulfur and molasses (Niven and Entwistle 1983) and/or phosphorus (Ozanne et al. 1976) and intake of lignocellulosic material may also be increased by processing using physical, biological or chemical means (Wilkins 1982).

Tannins

The presence of tannins, which are known to affect the intake of foliage and the availability of nutrients in that foliage—such as sulfur (Gartner and Harwood 1976), was not evaluated in this study. Of the species tested here, *Acacia salicina* has been reported to have high tannin levels although this may vary with provenance.

Toxins

The fruit of *Melia azedarach* has poisoned pigs (Everist 1969), and the possibility of toxic compounds being present in these species should not be overlooked. The work done by Conn et al. (1985) and Maslin and Bennett (1985) on cyanogenic glycosides in acacias are studies which could be used as a basis for further research into toxic compounds.

Species Recommended for Further Study

The species are grouped below according to their estimated ability (based on the laboratory figures) to meet maintenance requirements (in vivo digestibility >50%), those below maintenance requirements (in vivo digestibility 40–50%) and those species where protein probably could not be efficiently extracted by animals (in vivo digestibility <40%). Species in the first two groups are suggested for further study on the basis of their reasonably high digestibility estimates and protein levels compared with the more well-known fodder species (in Australia)—*Acacia aneura* and *Brachychiton populneus* (these species are highlighted in the tables for easy reference):

Maintenance—*A. shirleyi, A. bidwillii, A. salicina, A. leptocarpa, Melia azedarach, Cassia brewsteri, Albizia lebbeck.*

Below maintenance—*A. melanoxylon, A. deanei, A. concurrens, A. stenophylla, A. glaucocarpa, A. fimbriata, A. holosericea.*

Not recommended—*A. irrorata, A. aulacocarpa, A. flavescens, Eucalyptus argophloia, Alphitonia petriei, Commersonia bartramia.*

Priorities for Further Research

1. *Variation within species grown in different environments*—Further laboratory studies should be carried out to determine the degree of variation that can be expected for these species growing under different soil and environmental conditions. This may give some indication of how the species will vary when grown overseas. For example, Meakins (1966) gives foliar mineral concentrations for *A. melanoxylon* which are considerably different from those recorded for this species in this study (P = 0.21%, K = 0.89%, Ca = 0.37%, Mg = 0.15%).

2. *Animal feeding trials*—The next step in evaluating the fodder potential of each species recommended for further study is to carry out feeding/nutrition studies involving animals. Intake and in vivo digestibility of each species should be assessed and ultimately the ability of the browse to increase production (animal weight, wool growth, milk yield) or reduce production losses should be evaluated. Useful conclusions could then be drawn on the value and limitations of a particular feed and standard samples of known in vivo digestibilities would then be available for future in vitro screenings of unknown species.

3. *Provenance variation*—Some seasonal variation in nutrient status and digestibility of browse foliage has been reported by McLeod (1973) and McDonald and Ternouth (1979) but very little work has been done on provenance variation and this research could be usefully incorporated into provenance trials for other characteristics.

4. *Forage processing*—Wilkins (1982) reports increases in digestibility, intake and liveweight gain by processing forage by various biological, chemical and mechanical means. The economics of these methods should be studied to ascertain their usefulness in developing countries.

5. *Early laboratory screenings*—Future early laboratory screenings might profitably concentrate on species with observed intake. However, observations are scarce and can depend on other factors such as the proximity of a species to a watering point and the presence of other plant species.

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Nutritive Value of *Acacia* Foliage and Pods for Animal Feeding

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TREES and shrubs are valuable components of grazing lands, and in most arid and semi-arid areas domestic ruminants obtain significant quantities of food from them (Unesco 1979). Trees taller than about 5 metres (including most members of the genus *Acacia*) provide shade and shelter for livestock, and can also keep fodder out of their reach until it is cut down. Trees also provide larger quantities of firewood and building poles than shrubbier plants. The canopies of woody plants protect soil from erosion by wind and raindrop impact and their deep roots act as soil stabilisers (Hall 1972) and nutrient pumps (Everist 1969); therefore they can also contribute indirectly towards sustaining grazing land productivity. In addition, the root nodules of most *Acacia* spp. fix atmospheric nitrogen.

Utilisation Systems

Trees and shrubs that contribute to animal diets can be managed in several ways. Firstly, shrubs and low trees may be browsed in situ; appropriate management aims, by seasonally controlling stocking rates, to avoid grazing the plants at times of the year or at growth stages when they are most susceptible to damage. Secondly, trees may be tall enough to be out of the reach of livestock so that animals only consume fallen leaves and pods. Thirdly, trees tall enough to avoid browsing may be lopped to provide fodder; this may damage some tree species if done injudiciously, or alternatively may provide an opportunity for careful management (Everist 1969). Fourthly, tree fodder may be cut and carried to the livestock, offering an opportunity for planned rationing and individual feeding.

Trees and shrubs for livestock feeding may already be part of the landscape and their subsequent distribution may be modified by selective clearing, for example by leaving stands near water supplies or by removing plants of unwanted size and species. However, when trees and shrubs are planted there is a wider choice of species and it is easier to plan their spatial arrangement, e.g. as shelter belts or as live fences (Sumberg 1983). The layout for alley cropping, in which cropped strips alternate with rows of trees planted at approximately 4 m intervals, may serve to provide long, narrow, fenced paddocks in which animals graze weeds and crop residues supplemented with cut browse. Research is still needed on appropriate species other than *Leucaena* and *Gliricidia* spp., and to determine how much of the foliage may be fed to animals and be returned to the land as dung rather than as mulch.

Biological Adaptations to Survival

Woody plants have developed mechanisms to defend themselves against herbivores such as mammals and arthropods (Coley 1983). These mechanisms can have direct and indirect effects on the nutritive value of the plants. Characteristics such as toughness, fibrosity and phenolic compounds (tannins) typify persistent tree species as opposed to pioneers. As leaves mature and become physically tougher and less digestible, tannin concentration decreases (Coley 1983; Provenza and Malechek 1983). Plants have also evolved other strategies to deter herbivores which include unpleasant aromas, toxins and structures such as thorns and hairs. Plants also have to contend with fungi, particularly if they are under moisture stress, and to do this their leaves may contain high levels of phenolics (Van Soest 1982) and volatile oils. Besides defenses against herbivores, plants have adaptations to counteract dehydration including a tough cutin-covered outer layer.

Nutritive Value

Composition

Chemical composition and organic matter digestibility of some representative *Acacia* species are shown in Table 1. The leaves of phyllodenous acacias tend to have higher crude fibre, lower crude protein and phosphorus content and lower organic

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Table 1. Chemical composition and organic matter digestibility (OMD) of leaves and pods of commonly eaten species of Acacia.

	Means and ranges								
	Crude protein (g/kg)	Ether extract (g/kg)	Crude fibre (g/kg)	Total ash (g/kg)	Calcium (g/kg)	Phosphorus (g/kg)	O M D in vivo	(g/g) in vitro	Method of utilisation*
Leaves									
Phyllodenous acacias									
A. aneura	122	35	288	49	11	0.9	0.47	0.41	D (S) B L
	(92–203)	(21–56)	(238–366)	(34–69)	(9–13)	(0.5–2.2)	(0.35–0.63)	(0.35–0.50)	
A. cambagei	121	45	148	125	23	0.7	—	0.44	(D) F
	(109–133)	(31–59)	(137–159)	(110–140)		(0.7)			
A. pendula	151	34	280	71	4	1.1	0.43	0.47	D (S) (B) L
	(132–164)		(255–296)	(56–89)		(0.8–1.3)	(0.43–0.43)	(0.43–0.50)	
Non-phyllodenous acacias									
A. farnesiana	198	37	171	71	5	2.2	—	0.60	S B
	(150–242)	(20–60)	(100–223)	(44–78)		(2.1–2.4)		(0.54–0.68)	
A. albida	178	22	178	76	12	2.0	0.53	—	S F L
	(171–197)	(15–30)	(124–215)	(64–86)	(10–14)	(1.4–2.5)			
A. seyal	182	30	158	64	14	2.6	—	—	S B L
	(111–293)	(12–68)	(84–228)	(10–84)	(6–38)	(1.4–3.8)			
Pods									
Phyllodenous acacias									
A. cambagei	177	—	—	—	12.1	2.5	—	—	S F
Non-phyllodenous acacias									
A. farnesiana	172	16	194	41	6	2.0	—	—	S B
A. albida	110	14	226	47	6	1.6	0.58	—	S F
	(56–143)	(9–25)	(144–296)	(32–100)	(2–11)	(0.5–2.8)			
A nilotica	113	18	166	52	7	1.8	0.66	—	S F B
	(88–131)	(8–30)	(123–285)	(39–88)	(4–11)	(1.3–2.8)			
A. seyal	194	18	199	65	9	5.1	—	—	S F B
	(171–213)	(12–26)	(186–216)	(52–93)	(8–13)	(2.5–10.0)			
A. tortilis	145	18	211	66	9	2.8	—	—	S F
	(104–178)	(8–31)	(175–259)	(54–84)	(5–13)	(1.6–3.6)			

* S—dry season supplement; D—drought fodder (non-deciduous); B—browsed *in situ*; F—fallen material eaten; L—lopping practiced; Parentheses denote that the practice is of minor importance.

Sources: Gohl (1981), Lamprey et al. (1980), Le Houerou (1980a,b), McDonald and Ternouth (1979), McLeod (1973), McMeniman et al. (1981), Skerman (1977).

matter digestibility than other members of the genus. Ether extract of all species is high and their ash content is moderate; ash (and calcium) tends to be higher in the bark of twigs (Lamprey et al. 1980). In general, pods have lower crude protein concentrations and rather higher organic matter digestibilities than leaves (Gohl 1981).

The leaves of *Acacia* spp. contain similar amounts of cell wall to the leaves of pasture legumes but less than is found in grasses. However, when one compares the cell wall composition of grasses and the leaves of *Acacia* spp. it is evident that the *Acacia* leaves have higher concentrations of lignin; the proportions of hemicellulose and cellulose in grasses and *Acacia* leaves are similar. There is no relationship between the cell wall content of *Acacia* leaves and their crude protein content (see Pellew 1980; Sen et al. 1978; Van Soest 1982).

Digestibility

The dry matter digestibility coefficient of *Acacia* leaves has not been determined for a large number of species but the available data indicate that it is relatively low, varying from 0.45 to 0.55. The lower values have been recorded for the phyllodenous species (Gohl 1981; McDonald and Ternouth 1979; McLeod 1973; McMeniman et al. 1981; Skerman 1977). This relatively low dry matter digestibility is probably associated with the high lignin content of the cell wall; fibre digestibility is inversely related to lignin content of the fibre (Van Soest 1982). Further depressions in dry matter digestibility can be caused by tannins, which appear to inhibit the activity of rumen microbes.

In pasture grasses and legumes the content of apparently digestible protein is related to their protein content (Milford and Minson 1965); 1 g/kg increase in crude protein content results in a 0.9 g/kg increase in digestible crude protein content. This is not the case for *Acacia* spp. and other browse leaves. The apparent digestiblity of crude protein tends to be lower than would be expected for grasses and legumes especially when tannins are present.

The leaves of many *Acacia* spp. contain tannins and it appears that tannins depress protein and organic matter digestibility (Barry and Manley 1984; McLeod 1974). Work with *Acacia aneura* (mulga) has shown how these depressions may be overcome. Mulga leaves contain a high (52–73 g/kg DM) tannic acid equivalent (Gartner and Hurwood 1976) and have a low (0.29) rumen digestibility of crude protein (N. P. McMeniman and I. F. Beale, unpublished data). Pritchard et al. (1985) have shown that their nutritive value can be improved by dosing mulga-red sheep orally with 8 g $head^{-1}$ day^{-1} polyethylene glycol (PEG) of molecular mass 4000. It is known that PEG displaces protein from tannin-protein complexes, but whether inactivation of tannins with PEG or other compounds is economic in practice is not yet known. Complete inactivation of tannins may not be necessary as small amounts of tannin in pasture legumes can protect some protein from breakdown in the rumen and allow it to be absorbed from the small intestine (Barry and Manley 1984).

Alternative but usually less effective methods of supplementation can be used to overcome the results of depressed protein digestibility of mulga leaves. The intake and dry matter digestibility of mulga are increased by supplementing sheep with molasses (Entwistle and Baird 1976; McMeniman 1976). Hoey et al. (1976) showed that this response was due to the sulfur content of the molasses. Presumably relatively high levels of tannin, by depressing protein digestion, reduce the quantity of sulfur available to the rumen microbial population and further depress their ability to digest dry matter. Increases in intake and live weight have been obtained when supplementary protein, i.e. 50 g/head/day of cottonseed meal was given in addition to sulfur (McMeniman et al. 1981). Field experiments with sheep (McMeniman and Little 1974; Niven and McMeniman 1983) and cattle (R. Clarke, pers. comm.) have shown that production responses including faster liveweight increase, faster wool growth and improved reproductive performance can be obtained by supplementing a mulga diet with sulfur (or molasses), phosphorus and protein.

Pods

Acacia pods provide food for livestock in large areas of the semi-arid zone of Africa, and the fact that the trees producing them tend to be above the animals' reach helps to prevent over-utilisation of such trees. Seeds tend to have low crude fibre content (Gohl 1981; Le Houerou 1980b; Skerman 1977), but those from several *Acacia* spp. pass through the gut of ruminants apparently intact. At Mpwapwa, Tanzania, the proportion of seeds of *Acacia tortilis* subsp. *spirocarpa* that passed through the gut of yearling cattle was in the order of 12% (Goodchild, unpublished data). Approximately 56% of the seeds had been attacked by an unidentified boring insect before being eaten and as a result were more likely to have their contents digested. Of the seeds that were intact when fed, less than 30% appeared in the faeces. In a grazing trial (Goodchild, unpublished data), milled pods with seeds provided a supplement of similar value to maize bran (0.17 and 0.35 kg, body mass increase of 173 and 133 g); unmilled pods, though palatable, did not increase liveweight significantly (68 to 88 g), suggesting that the nutritive value of the unmilled pods was little better than dry season grazing.

In Africa, much attention has been given to the nutritive value of pods (Table 1). In Australia, there are fewer reports of nutritive value, but mulga pods are much sought after by sheep, either on the trees or after they have ripened and fallen (Everist 1969).

Toxic Compounds in *Acacia* Leaves and Pods

Apart from tannins that have already been referred to, the leaves, flowers and pods of several *Acacia* spp. contain potentially toxic compounds. The available data are summarised in Table 2. Poisoning is not common and stock are only likely to be affected if they consume abnormally large quantities of components containing the toxins. This usually occurs when the animals are hungry or are unfamiliar with the plant. The concentrations of toxins vary with plant part, stage of growth and geographical location (Hall 1972; Table 2). Hydrogen cyanide is possibly the most serious toxin occurring in acacias; it appears that this poison is released when two compounds in the plant, a cyanogenic glycoside and a hydrolysing enzyme react in the animal's digestive tract. In ruminants, the rumen contents tend to buffer the absorption of cyanide.

Palatability

There are pronounced species differences in palatability within the genus *Acacia* (Cunningham et al. 1981; Everist 1969; Hall 1972). Little is known about the factors affecting palatability, although some observations suggest that volatile oils are responsible in the case of mulga. Melville (1947) in Western Australia noted that the acceptability of mulga for sheep increased with age of the tree and that this was associated with a decrease in the ether extract content of the leaves. In Queensland, the leaves from vigorous 'sappy' mulga trees are not readily eaten, and allowing lopped mulga foliage to lose volatile matter before feeding increases its acceptability.

Browse-Herbage Interactions

Nutritional Value

The hypothesis that browse can be used as a supplement when grasses are mature and have a low nutritive value is being examined in our laboratory (Goodchild, unpublished data). Graded quantities of fresh mulga (*Acacia aneura*) were fed with a low-quality sorghum stubble diet. The mulga contained five times as much protein per kilogram of dry matter as the stubble. The mulga supplement only slightly increased rumen ammonia concentrations

Table 2. Toxic compounds in *Acacia* spp. leaves and pods for ruminants.

Species	Part of plant	Toxin	Reference
aneura	leaf	oxalate	1
	leaf	tannin	1
burrowii	flowers	hydrogen cyanide	2
cambagei	leaf	hydrogen cyanide	2
	timber, bark	oxalate	2
cana	browse	selenium	2
deanei	browse	hydrogen cyanide	2
decora	browse	sheep abortion suspected	2
doratoxylon	browse	cyanogenic glycoside, but no hydrolytic enzyme	2
georgina	browse	hydrolytic enzyme only	3
	seeds and pods	fluoroacetate	4
*giraffae**	unripe pods	†	5
implexa	unripe pods	†	2
longifolia	browse	hydrogen cyanide	2
murrayana	browse	†	2
paradoxa	browse	†	2
salicina	leaf and bark	tannin	3,4
	pods	saponin	3,4

* The only non-phyllodenous species listed here.
† Stock mortality suggests the presence of a toxin that has not been identified.
References: 1. Gartner and Hurwood (1976); 2. Cunningham et al. (1981); 3. Hall (1972); 4. Everist (1969); 5. Gohl (1981).

Table 3. Voluntary intake, digestibility and concentrations of rumen ammonia in sheep offered sorghum stubble supplemented with fresh mulga and minerals† (3 sheep/treatment).

	Mulga, % of dry matter intake				
	0	13	27	42	0*
Crude protein, g/kg	20	32	47	62	55
Voluntary DM intake, g/kg body mass	15	18	23	23	28
DM digestible coefficient	0.39	0.32	0.31	0.28	0.35
Rumen ammonia, mg/l:					
minimum	6	6	8	13	53
maximum	18	24	28	27	275
Apparently digestible crude protein, g/kg	-18	-11	-2	2	14

* Diet supplemented with urea, 1.5 g/kg DM.
† Mineral supplement contained 0.75 g P, 1.12 g Ca, 1.26 g Na, 0.67 g S and trace amounts of Co, I, Se and Zn daily.

(Table 3), indicating that the protein in mulga was not being broken down rapidly in the rumen. Mulga at the highest inclusion level increased the crude protein content of the total diet by 42 g/kg; however, digestible crude protein only increased by 20 g/kg, suggesting a tannin effect as noted above.

Dry matter digestibility declined with increasing amounts of mulga in the diet, despite intakes being high. A depression of digestibility larger than would be expected by mixing two foods was also seen by Shorrock (1981) in oesophageal fistula samples from animals eating browse-grass mixtures; he suggested that tannins in the browse were interfering with the digestion of the grass.

While these results suggest that mulga cannot be used to improve the quantity of nutrients obtained from a mature pasture, the leaves could still be used to extend the period of grazing on a grass pasture providing sufficient trees were available.

Yield of Edible Material

In mulga, Pressland (1975) found that relationships existed between leaf and wood yield and tree bole circumference 30 cm above the ground. He concluded that trees with a circumference of between 40 and 60 cm yielding 10–24 kg of dry leaf per tree would be 'ideal fodder trees' and noted that such trees would be found in forests with a density of 660–1100 trees/ha and the forest would be about 60 years old.

The ideal number of trees to have in a mulga/grassland association is not clear. Several studies (Beale 1973; Pressland 1974) have shown that even low densities (40 ha^{-1}) can significantly depress herbage growth and Beale (1973) and Pressland (1975) have suggested that the best way to conserve mulga for drought feeding may be to reserve a portion (40%) of the grazing area as mulga forest.

Conclusion

Under Australian conditions, the acacias that are present in sufficient quantities to contribute significantly to ruminant diets have a relatively low nutritive value. For at least one of these species (*Acacia aneura*), methods of supplementation have been devised which partially alleviate the depressed nutritive value. However acacias, even if they do only provide a maintenance diet, can provide a valuable store of nutrients that can be used during periods when herbage is in short supply. In addition, *Acacia* spp. provide shade, shelter, erosion control, combustible fuel and building materials, and these should be important considerations where these commodities are in short supply.

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Cyanogenic Australian Species of *Acacia*: A Preliminary Account of Their Toxicity Potential

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CYANOGENESIS is the process whereby hydrogen cyanide (HCN) is produced when cyanogenic substrates (usually glucosides) are brought into contact with enzymes that catalyse their breakdown. To date cyanogenesis has been recorded in at least 2050 plant species from about 110 families (Gibbs 1974; Hegnauer 1977).

Hydrogen cyanide is a moderately toxic substance which affects a wide range of organisms (Harborne 1982). Many commonly consumed legumes are reported to be cyanogenic; however, the amount of cyanide produced by most of these species is quite low and they pose little, if any, human or domestic animal health problem (Seigler et al. in press). Generally, only plants that produce more than 20 mg of HCN per 100 g (= 7.5 μmol/g) fresh weight are considered dangerous (Everist 1981).

Finnemore and Gledhill (1928) first reported cyanogenesis in Australian species of *Acacia*. Of 62 species examined they found that *A. cheelii, A. cunninghamii*†, *A. doratoxylon* and *A. glaucescens* (= *A. binervia*) released HCN provided an extract of sweet almonds was added to their fresh phyllode homogenate. Finnemore and Cox (1928) subsequently isolated the cyanogenic glycoside sambunigrin from *A. cheelii* and *A. glaucescens*. Other early reports of cyanogenesis in Australian acacias appeared in Hurst (1942) and Gardner and Bennetts (1956). Everest (1981) lists reports of livestock poisoning under field conditions by *A. binervia, A. cunninghamii* sens. lat. and *A. sparsiflora*.

The aim of the present study is to provide a preliminary assessment of the toxic potential of cyanogenic Australian species of *Acacia*. Our data were derived during the course of a chemotaxonomic survey of cyanogenesis in Australian species of *Acacia*. The results of this survey will be published elsewhere.

Methods

In order to locate cyanogenic individuals a mass screening procedure was adopted using foliage from both herbarium specimens and living plants. Our method of testing for the presence of cyanogenic glucosides is described in Conn et al. (1985) but it is emphasised that in all cases the test procedure involved the addition of a β-glucoside hydrolysing enzyme to the tissue homogenates. Bulk foliar material (100 g or more) was subsequently collected from living plants of many of the species giving a positive test for cyanogenesis. This material was airfreighted to Davis, California, where the glucosides were characterised by NMR or GLC spectroscopy. Prior to characterisation a sample of most bulk collections was tested with Feigl-Anger papers (fide Tantisewie et al. 1969) for its ability to release HCN without the addition of β-glucosidase. Samples which gave a strong, positive Feigl-Anger test within a few hours possessed a specific β-glucosidase which hydrolysed the cyanogen(s) present. Samples which yielded a weak positive reaction after 24 hours or more may possess a non-specific β-glucosidase. They clearly, however, lacked a more substrate-specific enzyme capable of rapidly hydrolising the cyanogenic substrate(s). Samples giving a negative Feigl-Anger test lacked enzyme.

The method employed for the quantitative determination of the cyanogenic glucoside will be described elsewhere.

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† In the past there has been considerable confusion concerning the name *A. cunninghamii*. This name has been applied in an extremely broad sense to *A. concurrens, A. crassa, A. cretata, A. leiocalyx, A. longispicata* and *A. tropica* (Pedley 1974 and 1978). As noted by Everist (1981), it is now not possible to determine with certainty the correct identity of plants described as toxic under the name *A. cunninghamii*.

Table 1. Cyanogenic Australian species of *Acacia* arranged according to the quantity of foliar cyanogenic glucoside. Unless otherwise stated the HCN and enzyme results (columns 2 & 3) are based on a vouchered bulk sample (column 5) collected from living plants in Australia; chemical analyses were conducted in Davis, California.

Taxon (Section)[1]	HCN produced (μmol/g)[2]	Endogenous hydrolysing enzyme[3]	Distribution[4]	Voucher specimen
A. caroleae (J)	90.0	Absent	Q, NSW	CBG 8500771 (CBG)
A. caroleae (J)	75.0	? Present[5]	Q, NSW	N. Hall 84/53 (PERTH)
A. signata (J) ('*yorkrakinensis*' variant)	71.0	Absent	WA	E. E. Conn 18-82 (PERTH)
A. cheelii (J)	62.0	Absent	NSW	CBG 8500774 (CBG)
A. exilis (J)	56.7	Unknown	WA	B. R. Maslin 4666 (PERTH)
A. atkinsiana (J)	54.0	Present	WA	K. Atkins 1268 (PERTH)
A. binervia (J)	51.5	Absent	NSW	E.E. Conn s.n. (AD)
A. sutherlandii (A)	51.0	Present	NT, Q	N. Hall 84/27 (BRI, PERTH)
A. pulchella var. *goadbyi* (P) (Typical variant)	47.3	Absent	WA	B. Grivell s.n. (AD, PERTH, UCD)
A. yorkrakinensis (J)	42.0	Absent	WA	E. E. Conn 2-82 (PERTH)
A. atkinsiana (J)	40.3	Present	WA	K. Atkins 1263 (PERTH)
A. lasiocalyx (J)	32.7	Absent	WA	E. E. Conn 40-82 (PERTH)
A. curvinervia (J)	28.0	Absent	Q	R. E. Cottam s.n. (BRI)
A. caroleae (J)	27.9	? Present[5]	Q, NSW	N. Hall 83/76 (PERTH)
A. lasiocalyx (J)	27.5	Absent	WA	E. E. Conn 41-82 (PERTH)
A. pycnostachya (J)	25.0	Absent	NSW	N. Hall 84/51 (PERTH)
A. atkinsiana (J)	25.0	Present	WA	K. Atkins 1264 (PERTH)
A. doratoxylon (J)	23.0	Absent	NSW, ACT, V	N. Hall 84/58 (PERTH)
A. sibina (J)	20.3	Absent	WA	B. R. Maslin 5314 (PERTH)
A. blakei (J)	19.1	Present	Q, NSW	H. Dillewaard 907 (BRI)
A. sparsiflora (J)	18.8	Absent	Q	N. Hall 83/70 (PERTH)
A. granitica (J)	17.5	Absent	Q, NSW	N. Hall 83/20 (PERTH)
A. pulchella var. *glaberrima* (P) (Wannamal variant)	14.9	Polymorphic[6]	WA	B. R. Maslin 5503 (PERTH)
A. sutherlandii (A)	13.2	Unknown	NT, Q	N. Hall 84/27 (BRI, PERTH)
A. polybotrya (B)	c.10.0	Unknown	Q, NSW	N. Hall 85/6 (PERTH)
A. olgana (J)	9.5	Present	WA, NT, SA	D. V. Matthews 441 (NT)
A. conniana (J)	9.4	Unknown	WA	S. D. Hopper s.n. (PERTH 00582131)
A. deanei subsp. *paucijuga* (B)	8.4	Unknown	NSW, V	N. Hall 85/10 (PERTH)
A. diphylla (J)	8.3	Absent	NSW	N. Hall 84/5 (PERTH)
A. pulchella var. *reflexa* (P)	8.0	Unknown	WA	B. R. Maslin 5758 (PERTH)
A. longiphyllodinea (J)	7.4	Absent	WA	B. R. Maslin 5316 (PERTH)
A. resinomarginea (J)	6.8	Absent	WA	E. E. Conn 20-82 (PERTH)
A. doratoxylon (J)	6.5	Absent	NSW, ACT, V	CBG 8500772 (CBG)
A. beauverdiana (J)	5.9	Absent	WA	E. E. Conn 15-82 (PERTH)
A. ? schinoides (B)[7]	5-10	Trace	Cultivated	CBG 8500770 (CBG)
A. ? schinoides (B)[7]	5-10	Trace	Cultivated	CBG 8317443 (CBG)
A. adsurgens (J)	5.1	Absent	WA, NT, Q	B. R. Maslin 5280 (PERTH)
A. farnesiana (A)	5.1	Trace	Cultivated	Secor et al. (1976)
A. sibina (J)	4.9	Absent	WA	B. R. Maslin 5314 (PERTH)
A. olgana (J)	4.8	Present	WA, NT, SA	D. V. Matthews 468 (NT)
A. julifera subsp. *julifera* (J)	4.4	Absent	Q, NSW	N. Hall 83/39 (PERTH)
A. gracillima (J)	4.3	? Present[5]	WA	T. Willing 75 (PERTH)
A. adsurgens (J)	3.7	Absent	WA, NT, Q	B. R. Maslin 5281 (PERTH)
A. pulchella var. *reflexa* (P)	2.6	Unknown	WA	S. D. Hopper s.n. (PERTH 00174378)
A. trachycarpa (J)	2.1	Absent	WA	B. R. Maslin 5356 (PERTH)
A. pachyphloia (A)	2.0	Absent	WA, NT	T. Willing 74 (PERTH)
A. signata (J) (Typical variant)	1.2	Absent	WA	B. R. Maslin 5158 (PERTH)
A. gracillima (J)	1.0	Absent	WA	T. Willing 88 (PERTH)

Taxon (Section)[1]	HCN produced (μmol/g)[2]	Endogenous hydrolysing enzyme[3]	Distribution[4]	Voucher specimen
A. pubifolia (J)	0.90	Absent	Q	N. Hall 83/17 (PERTH)
A. stowardii (J)	0.90	Present	WA, NT, SA Q, NSW	B. R. Maslin 5571C (PERTH)
A. sibina (J)	0.50	Absent	WA	B. R. Maslin 5308 (PERTH)
A. aff. *blakei* (J)	0.41	Absent	Q	L. Pedley 4952 (BRI)
A. parramattensis (B)	0.37	Absent	NSW, ACT	Unvouchered, cf. Secor et al. 1976
A. pulchella var. *glaberrima* (P) (Wannamal variant)	0.26	Unknown	WA	B. R. Maslin 5764 (PERTH)
A. trachycarpa (J)	0.20	Absent	WA	B. R. Maslin 5357 (PERTH)
A. deanei subsp. *paucijuga* (B)	0.16	Absent	NSW, V	Unvouchered, cf. Secor et al. 1976
A. diphylla (J)	0.11	Unknown	NSW	N. Hall 83/12,22 (both PERTH)
A. diphylla (J)	0.00	Unknown	NSW	
A. aff. *atkinsiana* (J)	Cyanogenic species for which no bulk material is available for chemical analyses.			
A. burrowii (J)				
A. aff. *citrinoviridis* (J)				
A. deanei subsp. *deanei* (B)				
A. gonocarpa (J)				
A. kempeana (J)				
A. aff. *kempeana* (J)				
A. lysiphloia (J)				
A. aff. *macdonnelliensis* (J)				
A. pulchella var. *glaberrima* (P)				
A. pulchella var. *pulchella* (P)				
A. pulchella var. *subsessilis* (P)				
A. pulchella var. ? (P)				
A. rhodophloia (P)				

[1] Abbreviations for sections: A—*Acacia*, B—*Botrycephalae*, J—*Juliflorae*, P—*Pulchellae* (fide Pedley 1978).
[2] Values were obtained in the presence of added β-glucosidase.
[3] Presence of enzyme determined by Feigl-Anger test (fide Tantisewie et al. 1969).
[4] Abbreviations refer to States of Australia. Maps showing distribution of described species are given in Maslin and Pedley (1982).
[5] This sample appears to possess a non-specific enzyme capable of slowly hydrolysing a small proportion of the glucoside component.
[6] Seven bulk samples were collected from the population vouchered by B. R. Maslin 5503. These were tested at Perth for the presence of enzyme and found to be polymorphic (see text for discussion).
[7] Analysis performed in Adelaide on plants cultivated at Canberra Botanic Garden; these plants appear to be hybrids involving *A. schinoides* (and possibly *A. deanei* subsp. *paucijuga*).

Results and Discussion

The 46‡ Australian species of *Acacia* which released HCN in the presence of added β-glucoside hydrolysing enzyme are listed in Table 1. Bulk foliar material was collected from 32 of these species and in some cases multiple samples were obtained. The amount of HCN produced and the enzyme status of each sample is shown in Table 1.

The toxicity of cyanogenic plants depends on a number of factors, some pertaining to the plants and others to animals which feed on the plants. Animal factors such as type, size and condition of beast, rate and quantity of plant material devoured, rate of absorption, presence of endogenous detoxifying mechanisms, etc., are not discussed here (fide Conn 1979). Instead, we consider the cyanogenic properties of plants of Australian *Acacia* species and attempt to assess their potential toxicity.

‡ This total includes *A. farnesiana* which is probably an early introduction into Australia (Pedley 1979).

Quantity of HCN Produced

As shown in Table 1 the quantity of HCN produced by Australian cyanogenic *Acacia* species varies considerably (90–0.11 μmol/g). Species producing large amounts of HCN (more than 20 μmol/g) occur in three of the four sections in which cyanogenesis has been recorded, namely, section *Acacia* (*A. sutherlandii*), section *Juliflorae* (*A. atkinsiana, A. binervia, A. caroleae, A. cheelii, A. curvinervia, A. doratoxylon, A. exilis, A. lasiocalyx, A. pycnostachya, A. sibina, A. signata* and *A. yorkrakinensis*), and section *Pulchellae* (*A. pulchella* var. *goadbyi*). These species occur primarily in the arid, semi-arid and subtropical areas of Queensland, New South Wales and Western Australia (Conn et al. 1985; Maslin and Pedley 1982). Species with HCN levels less than 20 μmol/g occur in section Botrycephalae and also in the three above-mentioned sections. Quantitative data on the amount of HCN produced is required for 11 of the 46 Australian *Acacia* species which are known (at least qualitatively) to produce HCN in the presence of added β-glucosidase.

From the limited multiple testings undertaken it is evident that within many species there is a wide range of variation with respect to the amount of HCN produced. For example: *A. atkinsiana* (25–54 μmol/g), *A. caroleae* (27.9–90 μmol/g), *A. diphylla* (0–8.3 μmol/g), *A. doratoxylon* (6.5–23 μmol/g), *A. pulchella* var. *glaberrima*—Wannamal variant (0.26–14.9 μmol/g), *A. sibina* (0.5–20.3 μmol/g) and *A. sutherlandii* (13.2–51 μmol/g). In *A. signata* (1.2–71 μmol/g) the extreme HCN variation probably indicates that more than one species is currently included under this name.

The HCN values given in Table 1 should be interpreted cautiously. Most analyses were conducted at Davis, usually 1–2 months after the plant material was collected in Australia, and thus tissue water loss will undoubtedly have occurred, especially from soft-foliaged, bipinnate species from sections Acacia and Pulchellae (see later). Furthermore, it is not known whether there was loss of cyanogenic substrate during the period of transportation and storage. Apart from experimental procedure other factors need to be considered when interpreting the HCN levels recorded in Table 1 (see below).

Hydrolysing Enzyme(s)

Most samples listed in Table 1 were examined for their ability to hydrolyse their contained cyanogens in the absence of added β-glucosidase. It was shown that five species§, *A. atkinsiana, A. blakei, A. olgana, A. stowardii* and *A. sutherlandii*, rapidly produced HCN and therefore probably possess an endogenous enzyme which is substrate-specific for cyanogenic glucosides. Of the other species examined the enzyme was either absent, present in only trace amounts (*A. ? schinoides*) or non-specific for the cyanogenic substrate (*A. caroleae, A. gracillima).*

Very little is known concerning variation/polymorphism within the enzyme system. The only population which we examined from this viewpoint was the one from which B. R. Maslin 5503 (*A. pulchella* var. *glaberrima*—Wannamal variant) was collected. Of the seven plants tested for enzyme, six reacted positive (one within 1 hour, five within 6 hours) and one reacted negative. These results strongly suggest that this variety is polymorphic for enzyme. Data on a wider range of species is clearly required.

Polymorphism and Variation

Variation and polymorphism for the presence/absence of cyanogenic compounds and their hydrolytic enzymes is common in cyanogenic plants and there are many factors which contribute to this, e.g. genetical, ecological, seasonal, time of day, age of plant, part of plant sampled (Seigler et al. in press, for discussion in context of Leguminosae). Variation in HCN and enzyme production for samples included in the present study are discussed earlier and also in Conn et al. (1985). The fact that in many cases not every plant within a population of a known cyanogenic species will actually produce and accumulate glycoside and glycosidase has important ecological and agricultural implications.

Toxic Potential of Australian Acacias

The toxic potential of a cyanogenic individual will depend upon the amount of cyanogenic glucoside present and whether it possesses an enzyme system capable of hydrolising the cyanogen(s) to liberate HCN. Thus, individuals which can produce large amounts of HCN and which also possess endogenous β-glucosidases would have the highest toxic potential. The minimum danger level for cyanogenic glucosides is generally accepted as about 20 mg of HCN per 100 g (= 7.5 μmol/g) fresh weight of plant (Everist 1981). Allowing for a loss of 75% of the water in the plant material between collection and extraction it seems reasonable that our plants which produce at least about 20 μmol/g HCN must be treated cautiously. Species within this range and which also possess a β-glucosidase are *A. atkinsiana* and *A. sutherlandii.* These two species must therefore be considered the most potentially dangerous of the Australian cyanogenic acacias. To date neither species has been incriminated in stock losses. Curiously though, Everist (1969) lists *A. sutherlandii* as being eaten readily by sheep and cattle. In this case it is possible there is some effective detoxification mechanism within the animal preventing poisoning, or alternatively the species may be polymorphic for glucoside and/or enzyme. It is noted, however, that the relatively few samples of *A. sutherlandii* which we

§ In Conn et al. (1985) *A. deanei* subsp. paucijuga and *A. lasiocalyx* were erroneously included in this group.

have examined to date do not show polymorphism for glucoside. The other species (except *A. exilis*) containing more than 20 μmol/g HCN (Table 1) do not possess a substrate-specific enzyme capable of rapidly releasing HCN and therefore are to be considered potentially less toxic than either *A. atkinsiana* or *A. sutherlandii.* However, *A. binervia* (51.5 μmol/g) which lacks endogenous enzyme has been implicated in cyanide poisoning of livestock (Hurst 1942). Hurst suggested that glucoside hydrolysis may have occurred in the animals' digestive tract in the presence of enzyme(s) contained in other plants consumed at the same time (e.g. *Medicago*). *Acacia cheelii* also produces a large amount of HCN (62 μol/g) and lacks an endogenous β-glucosidase. Hurst (1942) reports that this species is stated to be highly valued as a fodder tree in various parts of New South Wales. Of the *Acacia* species listed by Everist (1969) as fodder plants five are shown in our Table 1 to release HCN in the presence of added enzyme, viz. *A. caroleae* (listed by Everist as *A. doratoxylon*), *A. deanei, A. farnesiana, A. lysiphloia* and *A. sparsiflora.* With the exception of *A. caroleae* these species contain relatively low amounts of cyanogenic glucoside. Endogenous β-glucosidase has not been found in *A. caroleae, A. farnesiana* and *A. sparsiflora; A. deanei* and *A. lysiphloia* have not been examined for enzyme.

As many cyanogenic species seem to vary considerably in the levels of HCN produced it is probable that some taxa currently placed below the rather arbitrary limit of 20 μmol/g will eventually be relocated within the higher-risk category. Similarly, individuals of some species currently thought to lack endogenous β-glucosidase may prove to possess such an enzyme. It has been suggested previously (Conn et al. 1985) that the apparent general absence of endogenous catabolic enzymes in the Australian cyanogenic *Acacia* flora might be the reason which has prevented poisoning by species which contain dangerously high levels of cyanogenic glucosides.

Three species, *A. dilatata, A. longifolia* and *A. oswaldii* are listed by Hurst (1942), Gardner and Bennetts (1956) and Everist (1981) to be cyanogenic but we have been unable to confirm these findings. With the possible exception of *A. oswaldii* it is highly unlikely that these species will be shown to be cyanogenic.

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Contribution of Australian Acacias to Human Nutrition

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IN the face of growing world population, one of the major problems confronting developing countries is that of food production. However, aridity, soil salinity and infertility render a great deal of the earth's tropical lands unsuitable for traditional agriculture in the form of grain crops, fruit trees, or livestock. Additionally, deforestation for various reasons has degraded large tracts of land by contributing to soil erosion and nutrient removal, and adversely altering micro-climate and catchment hydrology. In these situations, Australian forestry research has much to offer, as a great deal of our dry continent supports tree species which are well suited to reforestation of arid or infertile lands.

Such programs are invariably aimed at production of stock fodder and fuelwood, erosion prevention, and related needs. Little thought is given to the possible utilisation of Australian trees species for human food. In fact, little is known of the food potential of any of Australia's native flora. Only the genus *Macadamia* is exploited commercially, having undergone rigorous selection to improve quality and yield. A great many other Australian fruits, nuts and seeds are undoubtedly, as Cribb and Cribb (1974) describe them, 'in the crab-apple stage of development.' While it may seem extravagant to suggest that Australian acacias could achieve the status of food crop in their own right, they are a food resource and may have the potential to supplement the often limited food reserves of developing countries.

Acacias as Food

The earliest visits to Australian shores by Europeans generated rather unfavourable reports of the food potential of endemic plants. A few early explorers, such as Leichhardt and Grey, sampled many native food plants, but even Grey (1841) considered the perceived blandness of the Kimberley landscape to require modification and spent a whole day planting 'the most useful fruit and vegetables'. Early settlers understandably felt a need to grow familiar foods from their countries of origin, and little attempt was made to use local species.

Although the Australian Aborigines had clearly subsisted on native food resources for many thousands of years, a century of European settlement was to pass before any serious attempts were made at tabulation of local resources. The work of Roth (1897, 1901) in Northern and Western Queensland first revealed details of the precise resources used by Aboriginal people. Even in those early studies, the importance of acacias as staple foods at certain times of the year was evident. A wealth of anthropological and ethnobotanical research has been conducted since then (Golson 1971; Gould 1969a,b; Harris 1974; Hiddins 1980; Meggit 1957; Peterson 1978; Thomson 1939, etc.) and the invaluable role of acacias in the nutrition of Aboriginal people, particularly in the arid centre, is now well documented.

Some 50 of the 800 species of *Acacia* have been recorded as food items in the diet of Australian Aborigines (Brand and Cherikoff 1985), and many others had various cultural uses relating to medicine or tool and weapon construction. Twenty acacias appear to have been staple foods: they are listed in Table 1, together with the food resource provided by each species and appropriate references to the literature.

A great many of Australia's native plant foods are inedible or unpalatable raw or untreated, and many of the acacias fall into this category. Some are poisonous: *A. georginae* is known to be toxic to stock. The techniques developed by Aboriginal people over many thousands of years undoubtedly represent the best methods for treatment prior to human consumption. Three main methods of food preparation were employed, relating primarily to the type of food resource being utilised. These are described below.

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Ripe Seed Dry seeds were collected in large quantities either by stripping them from the pods on the bush into suitable containers or by winnowing fallen seeds, pods and litter from beneath the tree. Using stone implements, the seeds were ground up into a coarse 'flour' which was then mixed with a little water to form an unleavened paste or dough. Small flattened 'johnny-cakes' or larger 'dampers' were then baked on hot stones or in the ashes of a fire.

Unripe Seed Green pods were collected from the bushes and lightly roasted on hot stones or in the ashes. The seeds were then picked out of the pods and eaten. In some cases, the pods were steamed rather than roasted. The entire pods of *A. tumida* were eaten raw by Kimberley Aborigines, though cooked pods were discarded after picking out the seeds (Crawford 1982).

Gum Many species of *Acacia* produce edible gum, however it is not considered a staple food and only those species with additional food resources are included in Table 1. The gum seeps from wounds in the trunk or branches of bushes. It can be sucked, or steeped in a small quantity of water for a few hours to produce an edible 'jelly'.

Nutritional analyses of the food resources of *Acacia* species have produced some noteworthy results. The seeds of nine species, and gum from an additional species, from arid and semi-arid areas of Australia have been analysed by Brand and Cherikoff (1985), Brand et al. (1985), Maggiore (1985) and Peterson (1978). Their results are shown in Table 2.

The nutrient content of Australian *Acacia* seeds is outstanding in that protein, fat and energy values are considerably higher than those for traditional seed-crops such as wheat and rice. Brand and Cherikoff (1985) attribute this to the fact that acacias are legumes and hence exhibit a nutrient composition more typical of that family.

Table 1. *Acacia* species used as staple foods by Australian Aborigines.

Species	Food	Authors
aneura	ripe seeds	Cribb and Cribb 1974; Leiper n.d.; Meggitt 1957; Peterson 1978
complanata	ripe seeds	Leiper n.d.
coriacea	unripe seeds, ripe seeds	Brand et al. 1985; Meggitt 1957; Peterson 1978
cowleana	ripe seeds	Brand and Cherikoff 1985; Peterson 1978
dictyophleba	ripe seeds	Peterson 1978
estrophiolata	ripe seeds, gum	Brand and Cherikoff 1985; Meggitt 1957
farnesiana	unripe seeds	Leiper n.d.
holosericea	unripe seeds	Cribb and Cribb 1974; Hiddins 1980; Leiper n.d.; Peterson 1978
kempeana	unripe seeds, ripe seeds	Hiddins 1980; Meggitt 1957; Peterson 1978
longifolia	unripe seeds	Cribb and Cribb 1974
murrayana	unripe seeds, ripe seeds	Brand et al. 1985, Hiddins 1980
notabilis	ripe seeds, gum	Meggitt 1957
oswaldii	ripe(?) seeds	Cribb and Cribb 1974
pachycarpa	ripe seeds	Brand and Cherikoff 1985
retinoides	ripe(?) seeds	Cribb and Cribb 1974
sophorae	unripe seeds	Leiper n.d.
stenophylla	unripe seeds	Cribb and Cribb 1974
tenuissima	ripe seeds	Brand et al. 1985; Peterson 1978
tumida	unripe seeds, green pods	Crawford 1982
victoriae	unripe seeds, ripe seeds	Brand et al. 1985; Hiddins 1980; Peterson 1978

Table 2. Macronutrient composition of food resources from Australian *Acacia*. (Where a separate value is not given for Fibre, the C.H.O. value represents Total Carbohydrate.)

Species	Food source	Water %	Protein g/100 g	Fat g/100 g	C.H.O. g/100 g	Fibre g/100 g	Energy kJ
aneura	seed	4.3	23.3	37.0	25.5	—	2220
coriacea	(green) seed	56.8	23.7	3.3	6.4	8.2	627
	seed (a)	4.1	20.9	9.3	33.8	28.2	1240
	seed (b)	17.0	23.8	7.7	48.1	—	1491
cowleana	seed (a)	15.6	22.2	10.1	44.6	—	1507
	seed (b)	5.5	23.4	9.8	36.4	—	—
dictyophleba	seed	11.2	26.8	6.3	49.0	—	1519
estrophiolata	gum	7.1	0.2	0.0	89.1	0.0	1429
kempeana	seed	5.6	22.9	10.2	51.0	—	1631
murrayana	seed	5.4	18.1	5.8	37.6	28.9	1107
pachycarpa	seed	7.1	22.2	8.3	57.1	—	1598
tenuissima	seed (a)	1.6	25.0	15.6	29.2	25.7	1469
	seed (b)	14.5	24.8	16.4	33.0	—	1592
victoriae	seed	4.9	17.0	3.8	40.8	29.4	1082

Conclusions

Australian acacias clearly exhibit potential for investigation as a supplementary source of human nutrition in developing countries. Their development as a food crop may not be justifiable at the present time, though the outstanding nutritional status of *Acacia* seeds, and the group's general tolerance of adverse growing conditions, are favourable characteristics of a potential crop species.

Virtually nothing is known of the potential yield of seed from acacias, though revegetation trials at Mount Isa Mines (Anton Schmid, pers. comm.) and Gove (Hinz 1981) indicate that several of the species listed above set seed after 2–5 years and that large quantities are produced by mature trees in wet years. Figures for the population density of Aborigines subsisting partly on *Acacia* seeds in Central Australia are less encouraging. Estimates vary from one adult per 200 km^2 to one person per 12.6 km^2 (Peterson 1978), however it must be remembered that acacias crop heavily for a limited period and Australian Aborigines did not appear to practise any long-term food storage. Moreover, *Acacia* seeds were collected manually by small groups of people over a wide area, and there is no doubt that only a small fraction of the available resource was utilised.

It is clear that the food potential of this group of plants should not be ignored. At the very least, the choice of species for export to other countries for cattle feed, fuelwood, etc. could be influenced by their additional potential to supplement the human diet in times of food shortage. Long-term research into harvesting, processing, and storage technologies, and selection for improved quality and yield, could perhaps be worthy of consideration if these initial goals were achieved.

While there is no doubt that Australian acacias can and do contribute to human nutrition, whether or not they have such a role in the future of developing countries can only be answered by increased research in this neglected field.

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Use of Australian Acacias in North Africa

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THE countries of North Africa are Morocco, Algeria, Tunisia (together known as the 'Maghreb'), Libya and Egypt. The southern parts of each belong to one of the largest deserts in the world. The Maghreb countries have similar geographic and climatic characteristics, whereas Libya and Egypt have different geographic features and climate. Deserts represent 85% of their total surface area while arid, semi-arid and sub-humid/humid zones represent 10, 3 and 2% respectively. Areas of natural vegetation, forests and agriculture of economic importance are confined to the narrow coastal strips, mountains and Nile Valley and Delta. The natural forests of the Maghreb cover a vast area, but are mostly degraded and over-exploited. The species remaining include members of the genera *Quercus, Argania, Pistacia, Cedrus, Abies, Cupressus, Juniperus* and *Pinus*. There are some natural scrub forests of *Quercus, Cupressus* and *Juniperus* species on the Libyan plateau. In the rest of Libya and Egypt, the natural tree vegetation is very sparse and consists mainly of *Tamarix articulata, Zizyphus lotus* and *Acacia tortilis*.

All of the North African countries have had to rely on exotic tree species to supply their needs for timber and other products, because of their diminished natural forest resources. Many species were introduced to North Africa, notably from Australia, including several members of the genera *Eucalyptus, Acacia* and *Casuarina*. Introductions from other countries include species of *Pinus* and *Prosopis*.

Acacia Species in the Region

The North African countries have a limited number of native acacias. If the Sudan is included, important native species are: *A. albida, A. senegal, A. nilotica, A. seyal, A. mellifera* and *A. tortilis* (spp. *tortilis, raddiana* and *heterocanthos*). Some of these species are very valuable for browse, fuelwood, gum, tannins, sand stabilisation, and other purposes.

A number of Australian acacias were introduced to North Africa many years ago. The best known are *A. aneura, A. farnesiana, A. peuce, A. victoriae, A. ligulata, A. salicina, A. cyclops* and *A. saligna (cyanophylla)*. *Acacia saligna* is the most important acacia in the region. The following is a short account of the performance of some important Australian acacias.

Acacia salicina was introduced in the region in the early 1960s, and grows well under 150–300 mm annual rainfall on very poor, shallow gypseous soils in Tunisia, Libya and Israel (N. Negev). Its strong suckering from the roots makes it an aggressive coloniser in spite of its poor seed production. It produces good fuelwood, but has no fodder value (Le Houerou et al. 1983).

Acacia ligulata is perhaps the most drought-resistant exotic species under trial in the region. It has been successfully grown in Tunisia and Libya on shallow sandy soils with only 120–130 mm annual precipitation. It is a good sand-binding shrub, but is of limited fodder value.

Acacia farnesiana, although very slow-growing, is very valuable ornamentally and as hedges around citrus groves especially in Egypt and Isıael.

Acacia victoriae, both spiny and spineless types, has been successfully used in Israel and Libya under 150–200 mm of rainfall. It has feed value comparable to *A. saligna*.

Acacia cyclops is as drought-tolerant as *A. saligna*, and is more tolerant to sea spray. It is grown mainly to stabilise coastal sand dunes notably in Tunisia, Libya and Egypt. Its fodder value is inferior to that of *A. saligna*, but it produces a dense, high-quality firewood (N.A.S. 1980).

Other species tried in the region with mixed success include *Acacia peuce* and *A. aneura*. Contrary to many expectations the latter species has not produced convincing results in the Mediterranean arid zone (Le Houerou 1984).

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Acacia saligna was introduced to Libya in 1916 (Leone 1924) and has since been consistently used for inland sand dune stabilisation in the five countries. It may survive and grow on sites receiving as little as 200 mm of rain annually, or even less. However, it grows best on deep sandy soils, with annual precipitation over 250 mm. The area planted is over 500 000 ha, mainly as windbreaks, amenity and beautification projects and roadside stabilisation. In the arid zone of Tunisia and Libya, *A. saligna* produces up to 3500 kg dry wood/ha/yr on deep sandy-loam alluvia receiving an average of 150 mm annual precipitation and some runoff. The wood is used mainly for fuel (NAS 1980), and has been recently successfully processed into particleboard in Tunisia.

Acacia saligna has been the subject of several studies which dealt with fodder production (biomass), palatability, intake, digestibility and chemical composition. It has nutritive value, especially for sheep and goats (Dumancic and Le Houerou 1981; Le Houerou and Barghati 1982; Le Houerou et al. 1983). Consumption, over a long period, of up to 1.6 kg DM/ha/day has been recorded for sheep. The fodder value is about 4 MJ of digestible energy per kg DM with a crude protein content of 10.2% (Le Houerou 1984). Available information on chemical composition shows the following ranges: dry matter (50–55%), crude protein (12–16%), crude fibre (20–24%), crude fat (6–9%), and ash (10–12%).

A drip-irrigated plantation of *A. saligna* was established in the experimental station of the Desert Development Center, The American University in Cairo, in 1983. The site is characterised by coarse sandy soil and the trees receive water at a rate of 6 l/tree every second day. Biomass production has been under study according to the following plan: Age Group 1: One-year-old foliage (1984); Age Group 2: One-year coppice on 2-year-old stumps (1985); Age Group 3: Two-year-old foliage (1985). The average weights (in kilograms) per tree (foliage first, then wood) and the ranges for each age group are: Group 1: 6.27 (2.3–13.4), 6.61 (2.3–11.9); Group 2: 6.65 (2.0–11.4), 6.35 (2.2–10.0); Group 3: 6.86 (3.8–14.0), 8.45 (3.4–19.8).

The weight of the 1-year-old foliage, whether the first year's growth (1) or the coppice (2), was not significantly lower than the weight of 2-year-old foliage (3). In the meantime, the average weight of 2-year-old wood was only about 30% higher than the 1-year-old wood. Accordingly, it would be better to harvest irrigated *A. saligna* annually for biomass production. The wide range of variability suggests that useful gains might be obtained through breeding.

In an animal feeding experiment using a local sheep breed (Barki), the fodder potential of *A. saligna* was explored. The animals were fed alfalfa or *Acacia*, or a mixture of the two fodders. Replacing 50% of the daily dry matter intake from alfalfa rations by *Acacia* foliage increased the total digestible nutrients (TDN) and decreased the digestible protein (DP). Feeding alfalfa alone constitutes a loss of protein, while mixing it with an energy-rich fodder, such as *Acacia* foliage, leads to better feeding efficiency (El-Lakany and Mahmoud 1986).

Acacia saligna has been successfully micropropagated using a tissue culture technique. Its efficiency in fixing atmospheric nitrogen as well as mycorrhizal associations are under investigation in Tunisia (Nasr 1986).

Conclusion

Acacia saligna has been the most successful Australian *Acacia* in North Africa. Its attributes include tolerance to moderate drought, ability to grow on poor soil, ability to bind sand, high production of biomass (foliage, wood, litter), high coppicing ability, and a high nutritive value for sheep and goats.

It is easy to establish and manage and responds very favourably to supplemental irrigation. Provenance trials should be organised in order to explore the genetic variability within species. Other species of importance in North Africa are *A. cyclops, A. salicina*, and *A. victoriae*.

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Introducing Australian Acacias in Dry, Tropical Africa

Christian Cossalter*

IN dry tropical Africa, woody species are essential for environmental protection and play a major role in the local economy. From the very beginning they have constituted the main energy source and provided a number of other basic products and services. In spite of all development efforts, this dependence on woody vegetation is not going to change for many years, especially for fuelwood. Among the most useful plants of the Sahelian and north Soudanian zones, local acacias rank highly. Their use for fuelwood, fodder, gum production, soil improvement, and erosion control is well documented (Bellouard 1948, 1949; Depierre 1969; Giffard 1964, 1966, 1975; Michon 1968). West African acacias (about 30 species) only represent a part of the whole potential of the genus which includes nearly 1200 species. *Acacia* species from tropical Australia, Northeast Brazil and the Indian and Pakistani deserts may also include genetic material adapted for use by African populations for local needs and environmental protection. The evaluation efforts of recent years have mainly concerned Australian acacias which alone amount to nearly 850 species, about 140 being from tropical arid areas (Maslin and Pedley 1982). This paper describes the performances of Australian acacias tested in rainfed plantations in the Sahelian and Soudano-Sahelian zones (average annual rainfall less than 900 mm). This is now the area of greatest need due to the progressive deforestation over the last 15 years and the worsening drought situation.

Sites of Field Trials

Four countries (Burkina-Faso; Cameroon (northern region); Niger; Senegal) have taken an active part in the study of the adaptation, silviculture and uses of Australian acacias by establishing, in cooperation with C.T.F.T., a network of field trials. The national research organisations involved are: the Centre National de Recherches Forestières (Institute Sénégalais de Recherches Agricoles) of Senegal; the Centre de Recherches Forestières (Institute de la recherche agronomique) of Cameroon; the Institute National de la Recherche Agronomique of Niger; the Institute de Recherches en Biologie et Ecologie Tropicale of Burkina-Faso.

In addition to the results obtained in these field trials, this paper refers to observations made in Cape Verde, Mali, and Mauritania where Australian acacias have been introduced more recently and on a much smaller scale.

Plant Material Introduced

The introduction of Australian acacias to dry tropical regions of West Africa has been achieved in several steps. The earliest introductions started 20 years or more ago, and continued until the early 1970s, and have involved a limited number of species, viz: *A. aneura, A. cyclops, A. dealbata, A. mearnsii, A. microbotrya, A. peuce, A. pycnantha, A. pruinocarpa, A. saligna*, and one species introduced under the name of Gidge (very probably *A. cambagei*). In most cases the material was obtained from North Africa, where the cultivation of some of these species had been carried out for a long time. These introductions have led to discouraging results; in some cases it merely led to the death of the plants being tested.

During the introductions done with the 1973 C.T.F.T. collections only the coastal regions of northern Australia were explored and 20 species totalling about 40 provenances were collected (Martin and Cossalter 1974). This material was tested in several trials as early as 1974 in Burkina Fasso, Niger and Senegal and from 1979 in North Cameroon. The first results were generally encouraging, especially in Senegal, and merited further research with these species.

Trials were established during the period 1980–84. In Senegal where these trials were the most intensive, the number of *Acacia* species introduced up to the present is nearly 50, mainly with seed supplied by CSIRO.

Australian acacias have also been introduced during the past years in several neighbouring countries (e.g. Cape Verde, Mali, Mauritania) generally from material collected in Senegal.

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Assessment

Acacia coriacea

This species has demonstrated particular drought resistance in coastal areas, at Bandia (Senegal) in particular, where at the age of 6.5 years survival was 100% in spite of extreme drought periods (231 mm of rainfall over 15 days in the driest years; average rainfall of 414 mm over 20 days during the period of trial).

Acacia coriacea grows slowly, especially in the early years, not noticeably affected by dry periods, which seems to confirm its capacity to withstand dry conditions. In Senegal, its growth in height, at 7 years, ranges from 3 to 3.6 m depending on sites.

Acacia sclerosperma

The behaviour of this species on the coast and inland is very similar to that of *A. coriacea* with regard to resistance to drought and growth characteristics. In Senegal this species has proved to be adapted to most soils except waterlogged ones. At Bandia (coastal region of Senegal), *A. sclerosperma* was the best adapted Australian acacia and one of the most interesting species for the area along with *Prosopis juliflora, A. senegal* and *A. seyal*. However, the chances of obtaining suitable material for continental Africa appears rather limited due to the very restricted natural distribution of the species in the Australian inland.

The bushy habit of *A. sclerosperma* makes it suitable for erosion control.

Acacia bivenosa

This species has given interesting results in Senegal (coastal zone), however, its behaviour is less reliable in continental areas. This may be explained by the fact that the introduced provenances come exclusively from coastal zones. In Senegal *A. bivenosa* has shown lack of adaptability to certain soils, the waterlogged ones and the 'tannes' (salty soils). If planted in 'tannes' the species is totally eliminated within 3 years.

At all stations where *A. bivenosa* has been planted on suitable soils, a relatively uniform growth and good survival have characterised this species. In such conditions, a height of 3.10 m ± 15% and a survival rate over 80% can be expected. The growth in height may be slowed down, particularly during years with an exceptionally low rainfall. The growth in basal area with optimal conditions is rather similar to that of *A. trachycarpa*. In normal conditions the growth in basal area is lower than that of *A. trachycarpa* but greater than that of *A. coriacea* and *A. sclerosperma*.

The bushy habit of *A. bivenosa* ensures satisfactory ground cover and gives it the potential to help control erosion.

Acacia holosericea

At present, this is one of the most promising acacias for dry tropical Africa. Its major positive features are: (1) good wood production; (2) satisfactory adaptation to most soils; (3) capacity to produce good wood and charcoal; (4) high production of phyllodes for fodder. Its negative features are sensitivity to long periods of drought and low ability to coppice (even though observations on coppicing are still rather limited).

Our tests have shown that this species behaves satisfactorily with rainfall over 500 mm in areas of Senegal under coastal influence and over 600 mm in Continental Africa, and dies from 2 to 3 years of age onward in extremely dry years (annual rainfall less than 250–300 mm).

These limits do not apply to Cape Verde where, due to the island environment, low rainfall is to some extent counterbalanced by higher air moisture content, cooler temperature and lower evapotranspiration. In San Filipe (Santiago Island), *A. holosericea* (first introduced in the country in 1980) has withstood an average annual rainfall of about 200 mm over the last 5 years.

A trial comparing the behaviour of five Australian acacias (*A. bivenosa, A. holosericea, A. sclerosperma, A. tumida, A. trachycarpa*) on six types of soil found at Keur Mactar (Senegal), showed that *A. holosericea* is the only species adapted to all soil types even in very arduous situations such as 'tannes' (salty soils), where its rate of survival was 84% at 40 months. It was also the only species tested which tolerated waterlogged soils at which its growth was rather impressive at the age of 40 months: (1) the average height was 4.8 m; (2) the average basal area per tree was 106 cm^2; (3) survival was 100%. *Acacia holosericea* was highly productive in this trial (it gives the best performance on five out of six soil types), and showed very similar growth irrespective of soil conditions.

The first assessments of total biomass production (phyllodes and wood) were carried out at the age of 40 months, taking advantage of a thinning operation modifying spacing from 3 × 3 m to 3 × 6 m, carried out at Bambey. These data, compared to those obtained for the four other species in the same trial, are presented below.

	Avg. wt (g) of dry leaves or phyllodes/tree	Avg. wt. (g) wood/tree
Australian acacias		
holosericea	2 660	12.03
trachycarpa	1 993	10.65
African acacias		
senegal	60	9.92
seyal	208	4.39
tortilis	130	5.89

The species showed fast initial growth and good resistance to drought in the first months of plantation. The growth in the first years was noticeably slow during the dry season. The response to thinning was pronounced at Bandia, where the average cross-section of stems increased from 40 cm^2 at 40 months (date of thinning) to 122.2 cm^2 at 64 months in the thinned plot (spacing of 3 × 6 m after thinning), while in the unthinned control plot (3 × 3 m spacing) the average cross-section at the same age was 64.2 cm^2.

Seeds germinate naturally in the field in various sites (Keur Mactar—Senegal; San Filipe—Cape Verde; N'Debougou—Mali) without fire being required. Natural regeneration is nevertheless, relatively infrequent considering the prolific seed production of the species.

Coppicing ability is poor but could be improved by working out the correct time of harvesting and by practising high felling (40 cm or more above ground).

Utilisation

Acacia holosericea is by far the most frequently planted Australian *Acacia* in development schemes. It is used in forest plantations and also in rural afforestation schemes (field crop delimitation, windbreaks) and in amenity plantings. The fodder potential of this species is mainly due to a large phyllode biomass during the dry season, whereas local acacias traditionally used as fodder heavily shed their leaves during this period.

Since *A. holosericea* has a large phyllode biomass, whatever the season, it can also be used as a windbreak. The dense and large crown of the species as well as its moderate height, allow it to play an efficient screening effect in the lower part of windbreaks when grown with *Eucalyptus camaldulensis*. It should be noted that these two species are frequently associated in their natural range.

Acacia trachycarpa

This species, collected by C.T.F.T. in 1973, was introduced in dry tropical Africa under the name of *A. aff. linarioides*. Maslin and Pedley (1982) have clarified the exact identification and distribution of the species.

The main interest in *A. trachycarpa* is its good fodder production. Phyllodes are readily grazed by cows, sheep and goats. The nutritional value is good (nearly 15% of nitrogen compound), they are available all year, and are produced profusely.

Analyses effected at the C.T.F.T. Chemistry and Energy Laboratory have also shown good energy characteristics for wood and charcoal.

The species has a comparable drought resistance to that of *A. holosericea*. It has performed best in coastal areas of Senegal where average annual rainfall is over 500 mm. In such conditions, its main silvicultural features are: good behaviour on a number of soils except waterlogged ones; growth in basal area varies very little with site; it comes close to, but is always less than, the values recorded for *A. holosericea*; growth in height smaller than that of *A. holosericea*. According to measurements recorded in various trials, in Bambey, Bandia and Keur Mactar stations, an average height of 3.6 m ± 15% at 5.5 years, can be expected; abundant natural regeneration (Keur Mactar); initial survival rate high after direct seeding. However, the first encouraging results obtained cannot be considered as definitive and should be confirmed through further trials.

In inland regions (Burkina Fasso, North Cameroon, Niger) the behaviour of *A. trachycarpa* is much less satisfactory, mainly in survival and growth rate. These results are most certainly related to the coastal origin of the material used (provenance Port Hedland CC1466, located 10 km from the sea). As the occurrence of this species in inland Australia is restricted, the possibiliity to obtain provenances suited to dry continental Africa is limited.

Acacia tumida

This species has several interesting features: (1) rapid growth; (2) potential as a fodder producer; (3) good energy characteristics; (4) good ability to combat erosion. However, it is sensitive to drought and produces seed poorly in African conditions.

In coastal zones as well as inland, the survival rate at 3 years in plantations is poor. When 5 years old, the survival is generally less than 50%.

Acacia tumida is moderately palatable for stock and its high leaf production makes it a fairly interesting fodder species. A trial carried out in Keur Mactar, Senegal, on stand management, with the objective of fodder and wood production, yielded an average of 2600 g of dry phyllodes per tree and 8.69 kg of wood per tree.

These measurements were taken on trees felled during the second dry season after planting (i.e. between 18 and 23 months) in plots with a spacing of 3 × 3 m. However, the small sample size (25 trees per species) makes this trial an indicator only.

Acacia tumida is good firewood and analyses carried out at the C.T.F.T. Chemistry Energy Laboratory confirm this.

Species Requiring Further Study

Acacia monticola

Growth in height is medium, but, with few exceptions (trial no. 84 Bandia) its resistance to drought is poor. *Acacia monticola* is palatable to cattle but not to sheep; it can also be used as firewood. The very high content of alcohol-benzene in wood (11.6%—Chemistry Energy Laboratory, C.T.F.T.) points to a possibility of gum production.

Acacia salicina

This species has been rarely tried in sub-Saharan Africa. In Bandia, Senegal, its growth at 5 years and its resistance to drought are both satisfactory, in spite of the fact that unsuitable material from Tunisia was used. Further trials should be established with provenances from the inland regions of North Queensland. *Acacia salicina* is a fodder species that can also be used as firewood and for windbreaks.

Acacia tenuissima

Growth in height does not exceed 2.5 m, productivity is low and resistance to drought varies in Senegal but is rather good in North Cameroon (70% survival at 5.5 years with spacing 3 × 3 m, and an average height of 1.3 m in Laf). The only interesting characteristic of this bushy species is its good ability to cover and protect soils.

The following species have been recently introduced, but cannot yet be evaluated: *Acacia acradenia, A. ampliceps, A. cambagei, A. cowleana, A. eriopoda, A. hammondii, A. hilliana, A. latzii, A. ligulata, A. lysiphloia, A. pellita, A. platycarpa, A. retivenia, A. stipuligera, A. suberosa, A. tanumbirinensis, A. translucens, A. validinervia, A. victoriae.*

The following group of species will continue to be introduced despite poor results to date. In this group, there are species for which substantial improvement of behaviour should be possible by using provenances showing ecological features better matched to those of dry tropical Africa than the provenances that have been introduced to date. Each species has a relatively wide natural distribution in tropical arid and semi-arid regions. The species are: *Acacia ancistrocarpa, A. aneura, A. farnesiana, A. plectocarpa*, and *A. pyrifolia*.

Some species, whose poor performance is likely to be improved through new introductions, are: *Acacia auriculiformis, A. dunii, A. hippuroides, A. mountfordae, A. inaequilatera, A. peuce, A. pruinocarpa, A. spathulifolia*, and *A. tetragonophylla.*

Species from southern Australia failed to adapt to Sahelian and Sahelo-Soudenian zones. These included: *Acacia baileyana, A. cyclops, A. dealbata, A. mearnsii, A. microbotrya, A. pycnantha*, and *A. saligna*.

Species Available for Further Introductions

Substantial provenance collections were made of *A. holosericea* (9 provenances) and of a closely related species, *A. cowleana* (13 provenances). According to its habitat and shape, *A. cowleana* may demonstrate higher drought resistance than *A. holosericea* but may possibly be less productive. Four provenances were collected of *A. ligulata*, a closely related species to *A. bivenosa*; one of these provenances (Spinifex ridge) occurs in an area where the distribution of two species overlap. Three provenances were collected of *A. tumida*, two of these being located on sand dunes (Elsey Hills, Gregory Salt Lake).

Among the other species collected, the following seem particularly interesting: *Acacia ampliceps*: for its potential as a fodder, its ability to grow on heavy clay (species found along water streams) and for its possible use as a windbreak (tree 4–6 m tall, with a large and dense crown); *Acacia ancistrocarpa*: for its good ground cover (very bushy habit) and its ability to coppice; *Acacia pachycarpa*: for its potential to provide fodder and firewood, its ability to grow on heavy clay (species often found along drainage courses) and its possible use as a windbreak (tree 3–6 m tall with a dense crown); *Acacia shirleyi*: for its potential to provide fodder, its good energy characteristics, its fire resistance, its introduction, however, is recommended for zones with an annual average rainfall over 700 mm; *Acacia stenophylla*: for its potential to provide fodder (for sheep essentially), firewood, for its ability to grow on heavy clay (species found along water streams) and for its possible use as a windbreak (tree 4–6 m tall, with a dense crown); *Acacia stipuligera*: for its ability to cover and fix sandy soils (bushy habit); and *Acacia maconochiena* (a newly described species affiliated to *A. tephrina*): for its potential to provide fodder, its ability to grow on heavy clay, to tolerate alkaline soils and withstand partial flooding (water level up to 2.5 m in height observed on trees 7–8 m high on the shores of Lake Gregory.

Out of the 38 *Acacia* species collected, the 20 listed below have never before been introduced in Africa: *A. adsurgens, A. argyraea, A. calcigera, A. chisholmii, A. dictyophleba, A. difficilis, A. drepanocarpa subsp. latifolia, A. gonoclada, A. hemignosta, A. jennerae, A. laccata, A. limbata, A. orthocarpa, A. pachycarpa, A. pallidifolia, A. shirleyi, A. stenophylla, A. torulosa, A. translucens, A. maconochiena.*

Conclusion

The introduction of Australian acacias in dry tropical Africa has made great strides during the last 10 years. The first results showed that, on the whole, these species are sensitive to the severe drought conditions prevailing in certain trial locations. This is undoubtedly related to the essentially coastal origin of the plant material introduced to date.

The most encouraging results of these early introductions were obtained in coastal stations in Senegal. The species distinguishing themselves by their good performance in this zone are: (1) *Acacia coriacea, A. sclerosperma* and, to a lesser extent, *A. bivenosa*: due to their drought resistance, they are the three species most interesting in the prevention and control of erosion; (2) *Acacia holosericea, A. trachycarpa, A. tumida* for their good productivity and their fodder value; however, *A. tumida* is adapted to only a restricted number of sites because of its drought sensitivity.

Other species, with which there is as yet little experience, might turn out to be interesting.

A CSIRO-C.T.F.T. collection in 1984 gathered a great number of species and provenances from arid tropical inland Australia. New introductions made using this material and combined with *Rhizobium* inoculation trials—the first results of which are promising—should allow the selection of genetic material presenting both good performance in growth and yield and a better resistance to drought.

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Growth of Australian Acacias in Tanzania

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TANZANIA can be divided into three broad climatic zones: (1) the humid and warm coastal region 0–650 m above sea level, with tropical climate, maximum temperatures of over 26 °C (October–April) and minimum temperatures of 18–21 °C (May–September): rainfall ranges from 1100 to 1300 mm; (2) the hot and dry zone of the central plateau 650–1500 m above sea level: mean annual rainfall ranges between 500 and 760 mm; (3) the semi-temperate zone, with relatively low temperatures of 10–21 °C and a high rainfall, 750–2000 mm.

The environmental conditions of Tanzania vary from semi-arid to wet montane climate. The montane area is characterised by steep slopes. The semi-arid areas are characterised by variable unreliable and erratic rainfall. These areas have long dry seasons of 6–8 months. Most parts of Tanzania experience one major and one minor drought every 9–10 and 4–5 years respectively, the droughts occurring after a year of torrential rains and severe floods.

The soils are varied and complex with all the major tropical and temperate soil types.

Forest Resources

The forests and forest land in Tanzania occupy about 45% of the total land area. The reserved forests, known as the forest estate, account for 15% of the total land area. A total of 13.4 million ha are gazetted forest reserves. The forest estate consists of the natural forests, industrial plantations and fuelwood lots.

The natural forests are divided into the closed-forests, woodland, grassland and mangroves. Most of the closed-forests are located in the highland areas and around hill tops. These forests serve the functions of protection and sometimes both production and conservation. Wood from the natural forests is used for timber, firewood and building poles.

The total area under industrial plantations is about 70 000 ha and these provide raw materials to the wood-based industries. The main species planted are *Pinus patula, Cupressus lusitanica* and *Tectona grandis.*

Wood fuel constitutes over 91% of the total annual energy consumed in the country, and it is a major source of domestic energy in the rural areas. The use of firewood for domestic fuel is approaching a crisis point in some of the arid areas and in the tobacco-growing regions.

Australian Acacias Introduced

Australian tree species have played a significant role in the country's rural development. Tanzania has embarked on a massive village afforestation program in which the villagers are encouraged to grow their own trees for fuelwood, charcoal production and building construction. Australian species were introduced during the German colonial period and today over 200 000 ha are under *Eucalyptus, Acacia*, and *Grevillea.*

Acacia mearnsii

Acacia mearnsii has been planted on a commercial scale for tannin. The species was introduced during the colonial period in 1908. Records show that several trial plots were established in different parts of the country including the Western Usambaras, and Southern Highlands where it has been very successful. The species was also tried at Kasulu between 1937 and 1942. In the early 1950s the Colonial Development Corporation (now Commonwealth Development Corporation) established a total of 12 141 ha of plantations in the Southern Highlands. Several thousands of hectares were also established in other parts of the country by individuals and local authorities. At West Usambara a total of 4586 ha was established in the 1950s.

This tree grows best in a cool moist climate. Good growth has been achieved at high altitudes between 1200 and 2150 m with annual rainfall of 1020–1270 mm. There is evidence that at lower annual rainfall, e.g. 760 mm, the species is susceptible

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to diseases. It has grown well on soils derived from old crystalline rocks compared to those derived from volcanic rocks.

ESTABLISHMENT METHODS

Direct sowing of seed in the field has been employed in establishing plantations of *A. mearnsii*. The rate of sowing has been 1.2–2.4 kg/ha. Prior to sowing it is essential to undertake complete cultivation of the ground and the seed is sown at a spacing of 1.8 m. Clean weeding is essential for the first year because young plants are highly sensitive to weed competition.

After clear felling it is possible to achieve natural regeneration both for the second and subsequent generations. Several trials have been carried out in Tanzania to find the best methods of encouraging natural regeneration. Plantation establishment methods have been adopted from South African experience. Methods so far tried in Tanzania include strip burning of leaf litter, slash burning along rows of stumps, and slash burning spread over the whole plot on the taungya system. All these methods have given equally satisfactory establishment. Pretreatment of seed by boiling water gives faster and uniform germination.

Normally thinning is undertaken after 1 year to have plants spaced at 2.4 x 2.4 m and the plants left unthinned until clear felling (rotation ranging between 8 and 12 years). Early height growth rates of about 2.4 m/annum have been achieved on good sites with an average yield of 50 t of fuelwood and 6 t of dry bark (about 20 t/ha and 2t/ha respectively) on an 8-year rotation.

PESTS AND PREDATORS

Acacia mearnsii is susceptible to attack by *Loranthus* termites and *Icerya purchasi*. During 1984 a total of 290 ha of wattle plantations at Malibwi in Lushoto district were attacked by an insect suspected to be a species of *Plusia* (Lepidoptera).

During the 1950s attempts were made to introduce *Rodolia cadinalis* from South Africa to try biological control of *Icerya purchasi*. Records show that the predator has successfully established itself in the country. At the same time an unidentified local predator suspected to be Coccinelidae contributed to controlling the population of *Icerya purchasi*.

The recent outbreak of *Plusia* spp. at Malibwi *Acacia* plantations was effectively controlled by several parasites including an identified insect belonging to the family *Eulophidae* which was parasitising eggs of *Plusia*. Others included *Theronia* spp. nr *Lurida, Apanteles* spp. and *Metopius* spp. There have been several insect outbreaks on *A. mearnsii* in Tanzania and biological control methods have been used to check the population of the pest.

DISEASES

In 1954 the Colonial Development Corporation reported a disease outbreak on *A. mearnsii* plantations at Njombe in the southern highlands. The trees were noted to die back from the top, which was attributed to boron deficiency. This kind of dieback has recently been encountered in pine plantations at Sao Hill on other species besides *A. mearnsii* including *Pinus patula, Pinus elliottii* and *Eucalyptus saligna/grandis*. The dieback of these species is still being investigated. Attempts have been made to introduce this species in more marginal parts of the country with little success (e.g. Malya Mwanza). At the age of 3 years the mean survival was 2% and mean height was 2.2 m. This implies that the growing of the species should still be restricted to highland areas where it has given good performance.

Acacia melanoxylon

This species was introduced in Tanzania during the German occupation but has never been planted on a large scale. It prefers cool temperate rainforest conditions. By 1962 there were 40.5 ha of plantations. It has successfully been grown in Tanzania at altitudes between 1220 and 2140 m with a rainfall of 1000 mm or more on deep and fairly fertile soils. It is possible to direct-sow but better results can be obtained using 1-year-old seedlings which have been stumped in the nursery.

The tree is highly susceptible to attack by *Loranthus*. It has also been attacked by *Oemida*.

Trials at Mamba, Moshi revealed that at the age of 20 years the trees attained heights ranging between 24 and 32 m with 10–11 m of clean bole, and with a girth at breast height of about 1.5 m. A total of 6.3 m^3 log volume over bark was obtained from five trees. The tree has given straight-boled stems but logs develop severe star shakes when stored. At Meru (Arusha) 7-year-old trees have attained an average height of 12.2 m

The species has been planted as a windbreak and has also been used as a firebreak in softwood plantations.

Acacia mangium

The species was introduced in Ruvu along the coast in 1985 and its performance has been quite encouraging. At the age of 2 months the mean survival was 64% and mean height 2.6 m. *Acacia mangium* will grow on difficult sites and has been used extensively for rehabilitating degraded sites in other parts of the world. All efforts will therefore be made to try the species in parts of Tanzania where there are problems of site deterioration.

Acacia auriculiformis

This species was planted on an experimental scale in Tanzania in the early 1950s along the coast on infertile sandy soils.

There are no records that extended planting with this species has been undertaken in Tanzania since then except in Zanzibar. In Zanzibar it has attained a height of 10.6 m and diameter of 12.7 cm within 8 years on shallow coral soil, and a height of 10.6 m and diameter of 20.3 cm in 6 years on deep sandy soils. It has been planted at a spacing of 1.83 × 1.83 m (3000 stems/ha). The practice has been to reduce the stocking by 50% during the 4th year, and leave until clear-felling.

Acacia saligna

This species has shown poor performance in species elimination trials both at Dodoma and Malya. It is necessary to conduct further trials for the species in other sites before it is recommended for planting on a large scale in the country.

It is planted in the highland areas with *A. cyanophylla* for windbreaks, fencing and fuelwood. Results from trial plots indicate that the species is not suitable for arid-zone afforestation.

Acacia decurrens

This species was planted with *Acacia mearnsii* plantations, but its use is discouraged due to lower tannin yields.

Future of Australian Acacias

Fuelwood is the main source of domestic energy and accounts for 91% of the total energy consumed. It will continue to be the main source of energy in the future because of oil price increases and lack of foreign currency. In addition to the domestic consumption, fuelwood is also used for brick-making, tobacco-curing, tea-drying, fish-smoking and brewing. For example in 1983, the annual consumption of fuelwood was estimated to be 40.3 million m^3.

Almost all the fuelwood consumed in the country is harvested from the natural forests. The potential annual fuelwood supply from those forests is about 19.5 million m^3. Therefore, there was a deficit of 20.8 million m^3 of fuelwood in 1983. The gap is still widening due to population growth. The fuelwood crisis is very critical in the semi-arid regions and this has led to the overexploitation of the existing forests resulting in serious deforestation and soil degradation.

Village afforestation programs were started in 1967 to increase the fuelwood supply to the rural population. The program has shown some success in schools and private institutions. For any successful afforestation program there is a need to select the right species and find the suitable establishment techniques. This is where the Australian acacias and other species can play a big role.

Conclusion

The success of *Acacia mearnsii* in the fertile highlands, its fast growth and nitrogen-fixing ability suggest that other species such as *Acacia silvestris* might do well in those areas. *Acacia mangium* can compete well with the heavy grass and weed growth in the coastal areas. Australia's dry-zone species could be used in the arid and semi-arid areas of the country.

Status of Australian Acacias in Zimbabwe

D. P. Gwaze*

ZIMBABWE covers an area of 390 700 km^2. One-fifth of the country is over 1200 m, three-fifths between 600 and 1200 m, and one-fifth is below 600 m. Most of the country has a subtropical climate, except the low-lying valleys which experience tropical conditions.

Rainfall occurs mainly between November and March. Average annual rainfall varies from below 300 mm in low-lying areas of the country, to over 1000 mm on the central watershed, and limited areas in the Eastern Highlands receive over 1500 mm.

Soils are derived mainly from granite and igneous rocks. The soils are predominantly sandy, with heavier loamy and clayey soils occurring in relatively small local areas.

Zimbabwe has a population of 8 million people and 60% of the people live in communal areas where wood is the prime source of energy for cooking and heating. There is a shortage of fuelwood in many communal areas, and soil degradation caused largely by deforestation is also a problem. Afforestation is playing, and will continue to play, a major role in maintaining the living standards of the people in these areas.

Early Species Introductions

The most widely planted and successful Australian *Acacia* in Zimbabwe is *Acacia mearnsii* which is thought to have been introduced in 1902. Details of this species introduction and silviculture are given by Luyt et al. (1986).

The first comprehensive introductions of Australian acacias were between 1957 and 1960. Fourteen species were tested in widely distributed introduction plots located mainly at Mtao, Gweru, Harare and in the Eastern Highlands. These introductions comprised 24 documented plots, eight of which are reported to have failed, and of the remaining 16 plots, only four plots at Mtao provided worthwhile growth data (Table 1).

Because of inadequate data and insufficient coverage of a range of environments, the potential of these *Acacia* species can hardly be deduced from this original series of introduction trials. One of the early and impressive *Acacia* stands is an *Acacia melanoxylon* plantation in Gwendingwe estate in the Eastern Highlands. The mean annual rainfall of the site is 1500 mm and the soil is derived from shale and is moderately fertile and slightly acidic. The plantation was established in the 1968–69 season and covers 13 ha. The recent measurements show that at 18 years of age the mean dbh is 21 cm and mean height is 22 m. Thinnings from the plantation have been found to be good fencing posts. The plantation is managed for sawn timber.

There was no further testing of Australian acacias for the next 25 years. However, with the Zimbabwean government's focus on rural afforestation, a role for acacias was realised and further screening of species was commenced in 1984 under a project supported by ACIAR.

Recent Work

The ACIAR trials involve the testing of about 25 Australian *Acacia* species and also some species of *Casuarina, Melaleuca* and *Eucalyptus* genera for fuelwood and agroforestry in drier areas of Zimbabwe. The advantages of the *Acacia* species included in these trials are that they are fast-growing, have the ability to coppice, are nitrogen-fixing, are good fuelwood, and some provide good fodder.

The first trials were established during the 1984–85 season at three sites. Results of the two most promising *Acacia* species at Grasslands after 18 months growth are as follows: *A. holosericea*, 100% survival, 1.6 m mean height; and *A. aneura*, 90% survival, 1.4 m mean height. A second set of trials was established in the 1985–86 season, and *A. auriculiformis, A. leptocarpa, A. cowleana* and *A. ligulata* are showing promise. All trees in one of the ACIAR trials were assessed for termite susceptibility, and some interesting, though preliminary results have been discovered (Mitchell et al. 1986). It appears that acacias are generally more resistant to

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Table 1. Early survival and growth of four species of Australian *Acacia* planted at Mtao, Zimbabwe. Mtao is 1480 m above sea level and has a mean annual rainfall of 800 mm. The soils are deep, well-drained sands.

Species	Origin in Australia	Age from planting (months)	Mean height (m)	Survival (%)
Acacia acuminata	Western Australia	65	3.5	25
A. baileyana	Queensland	54	4.0*	21
A. decurrens	Queensland	40	1.0	7
A. podalyriifolia	Queensland	40	2.0	71

* Diameter was 11 cm.

termites than *Casuarina, Eucalyptus* and *Melaleuca* species. In communal areas where chemicals are not readily available because of cost and safety regulations, more resistant acacias may be more acceptable.

Apart from testing Australian acacias, we are also testing indigenous acacias. A lot of effort has gone into species and provenance trials of *A. albida*, which is a very valuable fodder tree and a tree that could be used in mixed cropping systems. A seed collection mission to the northern part of Zimbabwe was launched in September 1985 by the Forestry Commission and some of this seed was put in trials. Seed from several parts of the country has been obtained with help from National Parks. Also, seed from nine other African countries has been obtained and further provenance trials of the species will be established in the 1986–87 season. Other indigenous acacias will be tested.

Uses of Acacias

Acacia mearnsii has been grown mainly for the extract from its bark which is used in tanning. Some of the wood is used for poles and fuelwood, but most is burnt because plantations are too far from wood-using centres.

Most of the introduced acacias have found a place in our streets and gardens because of their attractive foliage and flowers. They are also fast-growing and evergreen. The most widely planted ornamentals include *A. podalyrifolia, A. baileyana, A. longifolia* and *A. cultriformis. Acacia melanoxylon* has been planted as a windbreak in high rainfall areas, and *A. saligna* has been used for the reclamation of mine dumps.

Discussion

There is great potential for Australian acacias to play an important role in rural afforestation in Zimbabwe. However, research in such areas as spacing, fodder value, calorific values, coppicing ability and nitrogen fixing needs to be expanded. It has been observed that the acacias in Zimbabwe are generally short-lived and do not last longer than 25 years. This may be a major disadvantage of acacias in communal areas and in commercial plantations where rotations are more than 25 years. The other disadvantage is that the acacias are vigorous colonisers and are likely to escape. In favourable environments, *A. mearnsii* is already a weed.

Australian acacias already play a big role in commercial forestry but this can also be increased, especially in respect of *A. melanoxylon* plantations. At the moment there are very small plantations of this species, which has high-quality timber. Increasing plantations of this species will reduce imports and save on foreign currency.

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Black Wattle (*Acacia mearnsii*) in Zimbabwe

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THE date of the first introduction of black wattle, *Acacia mearnsii*, into Zimbabwe is not known with any certainty but it is generally believed that some trial plantings were made at Cecil Rhodes's Estates at Nyanga in the Eastern Highlands and at Matopos near Bulawayo in 1902 (Sherry 1971). At about the same time, attempts were made to establish the species near the outskirts of Harare (Anon. 1956). By 1923 commercial plantations of black wattle amounted to 110 ha (Sim 1927) and, during the period 1929–34, some bark was exported from the Nyanga district, but low prices and difficulties of transport militated against the success of the venture (Anon. 1956).

The Rhodesian Wattle Company Limited was formed in 1945 at a time when vegetable tannins were in extremely short supply following World War II. Large-scale establishment of black wattle started in 1946 and, by 1962, the area of commercial plantation had reached 26 000 ha, all of it in the Eastern Highlands. Attracted by the booming industry, a number of private growers in the Eastern Highlands started to plant black wattle with the help and encouragement of the Rhodesian Wattle Company Limited (now The Wattle Company Limited) but their total plantations never amounted to more than a small fraction of the whole.

All plantations of *Acacia mearnsii* in Zimbabwe were established with seed provided initially from South Africa and subsequently from the abundant local supplies. But the Australian origins of Zimbabwean plantations remain obscure. Other Australian species of *Acacia* have been tried in Zimbabwe for commercial tannin production, notably green wattle, *A. decurrens*, and silver wattle, *A. dealbata*, but they both produce excessively red-coloured tannin extract that is not readily accepted by tanners.

In the latter part of the 1960s the wattle industry began to decline due to the impact of synthetic tannins and leather substitutes, and this led to a major reduction in the plantation area committed to black wattle. Most of the Wattle Company's holdings in the north of the Eastern Highlands were converted to pine and eucalypt and some of the wattle plantations in the south of the Eastern Highlands have given way to coffee and other crops. Today, the total area of commercial black wattle in Zimbabwe stands at about 14 000 ha, all but about 400 ha being owned by The Wattle Company Limited.

Climatic Zones and Soils

Black wattle plantations are confined to frost-free areas of the Eastern Highlands of Zimbabwe where the mean annual rainfall exceeds 1000 mm. Within this zone the altitude varies from 700 m to more than 2500 m but the higher, cooler regions are the most suitable. About 84% of the plantation area lies at altitudes of 1500–1800 m, where mean temperatures of the hottest months are 20–24 °C and mountain mists are frequent. The remaining 16% of the planted area is near the southern extremity of the Eastern Highlands at altitudes of 1100 to 1250 m with mean hot-month temperatures of 25–26 °C. Mean annual temperatures are 15–17 °C at the higher altitudes and 18–20 °C at the lower.

The soils of the main wattle-growing areas are derived mainly from granite, quartzite, and dolerite, with textures varying from sand to clay loam. The highest yields of wattle bark are obtained from deep, well-drained sites irrespective of the parent rock.

Nursery Practice

The establishment of the first crop in Zimbabwe was accomplished by direct field sowing in ploughed and harrowed land, but 90% of the current reestablishment is now being hand-planted with containerised nursery stock raised from local select seed or imported orchard seed.

Seed is sown in mid-August for field planting in December, or sooner if the main rains arrive early. All seed is given 'hot water' treatment before

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sowing, the standard technique being to boil the water and allow it to stand for five minutes before immersing the seed; when the water has cooled the seed is removed and sown directly into polythene sleeves that have been filled in advance with nursery soil. Fertilisers are not used in the nursery unless sowing is late, in which case single superphosphate (18.5% P_2O_5) is applied when the seedlings are 5 cm and taller. In some nurseries the filled sleeves are sterilised with methyl bromide a few days before sowing, but this is not universal practice. Generally two seeds are sown per sleeve, but when seed orchard seed is used (and this accounts for 35% of all planting) sowing is reduced to one seed per sleeve.

Some of the lower-altitude nurseries are troubled by white grub (*Lepidiota mashona*) which is controlled by applications of soil insecticide, but few other serious problems occur in the nursery. There may be occasional damage by grasshoppers and cutworms, and some damping off may occur in periods of unseasonably wet weather, or from overwatering.

An important operation in the 3-4 month nursery period is root-pruning. It is essential to confine the roots to the container either by drawing a taut steel wire below the sleeves or by lifting the plants individually and trimming the roots. Seedlings may also be shoot-pruned to the ideal planting size of 15-20 cm if planting is delayed.

Planting

Land preparation on sites being reestablished is done manually by digging 20 × 20 × 20 cm planting holes spaced at 2.7 m between rows and 1.5 m within rows (2469/ha). All planting is done in summer and each plant is given 50 g single superphosphate applied in a circle around it, about 20 cm away from the stem. Containers are always slit open and removed at planting. Site preparation in virgin land includes deep ripping, ploughing, and discing prior to pitting. Ten percent of current reestablishment is by direct field regeneration. This is achieved by stacking the slash at the required between-row spacing after clear-felling and bark-stripping, burning it, and then thinning out the seedlings that germinate from the abundant seed lying on the forest floor.

Cutworms are a serious problem after planting or natural regeneration and control is effected by placing a small quantity of insecticide bait around each plant, or along the seedling hedgerow in areas of natural regeneration.

Tending

Black wattle in Zimbabwe is intolerant of weed competition and must be kept clean until the canopy closes at 12-18 months after reestablishment. Herbicides have proved too expensive in local conditions and all weeding is done by hoe—immediately prior to planting, in autumn at the end of the first growing season, and finally just prior to the following growing season. The most troublesome weed is the grass *Eragrostis acraea*, which is not only a major competitor for moisture but is believed to produce exudates that inhibit wattle growth.

Naturally regenerated stands are 'lined out' (reduced to clearly defined rows) and then thinned to the same within-row spacing as the planted stands. This usually starts with 'two-foot spacing' (3000 stems/ha) when the wattle is 60 cm tall, then 'four-foot spacing' at 1.8 m height, followed by reduction to 2000 stems/ha at 4 m and finally to 1500-1700 stems/ha at 7 m, the final stocking depending on site, with the best sites carrying the higher number.

Planted stands are thinned to 2000 stems/ha when stand average height has reached 4 m, and to 1500 or 1700 stems/ha when the average height reaches 7 m.

Protection

There are three insect pests of economic importance in black wattle in Zimbabwe. These are the wattle mirid or froghopper (*Lygidolan laevigatum* Reuter), the white grub (*Lepidiota mashona* Arrow) and the cutworm. The wattle mirid, a sap sucker, is currently the major insect pest in wattle plantations in Zimbabwe and severe infestations in young wattle, which it favours, usually result in deformed growth and a consequent loss of up to a season's incremental growth. It attacks the growing parts of the leading shoot and upper branches, causing a stunting of apical growth and the production of numerous dwarf shoots to give the trees a 'witches broom' appearance. Control of mirid is effected by aerial spraying, and damaged trees usually require corrective pruning to a single leader when new apical growth begins.

At the lower end of the altitudinal range of commercial black wattle plantations in Zimbabwe, gummosis or the exudation of gum from the base and roots of a tree, may be attributable to pathological causes or to physiological stress. No pathogens have been identified so far, and the fact that gummosis is confined to plantations established at altitudes lower than 1250 m suggests that the problem is a physiological one.

Frost is the most serious form of climatic damage and periodic severe frosts have caused widespread injury, especially along water courses where trees up to 4 m tall may be killed outright (Anon. 1956). Wind and hail occasionally cause damage.

Exploitation and Yields

Black wattle stands are felled at about 10 years. Sometimes it may be necessary to carry out a pre-felling thinning or cleaning about 18 months before the end of the rotation. The object of this is to remove diseased and non-strippable trees to facilitate the main felling operation. It is usually necessary in naturally regenerated stands but may be omitted in those planted with nursery seedlings. This late cleaning operation does reduce competition but has little effect on the yield of the final crop.

Felling is done by axe or bowsaw during the time of the year when the bark is most easily stripped from the trees. Bark strippability is best when the sap is rising and this occurs during the warm, wet, summer months. In practice, this means that no felling is done between mid August and mid November, which is quite convenient because nursery and land preparation operations are in full swing during that period.

At clearfelling, the trees will have breast-height diameters of 15–20 cm, with heights up to 18–22 m on the best sites. The felled trees are debranched and the bark is stripped as far up the stem as possible, cut into lengths of 1.2 m, and tied in 50 kg bundles for transport to the tannin extraction factory. Bark should be as fresh as possible for delivery to the factory; any delays can result in oxidation and excessively red-coloured extract, or the formation of fungal mould, another undesirable characteristic.

Residual bark, left in the plantation after the factory 'season' has ended, is usually prepared as dried, or 'stick', bark for use in the following season. This involves careful drying of the bark in well-aerated strips to minimise formation of mould.

The wattle brushwood is no longer stacked on the stump lines after felling, but in windrows every fourth row apart with the timber lying between the windrows for later recovery against pole orders.

Yields of wattle bark in naturally regenerated stands are affected by past management, particularly the enforced neglect during the war years of 1972–79, and fairly generalised yields of 16 t/ha (range 8–26 t/ha) have been realised from such stands. These figures are low, but with the improved silviculture of more recent years, the planted stands should yield on average in the region of 22 t/ha, and in excess of 30 t/ha on the best sites.

As a result of the distortion in age-class distribution, wattle has had to be felled at ages between 7 and 9 years in recent seasons. Recovery of extract has consequently been low (31%) but it is expected that this percentage will increase in coming years when the better-managed stands are harvested, as the age class distribution evens out, and the optimum age of 10 years at felling is achieved.

Yields of wattle timber amount to 4–4.5 t of air-dry timber for every tonne of bark recovered, i.e. 64–72 t/ha from the naturally regenerated stands with the expectation of 80–120 t/ha in the future.

Utilisation

Black wattle is grown in Zimbabwe primarily for its bark extract. All other considerations are secondary but the considerable amount of timber that is produced is utilised wherever possible.

Ten percent of Zimbabwe's annual production of extract is marketed locally and the balance is sold externally. The excellent quality and light colour of Zimbabwean extract makes the product readily acceptable on world markets.

The general stem form of wattle trees is not good, which limits timber utilisation from the plantations to short, light posts, mine timber, and sawn fencing droppers. At one time the larger diameter timber was used for the production of very durable woodblock (parquet) flooring but market demand for this type of flooring is no longer significant. Currently the only other outlet for wattle timber in Zimbabwe, apart from poles, is charcoal. The quality of wattle charcoal is excellent but there is presently little tradition of charcoal usage in the country and production is well below annual capacity. This product does, however, have great sales potential as a domestic fuel in Zimbabwe.

Wattle timber makes good mine props, and some exports of this product have occurred in recent years.

The greater proportion, by far, of the timber produced by Zimbabwe's black wattle plantations cannot be marketed economically and is burnt during land preparation operations for the following rotation. This situation could change dramatically if the current investigation into the feasibility of a chemical pulp mill in Zimbabwe comes to fruition, or when the transport and shipping routes through the Mozambican port of Beira are rehabilitated. Wattle plantations could then become the most important source of the hardwood component of the raw material for the proposed pulp mill, or of chips or roundwood for direct export, and black wattle could, in the future, be grown as much for its timber as for its bark.

Research Needs

No formal research has been conducted into black wattle in Zimbabwe and the industry has relied largely on the Institute for Commercial Forestry Research (formerly the Wattle Research

Institute) in South Africa for advice on silvicultural matters and the provision of improved seed. The possibility that the future of black wattle in Zimbabwe lies more in its wood than in its bark suggests that the question of formal research in this country be reviewed. Rangewide provenance testing to identify the best seed sources for Zimbabwe, in terms of volume productivity, stem form, and bark tannin content, would be the most important starting point for a research program. This should lead on to the creation of one or more breeding populations for local conditions and end-products, and the establishment of silvicultural management trials along the lines of those already laid down in *Pinus* and *Eucalyptus*.

Acknowledgment

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Australian Acacias in Sri Lanka

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SRI LANKA can be divided roughly into a northern and eastern dry zone and a south-western wet zone merging into an intermediate zone. The dry zone occupies almost two-thirds of the land and consists mainly of flat and undulating land where the major irrigation schemes are in operation and the bulk of the agricultural and forestry activities take place. Annual rainfall varies from 760 to 1850 mm. The southwestern wet zone has an annual rainfall ranging from 2500 to 5000 mm spread throughout the year.

The complexity of the amount and patterns of rainfall and altitude are reflected in there being 20 climatic types delimited according to Thornthwaite's classification (Koelmeyer 1958), varying from Tropical Wet Evergreen to Montane Temperate Forest to Tropical Thorn Forest. In all of these zones there exists a potential for Australian acacias to contribute to the planting programs.

The first of the Australian acacias were introduced to Sri Lanka's up-country in the late 1870s with *Acacia melanoxylon* and *A. decurrens* being introduced for use as windbreaks, fuelwood plantings and ornamentals. A number of other species followed, mainly from the bipinnate *Acacia* group, i.e. *A. dealbata, A. mearnsii*. Interest in the acacias was focused mainly on the supply of fuelwood for the tea estates and railways in the up-country. After 1915 the Forest Department widely used a mixture of *Eucalyptus* spp. underplanted with *A. decurrens* for replanting logged-over fuelwood coupes in native forest (Champion 1935). This practice slowed in about 1928 when the railways decided to shift to coal as a source of fuel (Anon. 1928) and the Forest Department had to reconvert fuelwood plantations to ones of select timber species (Holmes 1947). There was pressure to release suitable lands in the up-country for *A. mearnsii* cultivation for tan bark production (Tropical Agriculturist 1889, 1901; Anon. 1924). Although seriously evaluated on many occasions, the proposals appear to have been abandoned on the basis of doubtful economics (Tropical Agriculturist 1888, 1897; Sherry 1971). *Acacia melanoxylon* displaced *A. decurrens* which was regarded as useless except for fuel (Champion 1935) and was the major component of the planting program from 1929 to 1935, when it fell out of favour, probably because of the difficulty experienced in protecting it from browsing by deer (Streets 1962).

Acacias remain a conspicuous part of Sri Lanka's up-country landscape where *A. decurrens* is used for windbreaks and fuel on the tea estates and *A. melanoxylon* used on a limited scale in reforestation programs. Recent attention has included tropical acacias such as *A. mangium* in the lower humid and semi-humid areas of Sri Lanka. *Acacia mangium*, introduced in 1980, is now planted on a limited scale and other new species are included in Table 1. In addition to the Australian acacias, four species (*A. eburnea, A. leucophloea, A. planiformis, A. sundra*) have been recorded as naturally occurring in Sri Lanka (Trimen 1895).

Silviculture

Seed for research and the broader plantings of species such as *A. mangium* and *A. auriculiformis* is currently imported from Australia. Locally collected seed is used for routine plantings of *A. decurrens* and *A. melanoxylon*. The seed of all acacias is given hot-water treatment before sowing following the technique described by Bowen and Eusebio (1981). Current practice is to dibble seedlings, or to direct-sow seed, into 23 × 10 cm polythene bags. Past recorded success of field sowing 3-4 treated seeds 'at stake' (Macmillan 1946) has prompted a planned reevaluation of direct sowing techniques in agroforestry trials. Weeraratne (1964) described the then Forest Department technique of line sowing of treated seed on contour bunds in eucalypt plantations grown at an espacement of 3 × 3 m.

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Rapid root development appears to be characteristic of *Acacia* seedlings and this presents problems for potted nursery stock. Most acacias appear to be very sensitive to root wrenching and nursery mortalities were recorded where a single heavy wrenching was given rather than several lighter root prunings.

Seedlings generally spend 12–14 weeks in the nursery before being sent to the field. Most species appear to be quite sensitive to transport damage (associated with root damage) and the use of planting boxes is recommended. Planting is done in 30 × 30 × 30 cm cultivated pits at a spacing of 2 × 2 m. It is proposed to develop planting pits 50 cm diameter × 20 cm depth in the 1986 planting season in an attempt to encourage faster lateral development of roots. An application of 60 g of NPK (14:12:12) is routinely made to all seedlings.

Grass competition is a major silvicultural problem for afforestation in Sri Lanka and frequent weedings of *Acacia* plantings are required. Fire protection is vital for newly planted acacias although in older plantations fire can be a useful form of regeneration. Light fire promotes profuse field regeneration of *A. decurrens*. Weeraratne (1964) recorded 32 000 seedlings/ha of average height 3–4 m 2 years after fire. Protection from browsing by domestic animals or wildlife is important. However, the lack of browse damage on some sites suggests that some species are less palatable than others.

Root nodules have been recorded on nursery stock of all species examined. New introductions to Sri Lanka demonstrated good nodulation and it does not appear as if the nodule-forming organism is species-specific. Although a long-recognised advantage of acacias in Sri Lanka has been their ability to fix nitrogen, there are no available records of rate of N fixation.

A word of caution must be added to the silviculture of the acacias, and to that of N-fixing trees in general. If a tree is recorded as being tolerant of weeds it does not follow that plantations need not be weeded and if a species has the ability to fix atmospheric nitrogen it does not follow that application of fertiliser is not necessary. For rapid growth and successful early establishment weed control is essential and fertiliser helpful especially on marginal sites. Expectations of high yield cannot be met unless a disciplined silviculture is followed.

Species Experience

Acacia decurrens

This species has a long history in Sri Lanka, being introduced by the tea planters probably in the 1870s and widely used above 1000 m as hedges, shelterbelts, shade trees, green manure and fuelwood. Early experience with rapid growth and an ability to grow in poor soils and tolerate grass competition (27 ft in 1.5 years, 40 ft in 4 years, Tropical Agriculturist 1890; Anon. 1892) encouraged wide cultivation of the species for fuelwood, and it was a major component of government fuelwood plantations until 1936 when plantation activities above 1500 m were stopped (Streets 1962; Champion 1935). There are currently 564 ha of *A. decurrens* of age 10–55 years in Forest Department plantations, mixed mainly with eucalypts. Streets (1962) recorded a fuelwood production of 378 m^3/ha at year 15. The tree produces an abundance of root suckers which are reportedly encouraged by scraping the soil (Tropical Agriculturist 1888). Holmes (1947) recorded that the root suckers can be controlled by first poisoning and then uprooting unwanted plants before the monsoon. In the early days it was suggested that trenches should be dug around acacias to prevent the roots spreading or that *A. decurrens* should be planted in discrete woodlots which would not compete with the tea (Tropical Agriculturist, 1881, 1888). However, current practice incorporates the acacias with the tea and no undue competition is noticed.

As a source of tannin the species is highly regarded although it takes second place to the slower-growing but higher yielding *A. mearnsii*. Macmillan (1914) records a yield of 7.9 t tannin bark per hectare after 8 years at a spacing of about 4 × 4 m.

Acacia melanoxylon

This species was introduced in the late 1860s (Tropical Agriculturist 1888) and is very common in the hills between 1400 and 2000 m. It grows very well to a large tree in better soils and when protected from wind. The main use for the species is as lumber for general construction purposes, fuelwood and amenity plantings. Timber quality is inferior to the Australian-grown wood (Troup 1932), however, it is quite durable. It can be established from seedlings or direct sowing (Streets 1962), however, the latter technique has been a failure in times of unseasonal drought (Anon. 1921). Natural regeneration is prolific from seed or suckers and varied reports have been recorded regarding its coppicing ability—Troup (1921) records it as coppicing poorly and McNeill (1935) records the stumps as coppicing well. Current experience has been that it is an indifferent coppicer when compared to the eucalypts. Windthrow has been recorded (Anon. 1924) although Macmillan (1946) reports it as windfirm. Initial growth rates are high with height increases of 3 m in the first year and second year recorded (Anon 1892, 1893). Laumans et al. (1983) recorded average growth in arboretum plots of 24–28 m height and 48–57 cm diameter, at age 36 years. Similar growth of 49–53 cm diameter at 45 years was recorded by Sutter (1969). Macmillan (1914, 1946) records the trees as a 'greedy feeder' and suggests caution if planting close to other crops.

Acacia dealbata

Introduced about the same time as *A. decurrens, A. dealbata* enjoyed an early popularity because of its attractive flowers and habit, rapid growth and successful early establishment. Its aggressive habit of producing profuse root suckers and its ability to dominate a site encouraged a caution to its widespread use. The possibility of utilising this habit and its ability to tolerate weed conditions made it a useful proposition for the afforestation of marginal lands. However, it was largely overshadowed by the success of the other bipinnate acacias *A. decurrens* and *A. mearnsii*.

Acacia mearnsii

Acacia mearnsii was introduced to Sri Lanka around 1890 (Anon. 1923; Sherry 1971) as a fast-growing fuelwood species and windbreak. However, later it gained attention because of its potential for producing tan-bark in the up-country where conditions for cultivation and growth above 1200 m are ideal. Although *A. decurrens* grew faster and yielded acceptable levels of tannins, these tannins contained undesirable colouring agents and *A. mearnsii* was favoured (Weeraratne 1964). It grows well on grasslands and enjoys well-drained soils. Letourneux (1955) recommended it as one of the species suited for up-country afforestation. Growth is rapid with heights of 5–6 m reached in 2 years (Macmillan 1946). Whilst there is no current exploitation of this species for tannin production, past experience as described by Macmillan (1946) is of interest. The tan-bark is ready for harvesting 7–8 years after planting and yields of about 17 t/ha can be expected.

Apart from the bark, useful yields of poles, small timber and fuel can be expected. Weeraratne (1964) estimated that 1000 ha of pure *A. mearnsii* plantations would meet Sri Lanka's projected annual need for tannin extract of 600 t. Currently Sri Lanka imports 390 t of tannin extract and extracts of vegetable origin per year and the total value of imported tannin extract and tanning chemicals is about Rs.9 million (about US$320 000). Sherry (1971) suggested that bark with acceptable tannin levels could be produced in Sri Lanka with better silvicultural practice.

Acacia mangium

Introduced in 1980, there are now about 50 ha of plantations of this species. It commands high expectations for future afforestation in the lower and mid-country humid and sub-humid zones because of its rapid growth and its apparent ability to tolerate weed competition. It demonstrates an unexpected ability to tolerate extended drought at Meegahakiula research trial and is being assessed in agroforestry trials.

Other Species

Recent introductions are under assessment for inclusion in new afforestation initiatives in the lower, semi-humid areas of the country, where they must withstand a prolonged annual drought. *Acacia auriculiformis* shows promise on these sites, demonstrating a drought-hardiness combined with rapid initial growth. In trials it has suffered from a tip dieback when trees are 2.0–2.5 m tall and this has affected the form. Although the trees recovered quickly the reason for the dieback is not currently known.

The Future

Afforestation will become a priority area for rural development with a newly developed draft Master Plan for Forestry in Sri Lanka, calling for the establishment of 100 000 ha of new plantations by the year 2000 (Anon. 1986a). It is likely that much of the land made available for this development will be marginal as the most suitable lands have already been assigned to agriculture and plantation crops. Apart from future wood needs for industry and construction, there is a large requirement for fuelwood (currently 8.4 million t annually) for domestic use, tea and tobacco drying and the manufacture of pottery and bricks. An estimated 52% of Sri Lanka's current wood requirements comes from the non-forest sector as clearings of rubber estates, coconut timber, tea prunings and wood from home gardens (Anon. 1986b). This sector will receive increased attention.

The Australian acacias have proved to be very successful in Sri Lanka, and they will play a part in the proposed expanded afforestation program with the draft Master Plan recommending that 20% of up-country planations be of hardwoods, e.g. *A. melanoxylon*. Webb et al. (1980) suggest that *A. decurrens, A. mearnsii* and *A. melanoxylon* are worth considering for up-country plantations. The initial success of *A. mangium* and its success in other countries ensure it will be a part of future programs. Initial results from trials of species such as *A. auriculiformis* and *A. crassicarpa* are encouraging for afforestation of lowland, sub-humid sites.

Research Needs

There are many gaps in the knowledge of the silviculture, genetics and physiology of Australian acacias in Sri Lanka. The following research priorities would partly meet the immediate requirement for information and to ensure that best use is made of the *Acacia* resource: (1) A review and assessment of tropical acacias particularly species which might be suitable for afforestation in the intermediate and dry zone; (2) A review and assessment of the bipinnate acacias, with special note of their suitability for planting on marginal up-country grasslands; (3) An assessment of provenance for *A. melanoxylon*. It is likely that the original introductions are from a southern source in Australia and that more northern provenances will be better suited to Sri Lanka's future afforestation; (4) *Acacia* taxonomy and identification. The considerable confusion with regard to *Acacia* identification and taxonomy experienced 100 years ago remains a problem today. There exists a need for a layman's guide to the more commonly planted Australian acacias; (5) Access to literature and certified seed for research are essential prerequisites for assessment of acacias.

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Australian Acacias in The People's Republic of China

Pan Zhigang* and Yang Minquan**

SINCE 1960 about 50 species of acacias have been introduced to China from Australia. Most acacias are still in an experimental stage, with only a few early introduced ones having been widely planted in the tropics and subtropics of China. The most important successful species are as follows:

Acacia auriculiformis

This species was introduced to Guangzhou, Guangdong Province, from Southeast Asia in 1961, and grows well south of 23°N on fertile soil. This species will grow in a variety of soils, with a pH range of 4–6.5. It will also grow on thin eroded gravelly soil, and on coastal sandy soil where salinity is high.

Acacia auriculiformis reaches 18.8 m in height and 32.5 cm in diameter at age 21 years. From stem analysis, mean annual increment was 1 m in height during the first 8 years. The largest volume increment appeared at 8–14 years of age.

It can be used for fuelwood, and in southern China a production of 24 358 kg/ha (absolute dry weight, stem 79%, branches 21%) can be achieved up to the fourth year of growth (1665 trees/ha). Its calorific value varies from 4.78 to 5.11 Kcal/kg at 1–4 years of age. Rotation age in China may be 3–5 years.

Acacia auriculiformis can help to improve the soil. On Hainan Island, Guangdong Province, a yield of stand decaying litter of 4800–5700 kg/ha/year has been reported. Nitrogen content in fresh leaves is about 1.32%; phosphorus and potash is 0.14% and 0.43%, respectively.

Black Wattle *(Acacia mearnsii)*

This species was introduced to China about 30 years ago. Its environmental requirements are as follows: mean annual temperature varies from 17 to 20°C; annual rainfall averages 1000 mm; and absolute minimum temperature above -5°C, with less than 80 days of frost. It does best on well-drained, deep and moist sandy soil with pH 5–7. In China, rotation age of black wattle is generally about 7 years, when it has reached a height of 9–11 m with a d.b.h. of 20–28 cm. It is used mainly for tannin and fuelwood. Tannin content in the bark averages 46%.

Gummosis has been reported, and some trees have been attacked by scarab insects, scale insects and termites.

Silver wattle *(Acacia dealbata)*

This species has been planted in the subtropics and southwestern basin of China. It is more cold-resistant than black wattle.

Acacia mangium

This species was introduced into China in 1979. The mean annual growth reaches 1.7–1.9 m in height with a d.b.h. of 28 cm and a volume of 0.014–0.016 m^3/tree at 5–7 years of age.

The growth in height and d.b.h. increase with increase in temperature and rainfall (Fig. 1). From observations in south China, *A. mangium* grows slowly when the mean monthly temperature is below 17°C. When the temperature is above 20°C, *A. mangium* grows faster.

Seed of *A. mangium* must be treated by soaking in boiling water. Seedlings 25–30 cm high are used for planting, because the roots are not too long to affect the vigour of the seedling. If the seedling is too short it is easily attacked by crickets. Bare-root planting is not common and not successful. Container seeding has been used successfully for afforestation.

Acacia mangium does best on deep, moist and fertile soil. The species has a vigorous shallow root system. Its roots mainly concentrate in the upper 28 cm of soil at 5 years of age, with an average root diameter of 5–9 cm.

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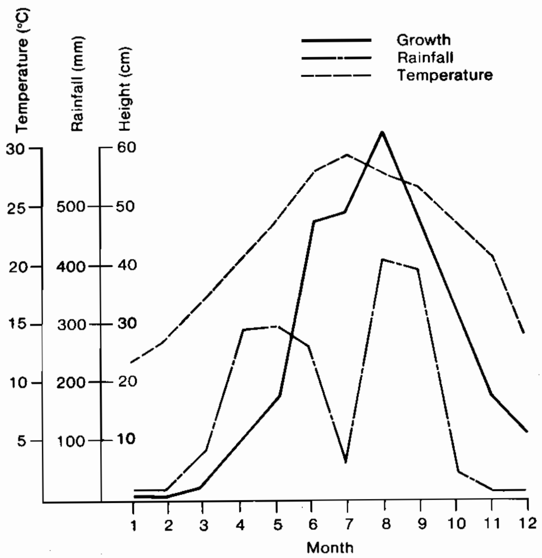

Fig. 1. Growth of *A. mangium* in relation to temperature and rainfall (Shantou, 24 °05,N, temp. 21.6 °C, rainfall 1715 mm).

At 20 °N latitude, with a mean annual temperature of 22 °C, *A. mangium* starts flowering in 3–4 years. In Wanning, at latitude 18 °40 ′N with a mean temperature of 24 °C, *A. mangium* flowers only 20 months after being established. In Nanning, at latitude 22 °49 ′N, the time between flowering and fruiting is about 9 months. It is evident that the lower the latitude, the earlier the flowering and fruiting. In order to improve *A. mangium* fruiting, it is necessary to plant it on deep fertile soil and to fertilise it with phosphorus.

Pests and diseases have not yet been serious problems with *A. mangium*. *Oidium* ssp. were found in seedlings and young trees. Leaf spot was also found in some trees, with symptoms showing it was caused by *Phyllostica* ssp. *Acacia mangium* seedlings are easily attacked by crickets, and young trees by scarab insects or termites.

The wind resistance of *A. mangium* is inferior to that of *A. auriculiformis*. According to observations in Zhanjiang, Guangdong Province, wind damage results in 3% break and 11% lean. In Wanning, Hainan Island, 2-year-old trees reached an average height of 6.7 m and average diameter of 10.3 cm. After force 12 typhoon and a 9-hour rainstorm in 1985, 56% of the *A. mangium* were seriously damaged. However, 84% of the stumps

Table 1. Provenance tests of *Acacia mangium*.
(1.5 years old)

Leizhou (21 °31 ′N, temp. 23.2 °C)		Quenhai (19 °09 ′N, temp. 24 °C)		
No.	Height (m)	No.	d.b.h. (cm)	Height (m)
13459	2.61	13459	4.88	6.04
13229	2.58	13229	4.78	5.67
13242	2.41	13242	4.64	5.29
13460	2.39	13232	4.38	4.64
13240	2.39	12992	4.30	4.61
13279	2.34	13234	3.77	3.60
13621	2.30	13233	3.54	3.29
13241	2.25	13621	3.30	2.77
13231	2.23			
13233	2.23			
12990	2.21			
13237	2.20			
13236	2.16			
13230	2.10			
13239	2.10			
13232	2.07			
13234	2.07			
13238	2.07			
13622	2.00			
12990	1.88			

survived by sprouting again after the stem was broken, but other trees with a broken stem below 1 m lost vigour.

Acacia mangium is sensitive to prolonged low temperature and frost. In Nanning, Guangxi Province, two 5-year-old trees died after prolonged low temperature of 4.9–5.6 °C, with cold rain.

Provenance trials of 1.5 years show that three seed sources from Papua New Guinea (13459) and Queensland (13229, 13242) were significantly superior to other provenances (Table 1).

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Relationship Between Chlorophyll Content, Photosynthesis, and Biomass Production in *Acacia* and *Eucalyptus* Seedlings*

Sun Jisheng**

THE relationship between chlorophyll content, chlorophyll a/b value and photosynthesis, and biomass production has been studied intensively (Liu 1982; Zhou and Cheng 1980; Buttery and Buzzel 1977; Bickman 1973; McCashin and Canvin 1979), but the evidence is as yet inconclusive. Bickman (1973) and McCashin and Convin (1979) report that their relationship is not significant, but Liu (1982), Zhou and Cheng (1980) and Buttery and Buzzel (1977) concluded it to be significant. In this experiment, the content of chlorophyll a (chla), chlb, and chla + b, chla/b, general and net photosynthesis rate were studied to investigate the function of chlorophyll in photosynthesis and biomass production, and to test the possibility of predicting the growth by measuring the chlorophyll content and chla/b value in the selection of fast-growing species and provenances.

Materials and Methods

Seedlings were developed in the nursery of the Department of Forestry, South China Agricultural University. Seeds were sown in March 1983, and the nursery procedures were the same for all seedlings.

Naked seedlings were transported to the laboratory in the early morning and 0.3–1.0 g of leaf, taken from the middle of the seedling crowns of middle-size seedlings (height: *Acacia auriculiformis*: 11–14 cm; *A. confusa*: 7–10 cm; *Eucalyptus citriodora*: 13–16 cm; *E. exserta*: 4–6 cm) was used for the extraction of chlorophyll. Photosynthesis was measured with 2–3 full leaves from the same location as above in the seedling crown on the FQ Infrared Carbon Dioxide Analyzer under 50 000 lux light density, and the leaf areas determined by a Leaf Area Meter.

Light intensity of the extracted chlorophyll solution, on which the chlorophyll content is calculated, was measured on a 751-G Spectrophotometer.

Results

Differences of Chlorophyll Content and Chla/b Value

As shown in Table 1, *A. auriculiformis* has significantly higher contents of chla, chlb and chla + b than *A. confusa*. The chla/b value of the former is much closer to that in the hypothetical photosynthesis unit (2.6) put forward by Thornber (1977). Also, *E. citriodora* has significantly higher content of chla, chlb and chla + b than *E. exserta*.

Differences in Photosynthesis Rates

Many differences appeared in the photosynthesis rates of the two pairs of species (Table 2). The general photosynthesis rate and net photosynthesis rate of *A. auriculiformis* were 22.3 and 42.4% higher than those of *A. confusa*, respectively, and those of *E. citriodora* were 38.9 and 55.2% higher than those of *E. exserta*.

Differences in Growth

The growth of the two pairs of species differs significantly at the age of 3 months (Table 3). Height growths of *A. auriculiformis* and *E. citriodora* are 60.1 and 28.4% faster than those of *A. confusa* and *E. exserta*, respectively. *Acacia auriculiformis* and *E. citriodora* have 51.1 and 54.5% more leaf area per seedling; 68.4 and 144.2% higher leaf area coefficiency; and 12.1 and 54.2% more biomass.

Variation of Chlorophyll Content and Net Photosynthesis

Based on that of the leaves at the middle of the seedling crown, the chlorophyll content of the

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Table 1. Differences in chlorophyll content and chla/b.

	A. auriculiformis				*A. confusa*			
	a	b	a + b	a/b	a	b	a + b	a/b
Average	3.0**	1.2**	4.3**	2.6	2.5	0.9	3.4	2.8
SE	0.2	0.1	0.5	0.3	0.5	0.0	0.5	0.2
CV %	5.8	7.1	11.3	11.3	17.8	2.6	15.5	5.7
	E. citriodora				*E. exserta*			
	a	b	a + b	a/b	a	b	a + b	a/b
Average	2.3**	0.9	3.2**	2.8	1.7	0.6	2.2	2.9
SE	0.2	0.0	0.3	0.2	0.1	0.0	0.2	0.3
CV %	4.9	4.4	8.4	6.8	7.0	2.4	9.0	9.4

Chlorophyll content: Chl mg/dm^2. The data figures are averages of 12 replicates measured on May 5, June 5, and June 6, 1983, respectively.

*, ** means different at the level of 95 and 99% respectively.

Table 2. Differences in photosynthesis rates.

	A. auriculiformis	*A. confusa*	*E. citriodora*	*E. exserta*
General photosynthesis rate	19.23	15.73	15.96	11.49
Comparison %	122.3	100.0	138.9	100.0
CV %	3.7	9.1	3.8	4.3
Net photosynthesis rate	12.39	8.70	12.39	7.99
Comparison %	142.4	100.0	155.2	100.0
CV %	6.8	12.5	11.3	2.9

Figures are averages of 12 replicates measured on June 4, 6 and 7.

Table 3. Differences in growth.

	Height		Leaf area per seedling		Coefficiency of leaf area		Biomass per seedling	
	cm	%	cm^2	%	cm^2	%	g	%
A. auriculiformis	21.1	160.1	43.8	151.2	0.85	168.4	0.43	112.1
A. confusa	13.2	100.0	29.0	100.0	0.50	100.0	0.38	100.0
E. citriodora	24.6	384.5	45.0	154.6	0.84	244.0	0.50	154.2
E. exserta	6.4	100.0	29.3	100.0	0.35	100.0	0.32	100.0

Heights measured on June 18, others on June 23. All the investigations were made on 20 seedlings in the same plot (30 × 30 cm).

leaves at the upper (1/3) crown and lower (2/3) crown changed within the range of 15%, while net photosynthesis rate changed within the range of 50%. For young trees (aged about 5 years), based on leaves from the middle branch crown, chlorophyll contents changed within the range of 4%, while net photosynthesis rate changed also within the range of 50% (Table 4).

Discussion and Conclusion

It is shown in Table 3 that *A. auriculiformis* and *E. citriodora* seedlings grew faster than *A. confusa* and *E. exserta*, respectively, which is consistent with the results reported (Wu 1983). According to Bickman (1973), 90% of tree biomass comes from photosynthesis products and the yield and biomass production of the plant correlates positively with the net photosynthesis capacity when the leaf density is not too high (Ledig 1975), and yields can be increased by the improvement of photosynthesis (Basshan 1977). From the results of this experiment, if the photosynthesis of leaf at the middle of crown is to be used to represent that of the whole seedling crown for comparison, the net photosynthesis rate of *A. auriculiformis* and *E. citriodora* is 1.15 times and 1.4 times higher than that of *A. confusa* and *E. exserta*, respectively. This may be one of the causes for the differences in growth. It also indicates that the growth of the seedling positively correlates with the net photosynthesis capacity.

Chlorophyll is the most important light-absorbing pigment in the photosystem. A positive correlation has been reported between photosynthesis rate, biomass production and the content of chlorophyll. Buttery and Buzzel (1977) reported that in a soybean cultivar and mutant with low chlorophyll content, a quadratic equation appeared between the photosynthesis rate and chlorophyll content, and that the variation of chlorophyll content accounted for 44% of the difference of photosynthesis. In rice, photosynthesis rate relates positively to the content of chlorophyll and negatively to the chla/b value (Liu 1982). The variety of *Homalium hainensis* with thick bark, which has a higher photosynthesis rate, contains 40% more chlorophyll than the thin-bark variety. The results of this experiment show that in the two pairs of species, the species having a higher content of chlorophyll has a higher rate of photosynthesis and growth, indicating that a relationship exists between the chlorophyll content, photosynthesis and growth, and the variations in the contents of chlorophyll accounts for at least one part of the differences of photosynthesis and growth.

Chla and chlb are the two most important chlorophylls in the photosystem. They can commence functioning only when combined with special proteins (Brown 1972). Thornber and Alberta (1977) concluded that chlb exists only in the chla/b–protein complex which is the most important component of the reaction centre of photosystem II and plays a decisive role in the equal distribution of energy between the two photosystems. In the hypothetical model of photosynthesis unit, the chla/b value is 2.60. If this value increases, the amount of chla/b-protein complex will decrease. Shade plants have lower chla/b value and higher light absorbability than sun plants. Compared with that of *A. auriculiformis*, *A. confusa* has less chlb resulting in the lower concentration of chla/b–protein complex and lower ability to absorb light and in the unequal distribution of energy between the two photosystems in some photosynthesis units, which may be part of the reason why these two species differ in photosynthesis capacity and growth. This can also explain the differences of growth and photosynthesis between the two *Eucalyptus* species.

Table 4 shows that in seedlings and young trees of *E. exserta*, the photosynthesis rate appears to give a wider range of variation than chlorophyll content. Vong and Muturate (1977) report that temperature affects photosynthesis. The diurnal variation of photosynthesis is also significant (Dziumara 1975). The methods to measure photosynthesis are more complicated than those for chlorophyll content. I therefore suggest that the chlorophyll content and

Table 4. Differences of changing range of chlorophyll content and net photosynthesis rate in *E. exserta*.

	Seedling crown			Young tree branch		
	Upper	Middle	Lower	Upper	Middle	Lower
Chla + b	3.39	3.73	4.25	4.27	4.44	4.27
%	90.8	100.0	113.9	96.3	100.0	96.2
Net Photosynthesis	3.45	6.74	4.32	14.47	9.82	4.59
%	51.3	100.0	63.8	147.7	100.0	46.8

Data average of four replicates.

the chla/b value be used in the selection of fast-growing species, varieties, provenances and trees in these two genera.

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Acacia Species and Provenance Trials in Thailand

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In 1985 the Royal Forest Department of Thailand (RFD) and the Australian Centre for International Agricultural Research (ACIAR) began a collaborative research project 'Australian hardwoods for fuelwood and agroforestry in the Kingdom of Thailand'. Twenty-three *Acacia* seedlots comprising 12 species (1–4 provenances each), along with some other Australian species, have been introduced and planted in a series of species provenance trials at six different locations. This paper reports height growth of the *Acacia* seedlots 6 months after field establishment.

Materials and Methods

Seedlings for the trials were raised at each planting site in January 1985. Details of the seed sources are given in Table 1.

Field planting took place during June–August 1985 at six locations selected to represent a range of climatic and geographic conditions in Thailand. The planting time of each site depended on the commencement of the rainy season.

A randomised complete block design with three replications was employed. Each plot contained 25 plants at a 2 × 2 m spacing.

The number of seedlots represented at each planting site varied but most seedlots were planted at four to six sites.

The planting sites were disc ploughed twice before the rainy season, and the planting spots sprayed with weedicide (Round-up at 1:100 in water) 2–3 weeks prior to planting. Following cultivation, 50 g of complete fertiliser (15:15:15) was applied to each plant 1 month after planting.

All trees were measured for height growth 6 months after planting. Analyses of variance were made for plot-mean data at each planting site, and F-tests used to test the significance of differences between seedlot means.

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Results

General Comparison of Species

There were marked differences in height growth between species at all planting sites (Table 2), and some trends in species ranking were evident.

In these initial assessments, *A. auriculiformis, A. leptocarpa* and *A. crassicarpa* are the fastest growing. Of these three species *A. auriculiformis* is the most promising. It was clearly the fastest growing at Sakaerat, Chanthaburi and Huai Bong with all of its three provenances being ranked in the top three. At other planting sites it was always amongst the tallest.

Acacia leptocarpa grew exceptionally well at Si Sa Ket. Seedlots from Starcke Holding, Queensland, and Woroi-Wipim, Papua New Guinea, reached a mean height of 301 and 297 cm respectively at 6 months. The Queensland provenance also performed very well at Ratchaburi, being ranked second for the site.

Acacia crassicarpa, A. auriculiformis and *A. leptocarpa* were growing faster than other species. Two provenances of *A. crassicarpa* from New Guinea (Woroi-Wipim and Mata) were among the leaders at many planting sites. A provenance from Shoteel (Queensland), however, was much slower growing.

The results recorded for *A. aulacocarpa* were much the same at all sites. Height growth of three seedlots (i.e. Oriomo and Keru, Papua New Guinea and Garioch, Queensland) was close to the overall mean whilst that of Julatten, Queensland, was much slower at each of the planting sites. One exception was at Sakaerat where the Julatten provenance was taller than the Garioch provenance.

Several species showed poor development. Slowest growth was recorded for *A. shirleyi, A. polystachya* and *A. melanoxylon*; while other species such as *A. flavescens, A. cincinnata, A. mangium* and *A. holosericea* though better than the slowest growing, were still far below the average at each planting site.

Acacia difficilis was poorly represented in this series of field trials with only one seedlot being

Table 1. Details of the seed sources of *Acacia* species and provenances trials in Thailand (1985).

D.F.R./C.S.I.R.O. Seedlot No.	Species	Locality	Latitude (S)	Longitude (E)	Altitude (m)
13688	*aulacocarpa*	Keru, PNG	8°32′	141°45′	40
13689	*aulacocarpa*	Oriomo River, PNG	8°48′	143°9′	20
13866	*aulacocarpa*	Garioch, Qld	16°40′	145°18′	400
13877	*aulacocarpa*	Julatten, Qld	16°35′	145°25′	410
13684	*auriculiformis*	Balamuk, PNG	8°54′	141°18′	18
13686	*auriculiformis*	Iokwa, PNG	8°41′	141°29′	35
13854	*auriculiformis*	Oenpelli Area, NT	12°20′	133°4′	50
13861	*auriculiformis*	Springvale Hld, Qld	15°50′	144°55′	500
13864	*cincinnata*	Shoteel, Qld	16°57′	145°38′	440
13680	*crassicarpa*	Wemenever, PNG	8°51′	141°26′	30
13681	*crassicarpa*	Mata, PNG	8°40′	141°45′	30
13683	*crassicarpa*	Woroi-Winpim, PNG	8°49′	143°0′	20
13863	*crassicarpa*	Shoteel, Qld	16°57′	145°38′	440
14623	*difficilis*	Daly Waters, NT	16°21′	133°22′	235
14175	*flavescens*	Mt Molloy, Qld	16°40′	145°18′	400
14660	*holosericea*	Turkey Creek, WA	17°4′	128°12′	400
13653	*leptocarpa*	Starcke holding, Qld	14°16′	144°26′	2
13691	*leptocarpa*	Woroi-Winpim, PNG	8°52′	143°3′	30
13621	*mangium*	Piru, Ceram, Indonesia	3°4′	128°12′	150
13846	*mangium*	Mossman, NQld	16°31′	145°24′	60
14176	*melanoxylon*	Atherton, Qld	17°17′	145°26′	1022
13871	*polystachya*	Bridle L.A., Qld	16°58′	145°37′	480
14622	*shirleyi*	Daly Waters, NT	16°19′	133°23′	225

planted at Ratchaburi. At this site it grew much faster than many other species, only exceeded by *A. auriculiformis, A. leptocarpa*, and *A. crassicarpa*.

Provenance Differences

Based on the results shown in Table 2, provenance performances were compared for the species which had more than one provenance represented at several planting sites. Those species were *A. aulacocarpa* (four provenances planted at six sites), *A. auriculiformis* (three provenances at six sites), *A. crassicarpa* (three provenances at four sites), *A. leptocarpa* (two provenances at four sites), and *A. mangium* (two provenances at five sites).

For *aulacocarpa* and *crassicarpa*, there was a tendency for the more northerly provenances to grow faster than the southerly provenances though to varying extent. In both species the provenances from Papua New Guinea were generally taller than those from northern Queensland. *Acacia leptocarpa* tended to exhibit an opposite pattern. The provenance from Starcke Holding, Queensland, was slightly taller than that from Woroi-Wipim, Papua New Guinea, a result consistent at all planting sites.

There was no clear pattern of provenance difference for *A. auriculiformis* and *A. mangium*. Provenance ranking within the two species differed from site to site. Nevertheless, in the case of *A. auriculiformis*, height growth of the Oenpelli, Northern Territory, provenance was slower than that from Papua New Guinea and Queensland.

Effect of Planting Sites

There were clear differences in height growth between the planting sites although direct comparison was not made (Table 2).

Discussion and Conclusions

The early results indicate marked differences in height growth between the twelve *Acacia* species tested. At 6 months of age, *A. auriculiformis, A. leptocarpa* and *A. crassicarpa* were the fastest growing at each planting site. Relatively slower growth was recorded for *A. shirleyi, A. polystachya* and *A. melanoxylon*, whilst growth of other species was considered to be intermediate. The results, although still preliminary, are considered to be important as they have demonstrated which of the *Acacia* species are capable of adapting to Thailand's conditions.

Table 2. Mean height growth (cm) of 6-month-old *Acacia* species and provenance trials in Thailand.

Species	Seedlot	Provenance location	Ratchaburi	Sai Thong	Si Sa Ket	Sakaerat	Chanthaburi	Huai Bong
aulacocarpa	13688	Keru, PNG	167	152	212	102	104	55
	13689	Oriomo River, PNG	168	125	210	117	109	66
	13866	Garioch, Qld	165	105	200	92	107	50
	13877	Julatten, Qld	128	85	142	115	57	36
auriculiformis	13854	Oenpelli, NT	209	150	257	177	145	89
	13861	Springvale, Qld	203	211	268	180	152	124
	13684	Balamuk, PNG	213	221	284	180	118	110
	13686	Iokwa, PNG	237	162	—	—	—	—
cincinnata	13864	Shoteel, Qld	89	80	163	109	79	—
crassicarpa	13863	Shoteel, Qld	152	140	254	93	—	81
	13681	Mata, PNG	223	149	272	133	—	—
	13683	Woroi-Wipim, PNG	227	191	296	149	81	—
	13680	Wemenever, PNG	207	171	264	—	85	—
difficilis	14623	Daly Waters, NT	184	—	—	—	—	—
flavescens	14175	Mt Molloy, Qld	142	106	156	60	47	—
holosericea	14660	Turkey Creek, WA	128	159	130	98	108	35
leptocarpa	13653	Starcke Holding, Qld	234	160	301	113	112	69
	13691	Woroi-Wipim, PNG	212	—	297	—	105	55
mangium	13621	Piru, Ceram, Ind.	143	102	179	65	100	38
	13846	Mossman, Qld	148	77	187	81	88	—
melanoxylon	14176	Atherton, Qld	94	83	85	83	47	63
polystachya	13871	Bridle L.A., Qld	113	84	118	59	62	27
shirleyi	14622	Daly Waters, NT	83	73	143	45	—	—
General mean			168	133	210	108	95	64
Least significant difference (.05)			39	68	37	22	47	15
F-test (seedlots)			12.47***	3.67***	25.93***	29.71***	3.32**	27.63***

** and *** indicate significance at the 1 and 0.1% levels respectively.

[1] Central region, 30 m alt, 880 mm rainfall, lateritic soil, pH 5.2–5.7.
[2] South region, 50 m alt, red yellow podzolic soils, pH 4.9.
[3] Far northeast region, 130 m alt, 1300 mm rainfall, humic grey soil, pH 5.3.
[4] Northeast region, 400–700 m alt, 1200 mm rainfall, red yellow podzolic soils, pH 5–6.
[5] Central (east) region, 200 m alt, 1300 mm rainfall, grey podzolic soil, pH 6.2.
[6] Far north region, 880 m alt, 1000 mm rainfall, lateritic soil, pH 5.6.

Among the twelve *Acacia* species being tested, *A. auriculiformis* has long been known for its ability to thrive well in Thailand. Another *Acacia* species recently introduced to Thailand is *A. mangium* but its relatively high rainfall requirement may be a limiting factor, suggesting that selection of suitable provenances is important. Initial growth of the two provenances in this study suggests this species may not achieve the excellent performance it has shown in other countries including Malaysia (Tham 1979; National Research Council 1983), Bangladesh (Das 1984), Indonesia (Turnbull 1984) and Sri Lanka (Vivekanandan 1985).

Except for *A. auriculiformis* and *A. mangium*, other Australian *Acacia* species in this study were unknown to Thailand until the establishment of this ACIAR project. Performances of these species outside their native habitats are currently being investigated in several tropical countries. The present study does indicate that some of these species in the trials may have potential as plantation species in Thailand. In particular, *A. leptocarpa* and *A. crassicarpa* should receive special attention.

Another interesting species, but poorly represented in the study, is *A. difficilis* which showed quite satisfactory growth at Ratchaburi. It should be tested on a wider range of sites in the future.

Provenance differences in height growth were found in *A. aulacocarpa* and *A. crassicarpa* with the more northern provenances showing faster growth rate than the southern. Similar results have been reported for *A. crassicarpa* in Queensland (Ryan 1986). It should be noted, however, that in this species trial the range of provenances was limited so the results are considered to be tentative.

There were clear differences in the growth rate between planting sites. The differences were so great that even *A. mangium* which was relatively slow-growing at Ratchaburi was still taller than *A. auriculiformis*, the tallest species at Huai Bong. The much poorer growth at Huai Bong was at least partly due to nutritional problems although field maintenance could also be involved.

It should be stressed here that this paper reports only height growth at 6 months old, and that other characteristics not reported (e.g. diameter growth, survival, pest (e.g. termite) resistance or disease damage, etc.) are also important and will be taken into account in future assessments. Furthermore, the growth rate of individual species and rankings may change with time.

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Improving *Acacia auriculiformis* through Selection and Breeding in Thailand

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ACACIA AURICULIFORMIS was introduced to Thailand from Australia as an ornamental tree in 1935, but the seed origin was not known. The species thrives in all site conditions. As a result, it has been planted widely in every part of the country. With its dense crown and foliage remaining throughout the hot season, it is a good shade tree and becomes very common along streets, around temples and schools, in golf courses, city parks, etc.

Forest plantations of *A. auriculiformis* were not established until 1964, but it has since become an important species because of its rapid early growth which enables it to compete with weeds (e.g. *Imperata* grass). Under favourable conditions it grows as tall as 15 m in 5 years (e.g. at Sai Thong Plantation, Prachuap Khiri Khan Province, approximately 430 km south of Bangkok). Generally, the tree attains 4–5 m in height at 2–3 years of age. However, its crooked stem and poor axis persistence tend to reduce its popularity among plantation managers. Most plantations of this species have, therefore, been established in small plots of 15–30 ha as a supplement to other species.

In the early 1980s, the Royal Forest Department of Thailand (RFD) revised the species to be used in its reforestation program. Subsequently, tree improvement programs have been planned for some of the selected species including *A. auriculiformis*.

The interest in including this *Acacia* in the improvement program stems from the following: (1) the species can grow over a wide range of site conditions in Thailand with satisfactory results; (2) its wood can be utilised widely ranging from fuel, raw material for pulp, furniture, construction purposes; and (3) preliminary exploration in several plantations revealed possible selection of straight-stemmed trees and provenances for breeding programs.

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Thus, the improvement program for *A. auriculiformis* was started in the latter part of 1983 with the specific objectives to: (1) improve qualities of the species (e.g. stem form) through selection and breeding; (2) produce genetically improved seed and other plant materials (e.g. clones) for plantation establishment; and (3) develop and improve sound techniques for nursery and plantation establishment.

Present Activities

Selection of Plus-Trees

Most of the effort has been spent on selection of plus-trees since the commencement of the program. The selection has been carried out in several plantations, and one stand naturally regenerated. The main criteria used in the selection are: (1) growth rate; (2) stem straightness; (3) persistent axis (exceeding 6 m); and (4) freedom from pests and diseases.

Other characters, though considered to be of equal importance, such as branching habit, may nevertheless be disregarded at this stage.

Up to now, a total of 89 plus-trees have been selected, 49 in 1983–84 and 40 in 1985. However, it is obvious that the perfect tree possessing all those qualities is seldom found. Therefore, the selection is a compromise between the ideal and the relative merit of the tree judged from the surrounding trees at each selecting site. Furthermore, the selection is on the basis of phenotypic appearance which has to be proved in future vegetative and generative tests whether the good appearance is genetically determined. The program will continue to select as many plus-trees as possible to provide the starting material for breeding work.

Seed Collection

Seed has been collected from the selected trees with the amount varying from 1 to 500 g/tree. Flowering period of *A. auriculiformis* varies from place to place so that sometimes the trees had already shed the seed before the collection team reached them. As a result, very little seed was collected from some trees.

Besides the collection of seed from each individually selected tree, provenance collections have also been carried out for the study of provenance variation.

Open-Pollinated Progeny Tests

The seed collected in 1983–84 was used to establish 3.5 ha of open-pollinated progeny tests in 1984 representing 20-25 mother trees. Progeny tests have not been extended since but are planned to be established again in 1987 with the material from more parent trees. In this program, open-pollinated progeny tests have been designed for conversion to seedling seed orchards after their performances are evaluated.

The results from all progeny tests will be a guideline for selecting appropriate plus-trees for the establishment of clonal seed orchards in the future.

Clone Bank

Although the proper techniques of vegetative propagation for *A. auriculiformis* are being studied, the selected trees have been propagated by means of cutting and/or grafting for the establishment of a clone bank. It has been anticipated that all 89 plus-trees will be propagated in 1986, and clone banks representing these plus-trees will be established in the following years at three to four locations.

The same procedures will also be carried out for the newly selected trees.

Provenance Trials

Eight local and four exotic provenances (two each from Australia and Papua New Guinea) were planted in trials in June 1986 at four locations. The main objectives are to investigate provenance differences (e.g. growth rate, stem form, branching habit, and damage by pests or diseases) and to find the most promising provenances for future selection.

Seed Production Area

It will take several years before all new plantings can be supplied with seed solely from seed orchards. Thus, in order to obtain better-than-average seed for immediate requirements, some outstanding plantations aged over 5 years have been selected for conversion to seed production areas. These plantations are subjected to heavy thinning and all inferior trees removed.

In 1985, a 30 ha seed production area was established at Sai Thong Plantation, Prachuap Khiri Khan. Another 30 ha are to be established in 1986 at the same plantation. There will be at least two more plantations in other parts of the country that will be converted in the following years.

Plant propagation

Vegetative propagation has been emphasised in the current program since it is desired to preserve and multiply the selected material for future clonal seed orchards as well as for clone banks. The methods being studied include cuttings, grafting, budding, and micropropagation (organ and tissue cultures).

So far, cuttings (stem) and grafting (cleft and side) are the most promising methods although the percentage of success was not impressive, being 10-45% for both methods.

Pruning Experiment

It is evident that the tendency to multiple leaders (stems) from a low height of *A. auriculiformis* is generally shown at the early age (i.e. at 1–2 years old). This character apparently limits utilisation for poles and heavy construction timber. An experiment is therefore being conducted to examine a range of pruning treatments with the ambitious objective of seeing whether or not persistence of stem axis can be improved by application of initial pruning to the trees. The regimes are pruning up to 1/3, 1/2, and 2/3 of total tree height at 1, 2 and 3 years after planting. The first-year prunings were accomplished in March 1986.

Investigation of Hybridisation

There are reports of suspected hybridisation between *A. auriculiformis* and *A. mangium*. Hybrids of the two species are also said to possess vigorous characteristics. Study of this nature is considered to be appropriate in order to obtain information on the occurrence and performance of hybrids of these two species.

Thus, seedlings of *A. auriculiformis* and *A. mangium* have been mixed-planted to allow natural and controlled hybridisation between the two species. It is hoped that trees of the two species will flower at the same period to allow cross-pollination.

Future Plans

In the immediate future, it is planned to study flowering phenology, fruit and seed production characteristics. Attempts will also be made to develop pollen handling and controlled pollination techniques in parallel with the investigation of hybridisation. These studies will be of great importance for planning and may result in our revising the breeding system in the future.

Introduction of *Acacia mangium* to Thailand

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DURING the past two decades, the forest area in Thailand has been diminishing quite rapidly. The destruction of forest cover is caused by population pressure compounded by widespread log-poaching activities. Various measures have been instituted to curb the loss of forest area at the same time preserving the remaining natural forests. One of the most important measures is to increase reforestation activities throughout the country. Until recently, these activities have been carried out by the public sector through the Royal Forest Department using government funds to reforest the denuded area. Due to limited budgets, however, this endeavour hardly keeps pace with the destruction rate. Private sector involvement is, therefore, promoted and encouraged by the government.

Since private sector involvement in reforestation must be based on economic factors rather than ecological and environmental factors, it is, therefore, inevitable that those who want to invest in reforestation very much base their decisions on the return on investment. In other words, they want fast-growing tree species with multiple-use characteristics, which reflect broader market and utilisation possibilities to justify their investment.

The Royal Forest Department, as the sole government agency responsible for reforestation activities, has to provide all relevant information and data on all aspects of reforestation activities. In order to acquire relevant data especially on introduced species, it is necessary to establish local experimental plots to determine essential silvicultural data. In the past decade, several exotic species have been tested in experimental plots. These include several species of *Eucalyptus, Pinus* and *Acacia*.

The most recently introduced species with promising potential for commercial plantation is *Acacia mangium* which was tested by the Royal Forest Department in the 1984 planting season. Since the testing of *A. mangium* was carried out in arboretum trials, no experimental design was used. This paper attempts, therefore, to describe initial performance of *A. mangium* compared with three other species planted in the same testing site, namely: *A. auriculiformis, Eucalyptus camaldulensis*, and *Leucaena leucocephala*.

Trial Establishment

The establishment of trial plots was carried out using conventional methods for site preparation: vegetation clearing followed by controlled burning, staking and planting hole preparation. Spacing was set at 2 × 2 m in all plots. Each plot contained 100 transplanted seedlings. Weeding was carried out three times per year. The average height of seedlings when transplanted was approximately 25 cm.

The trial site was a former dry evergreen forest located at Pakthongchai district, Nakhon Ratchsima province (lat. 14°13′N, long. 101°55′E). General topography is undulating hills with altitudes of 400–700 m. Average annual rainfall and temperature is 1200 mm and 27 °C respectively. The rainy season is May to September; dry season is October to April with the hottest period in March and April. Major soil types are red and yellow podzolics, and lateritic soil with pH 5–6 and low fertility. The site was an abandoned shifting cultivation area which was entirely covered with *Imperata cylindrica* and *Saccharum arundinaceum* before the establishment of this trial.

Initial Results

In the first 6 months after transplanting, *A. mangium* exhibited very good survival rate but grew slowest compared to the other three species. This trend persisted throughout the first growing season but improved visibly in the second. After 2 years in the field, *A. mangium* outgrew the other three species as can be seen in Table 1.

The values presented in Table 1 were taken from the average of each plot. Aside from growth parameters, general appearance of *Acacia mangium* in the trial plot is quite impressive with its straight stem and good symmetrical crown form.

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Table 1. Comparison of height (H) and diameter (D) growth of four fast-growing tree species at Nakhon Ratchasima, Thailand. All measurements were in centimetres. Diameter was measured at root collar.

	Age (months)							
	6		12		18		24	
	H	D	H	D	H	D	H	D
Acacia mangium	70	0.6	95	0.9	206	2.6	515	5.2
Acacia auriculiformis	80	1.0	126	1.3	208	2.1	332	4.6
Eucalyptus camaldulensis	86	0.9	163	1.6	210	2.5	313	3.4
Leucaena leucocephala	131	1.4	283	2.9	337	3.7	448	5.8

Prospect for *Acacia mangium*

From the initial experience with *Acacia mangium* it is generally believed that this species possesses great potential for plantation establishment in Thailand. Its good survival rate indicates that the species needs minimum tending practices to compete successfully with such weeds as *Imperata cylindrica* and *Saccharum arundinaceum*. In the second growing season, *A. mangium* exhibits spectacular growth both in height and diameter growth which is indeed impressive compared with other species. Although it appears to have some vulnerability to attacks of powdery mildew and insect pest of the family Psychidae, these attacks are not serious enough to disrupt its growth performance in the second year. This experience is, however, our first with *A. mangium* in a field trial. It has been followed by research plots set up in 1985 with cooperation from the Australian Centre for International Agricultural Research (ACIAR). The effect of pests on *A. mangium* will be assessed through the ACIAR project.

From our limited experience with *A. mangium*, we believe that in the very near future it will play a major role in reforestation activities of the private sector in Thailand, to replace the present favourite species of *Eucalyptus*. The major constraint of *A. mangium* at present is the limited availability and high price of seed. We hope, however, that we can acquire sufficient knowledge and experience on important aspects of *Acacia mangium* silvicultural characteristics before widespread planting of this species takes place in Thailand.

Introduction of *Acacia* Species to Peninsular Malayasia

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TROPICAL *Acacia* species have been introduced into Peninsular Malaysia since the early 1930s. *Acacia auriculiformis*, which is a native of the savannas in Papua New Guinea, islands of Torres Strait and northern Australia, was first used as boundary markers in the plantation plots of the Forest Research Institute Malaysia in 1932 (Selvaraj and Muhammad 1980). Subsequently two other species, *A. aulacocarpa* and *A. richii* were introduced in 1958-59. Both were tested out in plantation areas at Kepong. During the same period, small quantities of seeds of other *Acacia* species had been imported but in the absence of proper pretreatment, very poor germination was obtained. In 1966, *A. mangium* was introduced to Sabah as firebreaks. Its good growth created interest and some seeds were brought into Peninsular Malaysia. The seedlings raised were put into a 0.4-ha plot in the Kemasul Forest Plantation in 1978. In addition to these species which were established as plantation trials, *A. confusa* and *A. holosericea* were also introduced as avenue trees for urban centres (Mitchell 1964).

Role of *Acacia*

The main objective of the early introduction of *Acacia* trees to Peninsular Malaysia was afforestation of denudated land resulting from mining activities or excessive burning. Many trials were established (Table 1).

Acacia mangium has since been selected as the main species for the Compensatory Plantation Programme of the Department of Forestry, Pensinsular Malaysia. The annual planting is to be increased progressively from 5300 ha in the Fourth Malaysia Plan to 12 100 ha during the Fifth Malaysia Plan (Yong 1985). Four main areas have been selected for plantation establishment, two of which were established for *Pinus caribaea* in the late 1960s. Its vigorous growth and hardiness have made *A. auriculiformis* a popular species in soil improvement trials. Besides being used in plantations, *A. auriculiformis* is one of the more common trees used to provide shade in parks and roadsides. It flowers at short intervals but the fallen stamens stain the paintwork of cars thus making it undesirable for car parks. *Acacia holosericea* has been planted for the silvery phyllodes while *A. confusa* is selected for its crown shape. Both species are planted only to a limited extent. Owing to its growth rate and abundant phyllodes, *A. mangium* is gradually being used as avenue trees.

Performance of *Acacia*

Acacia auriculiformis

The Tanah Beris Site, a 0.4 ha plot, is situated on raised sand dunes by the coast on the eastern state of Trengganu in Peninsular Malaysia. Planting was at a spacing of 2.4 × 2.4 m. Two plantings were carried out with 378 seedlings established in the first phase and another 180 seedlings a year later. The seedlings were monitored at different intervals until 51 months later before the plot was abandoned. *Acacia auriculiformis*, after 3 years, reached a mean height of 5.2 m, with a 73% survival rate.

The slimed terrace of mining sites is an area where all the residue materials from the tin mines, consisting largely of mud over coarse sand, are deposited. A total of 233 seedlings were planted. Another 50 were established on sand tailings. Survival (77%) and growth (11.3 m) were monitored for 4.5 years. The performance of *A. auriculiformis* compared favourably with other species tested in the same area. A series of fires occurred over the planting sites in the rehabilitation trials at the mining land. *A. auriculiformis* survived. This is an important feature as these denuded areas with their abundance of weeds are highly inflammable during dry seasons.

The trunks of *A. auriculiformis* are generally crooked and sometimes twisted thus making the species unsuitable for timber production. Large lateral branches sometimes grow low on the trunk,

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Table 1. Trial plots of *Acacia* species in Peninsular Malaysia.

Species	Year of establishment	Area (ha)	Purpose
Kepong Plantation			
auriculiformis	1932	0.66	Boundary markers; species trials
	1954	0.08	Rehabilitate lalang area
	1959	2.28	Rehabilitate lalang area
aulacocarpa	1959	0.04	Rehabilitation of tin tailings
richii	1958	0.04	Planting in lalang area
States Plantations			
auriculiformis	1955	0.48	Species trial on sand dunes
	1959	1.40	Species trials on tin tailings
	1958	0.64	Species trials on tin tailings
	1958	1.08	Terraced and slimed areas
	1960	0.40	Raised sand dunes
aulacocarpa	1959	0.20	Species trials on burnt ground

requiring pruning. Young seedlings of this species cannot withstand drought conditions.

Acacia mangium

Since its introduction to Sabah this species has been planted widely in the ASEAN countries, mainly because of its rapid growth rate, reported to be better than *Gmelina arborea* and *Eucalyptus deglupta*. Its ability to grow in a wide range of soil types further enhances its choice as a plantation species.

Acacia aulacocarpa

This species was used to afforest burnt or illegally cleared land that had been colonised by *Imperata cylindrica* (lalang). The seeds originated from Queensland and the record shows that only 10% of the seeds germinated, probably due to improper treatment of the seeds; 450 seedlings were produced for testing.

Two sites were selected for trial, one in Kepong and the other in Sg. Buloh. The first site consisted of coarse sand resulting from gravel pump tin mining while temporary cultivation was carried out in the second site before being abandoned and later burnt. Higher mortality was observed in the first site with 31% of the seedlings dead after the second year. On the second site height growth after 30 months was ca 3 m compared to about 2 m on the first site.

Acacia richii

Seeds of this species were imported from Taiwan. Seedlings were planted in two plots, one at Kepong which consisted of sand tailings and the other at Mantin which was also sand but with clay dredge tailings. In both areas, the mortality rate of seedlings 30 months after planting was low (not exceeding 10%). Growth was better in the Mantin site which had more clay. The tallest tree was able to reach 9.3 m in 40 months. Those growing in the more sandy site at Kepong had only a maximum height of 2.1 m even after 45 months.

Problems with *Acacia* Planting

Establishment

Although the adult trees of *Acacia* are resistant to drought, young seedlings without proper root systems are not as resilient. Stump planting has been attempted in this species but with poor success.

Genetic Variation

Most of the *Acacia* species established in these trial plots came from small batches of seeds. These seeds may have been collected from a single tree or small group of neighbouring trees. This greatly reduced the available genetic variability of the species tested. The number of seedlings produced was also small thus limiting the number of trials to a few areas.

Diseases and Pests

With the exception of *A. mangium*, all the other species were established in small areas. The level of diseases and pests is therefore generally low. Isolated incidences of fungal root infestation and beetle damage on foliage have been observed in *A. auriculiformis*. Seedlings of *A. mangium* suffered from root diseases particularly *Phellinus noxius* (brown root disease) and *Macrophomina* (charcoal root disease) (Norani 1985). Bagworms defoliate this species. The effect of lepidopterous defoliators on other species has been discussed by New (1984). Expensive chemicals are required to control these problems.

Research Needs

Genetic selection is the main area of research which requires immediate action. The generally poor forms of *Acacia* trees, viz *A. auriculiformis*, have been recognised. Exceptionally good form trees have been reported and special efforts are required to introduce these genetic materials into plantations. *Acacia mangium* was selected as the plantation species in Peninsular Malaysia even before the full potential of other species had been assessed in various sites.

The seed biology of the common *Acacia* species has been investigated by Bowen (1981), Bowen and Eusebio (1982) and Yap and Wong (1983). Methods of pretreatment before germination and storage are therefore well establilshed. Proper coordination of collection and processing are, however, lacking in Peninsular Malaysia. Seeds are being imported from various sources and no strict control of quality has been practised. Seed stands and seed orchards need to be established for good quality seed production.

As the planting of *A. mangium* is increased each year, problems of diseases and pests will get worse. Proper documentation of the cause and effect of these problems is required. Experimental work on possible control has already been initiated in the Forest Research Institute Malaysia.

Future of *Acacia*

The ability of *Acacia* to grow in very poor soil will remain the main feature for planting these trees. Large areas of mined-over lands and lalang-covered patches can be planted with *Acacia* trees which will enrich the impoverished soil by adding organic materials. Other more valuable tree species can then be planted. Unless a genetic improvement program can improve their poor forms, utilisation of *Acacia* will be limited to low-value products like fuelwood. As *A. mangium* is planted for timber production in Peninsular Malaysia, greater research activities will have to be directed to this species.

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Growth of *Acacia mangium* in Peninsular Malaysia

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ACCORDING to the 'Fifth Malaysia Plan (1986–1990)' the Compensatory Forest Plantation Programme will establish 74 000 ha of forest plantations on cut-over degraded forest lands.

This is aimed at enhancing the productivity of degraded forest land by planting fast-growing and high-yielding general utility timber species such as *Acacia mangium*, *Gmelina arborea* and *Paraserianthes falcataria* in order to compensate for the projected shortage and maintain future self-sufficiency in domestic timber requirements. The first results of *Gmelina arborea* and *Paraserianthes falcataria* pilot plantations demonstrate that *Acacia mangium* received considerable attention for the plantation program.

The general approach of these trials is to make comparisons of the same provenances growing under two different climatic conditions.

Site Characteristics

Climate

Climate is typical of the humid tropics and is influenced by monsoon winds. For the Kemasul plantation area the main characteristics are the two dry seasons (February and June–July) and a peak rainfall from October to December.

The characteristic climate features of the Ulu Sedili region are a dry period from March to July and the northeast monsoon during October–December contributing more than 50% of the annual precipitation.

Topography

The general topography of Peninsular Malaysia consists of extensive coastal plains and inland lowlands of undulating terrain. The topography of the experimental area in Kemasul varies from level to gently sloping, undulating terrain. For Ulu Sedili the topography could be described as strongly sloping/undulating to rolling.

Parent Material and Soils

The local soil conditions developed from the parent material and influenced by climate and the local topography represent the most important and decisive site factors regarding growth potential and yield possibilities of a given area.

The parent material in Kemasul is composed of Triassic and Jurassic sediments, mainly of argillaceous strata. The soil series belong to the Durian–Musang series (Adzmi 1985). The result of the soil survey in Ulu Sedili carried out by Otto (1986) indicates that the soils in the area are derived mainly from calcareous sediments and belong mainly to the Tai-Tak series.

Vegetation

The occurrence of certain plant/tree species or plant communities on a defined site cannot be explained by site factors only. Indeed relations exist between plant communities and site in plantation areas as well, which is largely ignored because of the lavish abundance of plants or plant species, and partly because of the lack of silvicultural experience. Research activities in these fields have a high priority since almost all afforestation works occur in this field (problems of plant competition).

Observational Layout

Each experimental plot consisted of 8 × 8 trees (plot size) and 6 × 6 trees (assessment plot) respectively. The plots were arranged to answer the following questions: how does *Acacia mangium* respond to further fertilisation (age 2–3) with Christmas Island Rock Phosphate (100 g), and; is there a need for additional potassium and magnesium (25, 50, 100 g K_2SO_4 and 25, 50 g $MgSO_4$)?

Observations

Initial height (dm) and diameter (cm) measurements were taken 2 years after plantation establishment (on 16 May 1985 in Kemasul and on

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30 October 1985 in Ulu Sedili). In the assessment, six variables were measured or scored, and divided into quantitative (metric or continuous scale) and discrete variables (classes or counts on discontinuous scales). These variables are: (1) height (dm); (2) diameter (cm) at 1.3 m (dbh); (3) condition; (4) straightness of stem; (5) forking or branching frequency; (6) state of health. The measurements are taken at 6-month intervals.

Results

Height and Diameter Development

The initial height and diameter (Table 1) in Kemasul are calculated, based on 10 height measurements in each plot.

Table 1. Height (dm) and diameter (cm) measurements.

Obs. area	H1	H2	H3
Kemasul	92	121	144
Ulu Sedili	87	107	—
	D1	D2	D3
Kemasul	11.8	13.5	14.8
Ulu Sedili	10.3	12.5	—

Table 2. Stem straightness.

	Ulu Sedili		Kemasul	
	No.	%	No.	%
Straight trees	402	41	206	23
Fair trees	425	44	385	44
Unacceptable trees	141	15	294	33

Stem Straightness

When assessing the stem straightness we are not looking at the whole tree but only the lower part of the stem in order to assess its possible use for saw logs. Table 2 contains the results of the observations.

Forking and Branching System

The height above ground level of the point where the fork begins is estimated in the following way: The total tree height is divided visually into three equal parts. The following classes and the corresponding scores are defined: FO1 = Forking below 1/3 of total height; FO2 = Forking between 1/3 and 2/3 of total height; FO3 = Forking above 2/3 of total height.

The point of forking is then referred to the appropriate group and the corresponding score is recorded. There are significant differences not only in the percentage of forked trees but also in the kind of forking system. Table 3 contains the basic information for these calculations of the diameter measurements in Kemasul (Pahang), and shows the result of Duncan's Multiple Range test. Treatments with the same letter are not significantly different from each other at the 0.05 level.

Discussion

Puri (1985) estimated in a study conducted in 16 countries of tropical Asia an annual loss of forest cover of 2 million ha/year. This will result, in the

Table 3. Diameter increment in Kemasul in response to fertiliser.

Treatment (g)	Average diameter (*cm*)	Duncan's Test				
Control	15.5	a				
250 P + 25 K + 25 Mg	15.2	a	b			
200 P	15.1		b			
150 P + 50 K + 50 Mg	15.0		b	c		
250 P + 50 K + 50 Mg	15.0		b	c		
250 p	14.8		b	c		
200 P + 25 K + 25 Mg	14.8			c		
150 P + 25 K + 25 Mg	14.6			c	d	
150 P	14.3				d	e
200 P + 50 K + 50 Mg	14.1					e

P = Christmas Island Rock Phosphate
K = Potassium Sulphate
Mg = Magnesium Sulphate

* Treatments with same letter not significantly different at 0.05 level.

future, in insufficient supply of indigenous timber and other forest products to meet both domestic and export needs. Therefore, the reasons for planting exotic species are many: (1) to meet the envisaged domestic demand and export needs for timber; (2) to meet the expanding requirements of tree species for providing shelter and shade; (3) to provide ground cover for the conservation of soil and water in eroded areas (e.g. reafforestation of tin mining areas). *Acacia mangium* is a good soil-improving species.

The decision to choose *Acacia mangium* for planting on several given sites results in a complex problem. In Peninsular Malaysia there are not only ecological factors such as growing conditions of the species (climate, soil and biotic aspects) that have to be taken into account, but also economic and socio-economic factors.

Acacia mangium has received considerable attention in Peninsular Malaysia. The results of the assessments so far show that, with the present stage of knowledge, the species cannot be recommended for large-scale plantation use.

The general consensus on exotics in Peninsular Malaysia seems to be that species should be chosen which are likely to satisfy the productive capacity of each particular site. *Acacia mangium* seems to fulfil these assumptions. However, it is still too early to give clear support to the possible uses of *Acacia mangium* timber.

According to the forestry policy for the compensatory plantations scheme, we require tall trees with straight, cylindrical stems and small crowns. The observed trees have many problems which reduce the quality of the timber considerably, such as early forking, multiple leaders as well as insect, fungus and mechanical damage. Only a small portion of the total amount could be used as saw or veneer logs. The bulk (60%) will only be used for pulpwood.

Conclusion

The following conclusions can be drawn from the work to date: for timber production there must be a long-term policy on the uses, quality, and size of timber likely to be required at the estimated time of maturity; there is a need for site mapping and description of the capacity of sites to produce such requirements in the desired period, before an exotic species is chosen; provenance choice is of paramount importance in plantation forestry; and Research work is needed in: preparation of the site for planting, nursery practice, methods of planting, and management of the plantations such as pruning and thinning.

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Development of *Acacia mangium* as a Plantation Species in Sabah

M. P. Udarbe and A. J. Hepburn*

SABAH is the easternmost State of Malaysia. It covers an area of 73 711 km^2 with a population of 1.2 million people. Lowland dipterocarp forest forms the main part of its natural forest resources and timber from these forests is the traditional major export and revenue earner. However due to the inherent problems related to the management of these resources, it is increasingly becoming evident that Sabah's forest plantation program must be accelerated in order to meet the anticipated shortage of natural forest logs in the not-too-distant future.

Acacia mangium plays an important part in this program. Since its introduction to Sabah from Queensland in 1966, it has developed from a species used for firebreaks to Sabah's most widely grown forest tree. However, being a relative newcomer as a tropical plantation species, there are as yet many aspects of its growth and utilisation which need to be studied and developed.

A. mangium Plantations in Sabah

There are presently three main agencies developing large-scale plantations in Sabah, namely, the Sabah Forestry Development Authority (SAFODA), Sabah Softwood Sdn. Bhd. (SSSB) and the Sabah Forest Industries (SFI). The extent of their plantations by area and species is tabulated in Table 1.

The combined total area of forest plantations established by the three agencies at the end of 1985 was approximately 51 150 ha, of which 38% was *A. mangium*.

SAFODA is concerned with the reforestation of wasteland comprising mainly lalang (*Imperata cylindrica*) grassland and non-commercial secondary forests. These degraded lands are found scattered throughout the West Coast of Sabah and are the result of shifting cultivation. In addition to tree plantations SAFODA has successfully developed rattan plantations on seasonally flooded sites and logged-over areas. In all its projects the participation of the local people is encouraged either through employment as daily workers, wage contracts or as settlers in forest development schemes. On the other hand, SSSB and SFI are companies developing commercial forest plantations for industrial wood. They are located at Tawau and Sipitang respectively.

Table 1. Forest plantation area in Sabah (in hectares) by species and agencies at the end of 1985.

Species	SAFODA	SSSB	SFI
Acacia mangium	16 336	2 142	1 200
Eucalyptus deglupta	—	9 340	—
Gmelina arborea	—	5 939	—
Paraserianthes falcataria	—	6 327	—
Pinus spp.			
(*P. caribaea, P. oocarpa*)	825	1 017	—
Rattan	6 757	—	—
Others	—	1 250	—

Planting Program

It is estimated that starting from 1986 the annual rate of planting of *A. mangium* in Sabah is 4000 ha/annum. This rate is expected to increase when the SFI pulp and paper mill comes into full operation and when other market outlets have been developed.

In 1982 the World Bank became involved in the Bengkoka Afforestation and Settlement Project being implemented by SAFODA which aims at the establishment of 36 000 ha of plantations and the settlement of 2000 families. Settlers will be given permanent employment as forest workers, housing facilities and amenities, and a share of the plantation proceeds through corporate ownership. In support of a proposed development program which envisages the establishment of some 250 000 ha of forest plantations throughout Sabah by the year 2000, the Bank has made a loan of US$6.5 million to cover half the cost of a 3000 ha pilot plantation project and various technical studies. Based on

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these studies it is expected that forest plantation develoment will be accelerated and expanded by 1990.

In Peninsular Malaysia, the Asian Development Bank is supporting compensatory plantation projects in several States aimed at the development of 40 000 ha of forest plantations by the year 1988. *Acacia mangium* is one of the main species planted.

Role in Soil Rehabilitation

The ability of *A. mangium* to grow on a wide range of sites has made the species the natural choice for reforestation and soil rehabilitation work in Sabah. Enthusiasm for the species is such that a high-ranking politician once declared that 'it grows on rocks'. In most of SAFODA's plantation areas where the sites are in general poor and degraded, the choice of species is limited to *A. mangium*. With its hardiness and fast growth the species is the best weapon for the eradication of lalang, and being a nitrogen-fixer it is an excellent soil rejuvenator. It is widely used for roadside planting, soil erosion control and rural beautification. There is roadside planting along a 150 km stretch of road in Sabah which is perhaps the largest species trial on record. *Acacia mangium* therefore plays an important role in the conversion of wastelands into productive forestry use.

Growing Knowledge and Practice

Planting sites range from infertile degraded lalang-covered wasteland to relatively fertile logged high forest. Thus growth varies considerably. However the general growth pattern is the same: very fast initially and tapering off after only a few years. MAIs of volume range from 10 to 29 m^3/ha/annum to a 10 cm top.

Silvicultural knowledge is limited. Rotation periods vary from 7 to 15 years depending on objectives of management. Initial spacing of 3 × 3 m is generally used. Wider spacings have been tried but these tend to lead to heavier branch development and low stocking. Closer spacing may be beneficial but this may not offset higher establishment costs. Regular thinning and pruning of stands has only started recently and little information is available. To produce saw logs in 15 years, stands will have to be opened out and two thinnings will be necessary, possibly three. Early pruning will be required to give maximum knot-free timber and will need to start before thinning; later prunings may be combined with thinning. Pruning height will be 6–7 m.

In the nursery liquid fertiliser is used while in the field 90 g of rock phosphate is applied at time of planting followed by 45 g of NPK mixture 2 months later at first weeding. Further fertilisation may be necessary.

With the fast initial growth few weedings are necessary, but it has been found that it is important to carry out the first weeding on schedule at about 2 months, otherwise growth suffers. Attention to nursery practice, establishment techniques and weeding schedules pays handsome dividends in the form of low failure and good initial growth.

To obtain speedy and regular germination, seed is pretreated using boiling water. If the appropriate treatment is used the seed can either be immediately sown or dried, repacked and stored ready for later use when no further pretreatment will be necessary. Seed is usually sown in a seed bed and then pricked out. Black polythene bags either 17 × 5 or 20 × 5 cm are commonly used. Seedlings are best kept under light shade for approximately 2 weeks and then exposed to full sunlight. With good nursery practice seedlings should reach a size for planting out after 12 weeks. They may be kept in the nursery for a further 4 weeks to harden off.

The MAL/UNDP Seed Source Establishment and Tree Improvement Project 1980–84 heralded a start to tree improvement. The collection and importation of seed from various provenances in Australia and Papua New Guinea was arranged and phenological studies, work on controlled pollination, and on seed were started. Throughout the life of the project, work on *A. mangium* was accorded a high priority.

The species is not fire-resistant but by shading out the ground vegetation it reduces the danger of fire and its own litter will not readily ignite. Trees of a reasonable size may survive a light fire undamaged but not a fierce one. Following severe fire in older stands natural regeneration is common.

In Sabah *A. mangium* has not been seriously bothered by pests and diseases. Slugs, caterpillars and grasshoppers occasionally cause problems in the nursery. In the plantations rats and squirrels may cause damage to young trees. It is susceptible to termites but attack is only sporadic and seldom serious. Various beetles and caterpillars do attack the trees but damage is seldom extensive.

In the nursery, damping off and other diseases may on occasion cause serious losses. In the plantations various diseases including heartrot do occur but have not been serious.

Utilisation

In 1983, sawing, plywood manufacture and slicing tests were carried out on 12-year-old, avenue-grown trees. The tests showed that there are no physical difficulties in carrying out these various processing operations. The test report described the machining properties as very easy. 'Ground angles, settings and types of cutting tools such as sawblades & knives currently used for processing light and medium tropical hardwoods, readily cut the timber at high production speeds without any chipping of cutting edges. There was no evidence of silica or resin pockets' (Waring 1983). However the timber does present problems and first and foremost are the numerous knots, many of which are unsound with a pithy core which on conversion collapses leaving a hole. Fluting particularly in the lower bole is also a problem.

Plywood can be manufactured without difficulty and in Japan it has been made using very small logs peeled on an ariston lathe. Slicing presents no problems apart from the defect of knots. In the sawmilling tests the incidence of spring was high and this is likely to prove a serious defect.

The timber kiln-seasons well and fairly rapidly without any serious defects. It planes well giving a smooth and lustrous finish and sands easily and can be nailed without splitting. Small scale tests have shown it to be suitable for particle board. It produces reasonably good-quality charcoal, and is suitable for the manufacture of wood pellets and activated carbon. The heartwood is light brown in colour with variation and the sapwood cream coloured. Opinions differ as to the attractiveness of the colour and appearance.

Work by CSIRO has shown that the wood can be easily pulped by either the sulfate or neutral sulfite semichemical process to produce pulp with excellent papermaking properties, which can be readily bleached to brightness levels acceptable for use in fine papers. Yields of screened pulp in excess of 50% can be obtained by the sulfate process and as high as 75% by the NSSC process (Logan and Balodis 1982).

Research: Needs and Priorities

The priority areas are seen to be in tree improvement, silviculture, utilisation and marketing.

Tree Improvement

- Establishment and assessment of experiments. Identification of problems, design of experiments and interpretation of results.
- Maximum possible use of computerisation to facilitate sorting and tabulation of data and streamline analysis.
- Regular assessment of all provenance trials with speedy analysis of assessments and interpretation of analyses.

Expansion of provenance trials

- Action to obtain seed if a provenance trial indicates potential gains.
- More progeny trials with work concentrated on candidate plus- trees and the ultimate aim of full sib testing.
- Work on the vegetative propagation of adult material and the bulking up of juvenile or rejuvenated material.
- Investigation of the hybridisation of *Acacia auriculiformis* with *A. mangium* and the possible potential of the hybrid.

Silviculture

- Determination of most suitable initial espacements and appropriate thinning and pruning regimes for different objects of management.
- Development of pruning techniques.
- Information on growth rates on different sites and development of site quality yield tables.
- Compilation of volume tables.
- Determination of fertiliser requirements.

Utilisation and Marketing

- Investigation of end uses in particular for furniture.
- Studies of processing techniques to maximise volume and value.
- Studies of seasoning.
- Investigation of preservative treatments.
- Investigation of world-wide markets and sales promotion.

Future Outlook

It is believed that *Acacia mangium* has great potential as a plantation species, particularly in the reforestation of waste and degraded land. With genetic improvement and the development of appropriate silviculture and processing technology it is envisaged that it will produce veneer and saw logs as well as pulpwood. With this facility plantations in Sabah could become major suppliers of timber products to Peninsular Malaysia and elsewhere. As pulpwood there will undoubtedly be a large and ready market in Japan while more specialised products may find markets further afield. In the future it may provide the raw material for the manufacture of charcoal, wood pellets and activated carbon.

Conclusion

The future for *Acacia mangium* looks bright and assured but adequate research and development is essential if its full potential is to be realised. In particular a major effort is required in the field of tree improvement and in promotion and marketing. The major constraint is seen to be a lack of skilled and experienced manpower.

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Growth of *Acacia mangium* Throughout Sabah

K. I. Thomas and G. A. Kent*

ACACIA MANGIUM was first introduced into Sabah in 1966 by the State Forest Department. Its performance in these first plantings and subsequent trials was promising. Of particular note are: (1) its ability to compete successfully with *Imperata cylindrica* (lalang grass) on poor soils which were often degraded by shifting cultivation; and (2) its good survival and growth on these poorer sites.

Since its introduction into Sabah, approximately 21 100 ha of *A. mangium* plantation have been established. Sabah Forest Development Authority (SAFODA) and Sabah Softwoods Sendirian Berhad (SSSB) first planted *A. mangium* in 1976. To date, they have established 16 336 and 2142 ha, respectively. SAFODA is involved in afforestation of grasslands, shifting cultivation areas, and noncommercial forests (Udarbe 1985). On these poor and degraded sites, *A. mangium* is the principal species planted. SSSB is involved in the establishment of commercial forest plantations on logged dipterocarp forest areas. Their plantings of *A. mangium* are usually restricted to lower quality sites which are considered unsuitable for other plantation species.

Although Sabah has a considerable area of *A. mangium* plantations, many are on lower quality sites. In these poorer areas, the performance of *A. mangium* is good relative to that of other plantation species, but its growth is affected. With this in mind, the growth of some *A. mangium* plantations in Sabah is examined, and wherever possible related to site and previous land use.

Methods and Materials

Acacia mangium plantations in three areas of Sabah were examined (Fig. 1). All the plantations sampled were over 3 years old. Thirty sample plots were established. Each plot was a block containing 30 live trees, with two exceptions. Plots 29 and 30 at Brumas had 20 trees only.

Each sample plot was assessed for topography, slope, and undergrowth. A soil profile was reconstructed from soil auger drillings and described. Auger holes were to a depth of 80 cm, or until parent materials or an impenetrable layer was reached. Soil samples were collected for chemical analyses. Soils were tentatively named according to the FAO/UNESCO soil classification (Acres et al. 1975a). A qualitative assessment of soil drainage was made using the categories outlined in Acres et al. (1975b).

For each plot, a subsample of ten trees was chosen at random for assessment of height and diameter. The form of all trees was also qualitatively assessed.

Only dominant and codominant trees are included in the calculated means. The data for some plots were pooled (plots 2 and 4; 14–17; and 23, 29 and 30), where site conditions and history were similar and total height and diameter were not significantly different.

Results and Discussion

The 3.7-year-old stand at Melima (plot 5) in the Sook area is growing on a poorly drained shallow gleyic podzol (Fig. 2a); the site was formerly lalang. Its height is considerably less than that of the Brumas stands of similar age (plot 23, 29 and 30) growing on more favourable orthic acrisols (Fig. 2b).

The Mompilis A and Hobut plantations are found in northern Sabah on former lalang sites (Fig. 2c and 2d). Both are 5-year-old, but the height growth of the Hobut site is significantly greater than that at Mompilis A. The latter plots are located on steep slopes and are somewhat excessively drained. In contrast, the Hobut site is on a plain and has better water retention. Seasonal rainfall patterns in northern Sabah show a drier period from April to August (Thomas et al. 1976). During the drier season, rainfall is extremely variable. In the northern area, excessively drained soils may not

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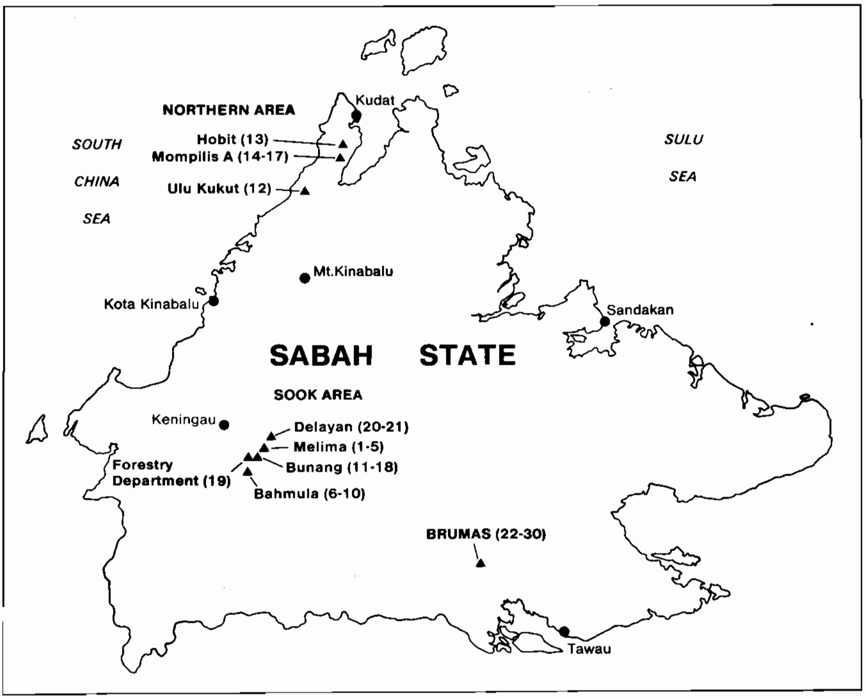

Fig. 1. Locations of the *Acacia mangium* plantations sampled in three areas of Sabah. The numbers in parentheses after the plantation names are the sample plot numbers.

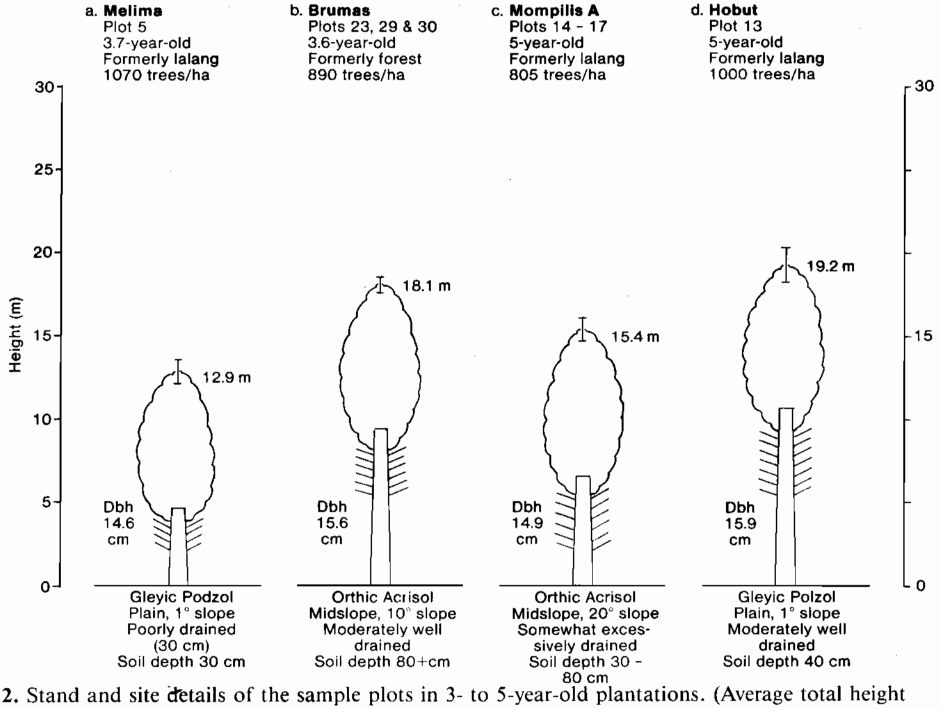

Fig. 2. Stand and site details of the sample plots in 3- to 5-year-old plantations. (Average total height and diameter at breast height over bark are given. Vertical line bars represent 95% confidence intervals of total height.)

be able to retain sufficient moisture to sustain rapid growth throughout the drier season.

Figures 3a and 3b contrast plantations of 6 years of age at Melima (plot 2 & 4) and 6.6 years of age at Brumas (plot 27), respectively. The Brumas plot has significantly better growth than the Melima plots. Both are on moderately well drained, former logged forest sites. Apparently, the dystric cambisol at Brumas is a more fertile soil than the orthic acrisol at Melima. In height growth, the 6-year-old Melima plantations (Fig. 3a) are comparable to the 50-year-old Hobut stand (Fig. 2d).

Plots 8 and 10 at Bahmula are located in 7-year-old plantations established on areas formerly covered by lalang (Fig. 3c and 3d). The height growth of plot 10 is better than that of plot 8. The soil at plot 8 is a poorly drained gleyic acrisol with a high clay content throughout the profile. In contrast, plot 10 is upslope from plot 8 and has improved drainage. The site quality of plot 10 at Bahmula (Fig. 3d) is similar to that of plot 5 at Melima (Fig. 2a) and Mompilis A (Fig. 2c). Plot 8 at Bahmula rates as one of the poorest sites examined (Fig. 3c).

The oldest stands examined are compared in Fig. 4. The two Bunang sample plots are comparable in age and located adjacent to each other (Fig. 4a and 4b). However, plot 11 has significantly greater height and diameter growth than plot 18. This is probably attributable to differences in soil properties. Plot 11 is located on a minor valley terrace and has a relatively fertile orthic luvisol. These soils are rare in the Sook area. In contrast, plot 18 is on a plain and has a gleyic podzol with much poorer drainage. The site quality of plot 11 at Bunang (Fig. 4b) is comparable to that of the Brumas areas (Fig. 3b and 4d).

Nine-year-old plantations are contrasted in Fig. 4c and 4d. The Ulu Kukut site with its shallow, stony dystric cambisol and somewhat excessive drainage is clearly less productive than the Brumas site.

In many of the Sook area plantations, poor drainage would appear to be a major factor limiting tree growth (Melima, Fig. 2a; Bahmula, Fig. 3c; and Bunang, Fig. 4a). The Sook area is relatively flat and soils are often shallow. Furthermore, the soils at Bahmula have high clay content. These sites are all of the lowest quality. Where drainage is somewhat improved, growth is better (Melima, Fig. 3a; and Bahmula, Fig. 3d).

In the northern area, excessive drainage may be restricting growth during dry periods (Mompilis A, Fig. 2c; and Ulu Kukut, Fig. 4c). The productivity of the sites in the northern area is comparable to that of the Sook area.

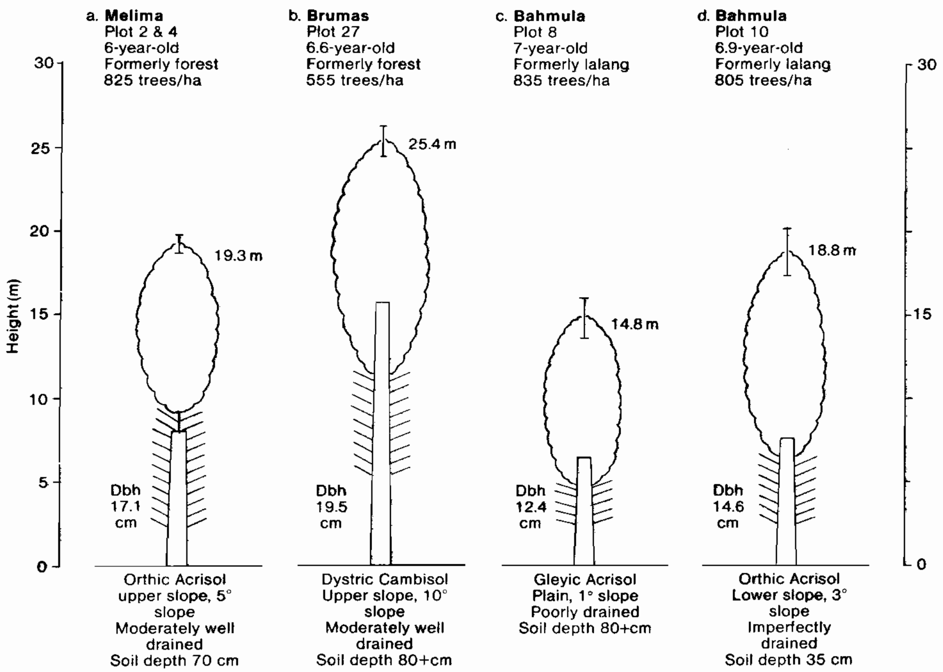

Fig. 3. Stand and site details of the sample plots in 6- to 7-year-old plantations. (Average total height and diameter at breast height over bark are given. Vertical line bars represent 95% confidence intervals of total height.)

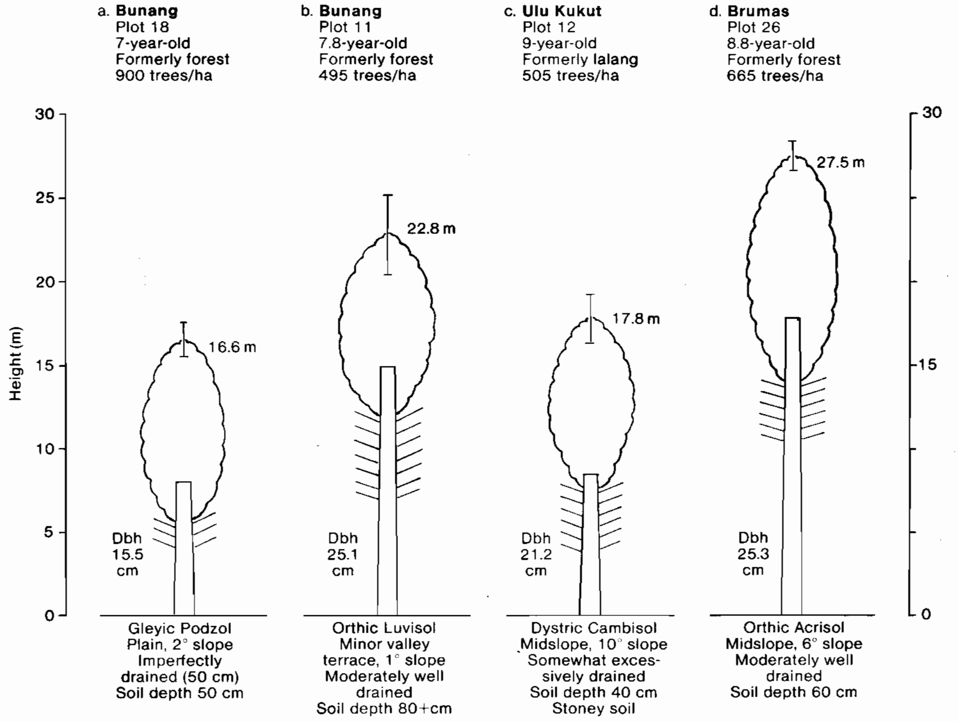

Fig. 4. Stand and site details of the sample plots in 7- to 9-year-old plantations. (Average total height and diameter at breast height over bark are given. Vertical line bars represent 95% confidence intervals of total height.)

With the exception of plot 11 at Bunang (Fig. 4b) in the Sook area, the Brumas sites are by far the most productive (Fig. 2b, 3b, and 4d). The Brumas plantations were established on areas formerly covered by dipterocarp forest. Disturbance and degradation of these sites prior to planting was relatively minor, in comparison to that of the Sook and northern areas. At Brumas, other sites of lower quality were examined. These also had better growth than those at Sook or in the northern area.

Conclusion

Although *A. mangium* does survive and grow successfully on a wide range of sites in Sabah, it is unrealistic to expect it to reach its full growth potential on a high proportion of these sites. The ability of *A. mangium* to attain modest growth on what are otherwise unproductive sites makes it an attractive species for afforestation. On moderately well-drained and relatively fertile sites, such as the logged forest areas at Brumas, it has the ability to be grown as a commercial species.

The experience gained to date in Sabah has illustrated these points. Provided that resource managers recognise this dichotomy, *A. mangium* should have a significant role to play in a variety of tropical forestry projects.

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Research on *Acacia mangium* in Sabah: a Review

Sim Boon Liang*

ACACIA MANGIUM is a vigorous species which occurs naturally in the humid tropical lowlands of northeastern Australia, Papua New Guinea and eastern Indonesia.

Early plantings in Sabah, East Malaysia, indicated the potential of *A. mangium* as a plantation species especially for rehabilitating difficult sites and revegetating newly cleared land. It has relatively good form, and is fast-growing with a volume increment averaging 25-30 m^3/ha/year. It has shown outstanding abilities to compete with weed species such as *Imperata* and *Eupatorium*. The area planted annually in Malaysia currently exceeds 6000 ha and trial plantings in other Southeast Asian countries are showing promise.

Adaptability of *A. mangium*

Acacia mangium is a leguminous species and, like many acacias, has wide adaptability. On good sites its growth is comparable with better-known, fast-growing species like *Paraserianthes falcataria* and *Gmelina arborea*; on more difficult sites, its growth rate exceeds that of many other trees (Fig. 1).

A noteworthy feature of the species is its ability to grow on acidic soils with a pH as low as 4.0. This is important because acidic soils are widespread in the tropics. This feature distinguishes *A. mangium* from some other leguminous trees, such as *Leucaena leucocephala*, which require a near-neutral soil. In Sabah, *A. mangium* is generally planted on less fertile sites, where species such as *Gmelina arborea* and *Eucalyptus deglupta* do not grow well.

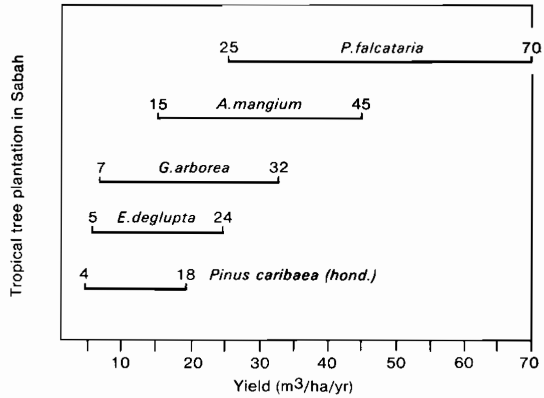

Fig. 1. Ranking of *A. mangium* with other common afforestation species in Sabah.

Symbiosis

This species, like most legumes, forms root nodules with nitrogen-fixing bacteria of the genus *Rhizobium*. The bacteria penetrate young rootlets in the aerated surface soil layers and form large and prolific orange-coloured nodules. This symbiotic relationship provides nitrogen compounds to the tree and nitrogen fertiliser is normally not required.

Acacia mangium also forms a symbiotic relationship with the mycorrhizal fungus *Thelephora ramariodes* (Gibson 1981). This fungus forms small tree-like dark fruiting bodies which are found under seedlings in the nursery as well as in plantations. The fungi benefit the plants by assisting the uptake of micro- and macro-nutrients, especially phosphorus. This association enables the trees to grow better in soils deficient in readily available minerals. *Acacia mangium* can grow in soils with a phosphate level as low as 0.2 ppm (National Research Council 1983).

Seed Treatment

Seed coat dormancy can be broken by immersing the seeds in boiling water (100 °C), with heat source removed, for 30 sec. The boiling water is then poured off and replaced by tap water (25 °C) in which the seed is soaked for 24 hours. The ratio of seed to boiling water is important with 1 part seed to 10 parts boiling water being optimum. Strict

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observance of the immersion period (30 sec) and water temperature (100 °C) is essential. Pretreated seed can be dried (to 6% MC) and stored for later use, at which time no further treatment is required. Pretreated seed can be stored in cold store (4–10 °C) for as long as 2 years without significant loss in viability.

Sowing

Conventionally, seedlings of *A. mangium* are raised in a seed bed and pricked into polybags at 2-leaf stage. Normal nursery recovery rate is about 37% because: (1) seed germination depends on soil conditions (texture, acidity, etc.), sowing depth, and the frequency and intensity of watering. If seeds are sown too shallow, they may be subject to excessive drying, and may also be carried away by insects, especially ants, which are attracted by the oily funicle; and (2) pricking out germinants is a very delicate task. It is time-consuming and extreme care must be exercised to ensure the seedling is not broken and to keep the tap root straight in the soil.

A new nursery method using pregerminated seed has raised the recovery rate from 37 to 85%. Seeds are sown in germination trays (a wet towel method) and pricked out using forceps directly into polybags after 6–9 days when the radicle appears. Advantages of this method include: (1) a high recovery rate; (2) a shorter and more precise 'pricking method' (6–9 days instead of 2–4 weeks); and (3) higher productivity in terms of number of germinants transplanted per person-hour.

Seedling Care

For the first 2 weeks after pricking out the young seedlings are protected under 75% nylon shade. Heavy rainfall tends to depress the seedling growth and in regions affected by the heavy monsoon rain, seedlings need protection for the first 6 weeks (Jones 1984). Seedlings can attain the plantable height of 24 cm in 12 weeks.

In Sabah inoculation of nursery soil with *Rhizobium* has not been necessary. However, it is recommended that 5 kg of triple superphosphate/CI rock phosphate mixture (1:3) be mixed into each cubic metre of nursery soil used for raising seedlings.

Up to now, there is no convincing evidence to justify the routine fertilisation of plantations of *A. mangium* planted on logged-over forest land.

Second Rotation

Acacia mangium stumps coppice profusely, but unlike *Gmelina arborea* or *Paraserianthes falcataria*, the coppice shoots do not develop into tree size. It is therefore impossible to develop the second rotation by the coppice method. However, large-scale natural regeneration from a clear felled *A. mangium* plantation takes place readily when the logging debris is burnt. The fire stimulates germination of the store of dormant seed in the soil.

Vegetative Propagation

Vegetative propagation of adult material for purposes of cloning selected material into seed orchard or clonal bank has been developed. Marcotting has proved to be an easy and reliable method with a success rate of about 70%. Patch budding is less efficent, as it takes 2 months for the bud to develop and the success rate is only about 40%.

The clonal bulking of juvenile or rejuvenated plant material for operational planting has achieved good results in some eucalypts, and *Gmelina arborea* has yet to be developed. Cuttings prepared from coppice and young saplings normally achieve only a 30% success rate.

Tree Improvement

A tree improvement program for *A. mangium* for Sabah was initiated in 1980, under the auspices of FAO/UNDP (1980–84).

Acacia mangium was introduced originally into Sabah as a single half-sib family. Since its introduction, several successive generations have been planted and used as a seed source for plantation establishment. Progeny trials have indicated a steady decline in vigour with successive generations. As a basis for future breeding work steps have been taken to broaden the species' genetic base. With the cooperation of FAO, CSIRO and National Forestry Departments, seeds have been imported from Australia, Papua New Guinea and Indonesia to establish provenance and progeny trials and provenance resource stands. In addition, plus-trees have been selected both from local populations and the new imports, and seed orchards established (Sim Boon Liang 1984).

Recently a network to coordinate the various breeding work in the ASEAN region has been initiated under the ASEAN–Australia Forest Tree Improvement Project (AAFTIP). Complementary to the AFFTIP program, a bilateral research program is being explored with the Australian Centre for International Agricultural Research (ACIAR) to develop an *Acacia* hybrid for operational planting.

Hybrids

The interest in hybrids stems largely from Ulu Kukut in Sabah where *A. mangium* was planted in close proximity to *A. auriculiformis*. The resultant hybrids are evident in stands originating from Ulu Kukut seed. They generally have better stem form than *A. auriculiformis*, and have lighter branching and smoother bark than *A. mangium*.

The opportunities and problems presented by hybridisation in *Acacia* are similar to those with *Eucalyptus* in Brazil. It is felt that the potential for selected hybrids and the development of reliable vegetative propagation technique for mass propagation of improved planting material will be of great value. A small amount of work on controlled hybridisation has resulted in some viable hybrid seed being produced. However, more intensive research is required to develop a repeatable and reliable technique for hybrid production.

Pests and Diseases

This species has been remarkably free from any serious pest and disease. In the nursery, losses from damping-off and root rots of older stock have been negligible and shoot diseases have been confined to black leaf spot and powdery mildew.

In young plantations, *A. mangium* has been subject to attack by pinhole and shothole borers. Heart rot has also been found but recent investigation indicates the problem is not serious. The heart rot takes the form of a white fibrous decay with a peripheral dark brown stain. The causative agent is suspected to be basidiomycete fungus but identification is yet to be confirmed.

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Growth of Acacias on a Logged-Over Forest in Sabah

Anuar Mohamad*

SABAH has now entered into an era of forest tree plantation. The extent of forest plantations that have been planted is by far the most outstanding in Malaysia. By the end of 1985, 44 376 ha had been established with *Acacia mangium, Gmelina arborea, Paraserianthes falcataria*, and *Eucalyptus deglupta*.

Various agencies such as the Sabah Forestry Development Authority (SAFODA), Sabah Softwood Sdn Bhd. (SSSB) and Sabah Forest Industries (SFI) were established to implement the plantation program in the State.

Acacia mangium was first introduced as a fire-break species in 1966. The species was later found to be suitable for plantation development in the State because of its fast growth and versatility to grow on a variety of sites (Tham 1976).

To date, 21 000 ha of *Acacia mangium* plantation have been established, making it the major plantation species. Of this, 17 160 ha were planted by SAFODA and the remaining 2140 ha by Sabah Softwood Sdn. Bhd.

This paper examines the growth of some *Acacia* species (e.g. *Acacia mangium, A. cincinnata, A. auriculiformis*) on a logged-over forest. However, for this study, two different seed sources of *Acacia mangium* were established. Whenever possible, stem form and deformity problems in relation to species will be discussed apart from the growth performance.

Table 1. Species origin.

Species	SEP* Seedlot No.	Seed origin
Acacia cincinnata	319	13 km SSE of Mossman, Queensland, Australia, altitude 480 m Collected from 9 parent trees
Acacia auriculiformis	110	ex Darwin, Northern Territory, Australia, altitude 30 m Collected from 48 parent trees
Acacia mangium	513	Local collection at Brumas seedstand, Tawau
Acacia mangium	002	Local collection from Jalan Madu at Ulu Kukut which represents half-sib trees Seeds collected from about 30 selected parent trees

* Seedlot No. (SEP) refers to Sabah Forest Research Centre's seed collection number.

Materials and Methods

Plot Description

The *Acacia* species trial (Table 1) was established at one of the Sabah Forest Department's Research Stations at Kolapis, Sabah. It is accessible by road and situated about 50 km west of Sandakan. It is located at an elevation of 15 m at 117°42′E and 5°51′N. The surrounding area is dominated by *Pinus caribaea, Maesopsis emenii* and *Swietenia macrophylla* trial plantation.

The plot covering an area of about 0.71 ha was planted in June 1982 at an espacement of 3 × 3 m. Randomised blocks design with four replicates was established. Each plot comprises 49 trees with the central 25 trees being assessed.

The area was formerly dominated by secondary vegetation, mostly *Octomeles sumatrana*. The area was cleared and burnt prior to planting. Circular weeding was done at 3-month intervals during the first year, with inter-row slashing done whenever necessary. In the second year, circular weeding was done twice. The plots were never fertilised.

Rainfall data collected at the nearest station by the Meteorological Department for a period of 10

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years (1974–84) indicate an annual rainfall of 2579–3400 mm with a monthly mean of 250 mm. The temperature is 27 °C with the hottest temperature at 31 °C and the coldest 23 °C. Heavy rainfalls generally occur during the northeast monsoon (October to March).

The soil is dominated by acrisols which includes the grey-brown and red-brown podzols and red-brown laterites and latisols of the Kolapis formation. The surrounding area is made up of low hills and narrow alluvial flats with an altitude of 15–30 m and short slopes ranging from 5–15° on the hills. Parent material is mudstone and sandstone (Acres and Folland 1975).

Assessment and Statistical Analysis

Height and Diameter Growth

The height and diameter breast height (dbh) of each seedling was first measured at the age of 8 months after planting. Routine measurements at intervals of 6 months were carried out until the stand attained the age of 26 months. The last two measurements were taken at 39 months and 47 months. The irregularity of data measurement was due to the shortage of manpower and the fact that many other research plots needed to be measured at about the same time.

Soil Analysis

There was no intensive soil survey, identification or analysis done on the trial-plots mentioned. Information cited in the earlier sections was based on general soil surveys and descriptions by Acres and Pollard (1975).

Mortality and Deformities

Seedling mortality and deformities such as multiple-leaders and forking were recorded at the time of measurement.

Pest and Diseases

No attack by pest or diseases was observed in the trial plot. However, at the nursery stage, a few seedlings were infested by *Eurema* spp. which resulted in some defoliation of some of the seedlings.

Results

Survival rate at the age of 4 years was best attained by *Acacia mangium* seedlot 513 with only 3% mortality rate recorded. A 7% mortality rate was observed for the other *A. mangium* seedlot 002. *Acacia cincinnata* recorded a 5% mortality rate while *A. auriculiformis* produced the highest mortality at 20%.

Seedlings/trees deformities such as multiple-leader, where a tree has two or more main stems, was another problem faced by this *Acacia mangium* trial plot. *Acacia mangium* seedlot 002 registered the worst deformity characteristic at 38% when the stand was about 4 years old. The least was *A. cincinnata* at 23%. This value is considered to be high and tree-improvement works and silviculture could play a vital role in improving this problem.

Height Growth

Acacia mangium recorded the best height growth. *Acacia mangium* SEP 513 gives the greatest height growth at 17.34 m with an MAI of 4.43 m at the age of 4 years. The other *A. mangium* SEP 002 recorded the next greatest height growth of 16.91 m with a MAI of 4.32 m. *Acacia cincinnata* attained a better height growth of 16.43 m as compared to *A. auriculiformis* at only 11.43 m. This gives a MAI height of 4.19 m and 2.92 m for *A. cincinnata* and *A. auriculiformis*, respectively.

Diameter Growth

Acacia mangium recorded better diameter growth as compared to *A. cincinnata* and *A. auriculiformis*. *Acacia mangium* seedlot 513 with seed source from Brumas performs better than *A. mangium* with seed sources collected at the west coast of Sabah. At about 4 years of age, *A. mangium* seedlot 513 attained a diameter of 14.91 cm (MAI 3.81) compared to a diameter of 14.06 cm (MAI 3.5) for SEP 002. *Acacia cincinnata* produced the second best diameter growth, followed by *A. auriculiformis* at 11.94 cm (MAI 3.09 cm) and 8.67 cm (MAI 2.21 cm), respectively (Table 2).

Discussion

In this preliminary assessment, significant difference in height and diameter growth between species at both 5% and 1% levels was found.

As expected, *Acacia mangium* recorded the best growth for both height and diameter. However, even in *A. mangium* there were slight variations in growth. Seedlot 513, derived from a culled seed-stand in Brumas (a logged-over site) grew better than seedlot 002 collected from avenue trees at Jalan Madu, Ulu Kukut (a grassland area). This variation may have a bearing on the importance of selecting a proper seed source for *A. mangium* for plantation development in the State. The better growth of seedlot 513 may be due to its better adaptability to the site which has a similar habitat to its seed source, being a logged-over forest. However this assumption needs to be confirmed through further assessment of the trial. It appears from regression analysis that the diameter growth for seedlot 513 may be surpassed by seedlot 002.

The next best growth was recorded by *A. cincinnata* with the mean height being 16.4 m and a

Table 2. Mean diameter (cm) and height growth (m) in relation to age for species tested.

Species	Seedlots No.	8 DBH	8 Ht	14 DBH	14 Ht	20 DBH	20 Ht	26 DBH	26 Ht	39 DBH	39 Ht	47 DBH	47 Ht	MAI DBH	MAI Ht
Acacia cincinnata	319	1.3	2.3	3.4	4.2	5.9	6.0	8.1	8.5	10.9	13.7	12.0	16.4	3.1	4.2
Acacia mangium	513	2.7	3.3	5.7	6.1	8.2	8.2	10.6	11.1	13.8	16.0	14.9	17.3	3.8	4.4
Acacia mangium	002	1.9	2.7	4.2	5.0	6.6	7.2	9.3	9.8	12.6	14.9	14.1	16.9	3.6	4.3
Acacia auriculiformis	110	1.1	2.4	2.9	4.3	4.2	5.7	6.2	8.0	8.0	10.8	8.7	11.4	2.2	2.9

Age (months)

diameter of 11.9 cm. This species commonly grows up to 8-10 m; however under favourable conditions, it could reach a height of 25 m and a dbh of 30 cm (National Academy of Sciences 1983). In this trial, the height growth is comparable to that of *A. mangium* but its diameter is slower. The tree form is good. It was also reported that *A. cincinnata* could colonise disturbed areas and in dense stand the form is exceptionally good (Bowen and Eusebio 1982).

Acacia auriculiformis recorded the lowest growth in both height and diameter. The height and dbh attained at 4 years were 11.43 m and 8.67 cm, respectively. Streets (1962) reported that in Peninsular Malaysia, the species reached a height of 9-12 m within 2 years. On poor sites however, it recorded a height growth of 6 m in 3 years (National Academy of Sciences 1983). Although it is too early to tell, it appears that this species would never produce better growth than *A. mangium* and *A. cincinnata* for both height and diameter.

Conclusion

From this assessment, *A. mangium* recorded the best growth both for height and diameter, followed by *A. cincinnata* and *A. auriculiformis*. *Acacia cincinnata* appears to have the potential as a plantation species in Sabah. Its height growth is comparable to that of *A. mangium*, however the diameter growth is quite slow. Further assessments are needed to confirm the species potential.

Acknowledgments

I wish to thank the Plantation Section's staff of the Forest Research Centre, Sepilok, for their competent technical work. Deepest appreciation and gratitude is also expressed to Mr Rahim Sulaiman for checking the manuscript. Special thanks and appreciation is extended to Mrs Chong Nyuk Moi for her great help and patience in typing the report. I would also like to thank the Conservator of Forests, Sabah, for his approval to attend this workshop.

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Nursery and Establishment Practices for *Acacia mangium* in Sabah

Barry R. Poole*

THE Bengkoka Afforestation and Settlement Project is located on the Bengkoka Peninsula in northeast Sabah. It is a pilot project, cofinanced by the World Bank and the Sabah State Government, and its prime objectives are to create 3000 ha of *Acacia mangium* plantations and thus provide employment and development for local people. The project was initiated by SAFODA (Sabah Forest Development Authority), an organisation that has been active in the afforestation of degraded lands in Sabah since 1977. In 1985, with World Bank approval, SAFODA engaged a project management team (PMT) from J. G. Groome Anfor (Sabah) Sdn. Bhd., to work with SAFODA staff in developing the pilot project. This report covers the first year of project activity.

Species

Acacia mangium has been used extensively by SAFODA in its afforestation efforts. The species has shown great ability to compete against weed species on low-fertility sites. Its growth rate and form are attractive and it has shown moderate density despite the relatively fast growth rate. There have been some small plantings of *Paraserianthes falcataria* and *A. aulococarpa* and *A. crassicarpa* within the project area. At this point, these plantings are not impressive but the PMT has plans to establish more species and provenance trials in the near future.

Climate, Topography and Soils

The Bengkoka Peninsula is only 5 km wide at its narrowest point and both the east and west coast are deeply indented by mangrove swamps. Development is restricted to ground above swamp level.

The rainfall pattern has a distinct peak during the northeast monsoon (November–February) and though rain occurs in most months of the year, the period May–August can be dry. Local observations are that the rainfall can be very discrete and this affects planting programs and fire danger ratings within the project area. Temperatures and humidities are relatively constant and vary between 24 and 32 °C and 75 and 100% respectively.

The terrain is relatively easy with a few short steep slopes of exposed sandstone. Elevations generally range between 10 and 65 m and 67% of the project area is less than 12° in slope.

Geologically the soils are formed from severely folded sandstones and mudstone shales of the Bongaya formation. Major soil types are orthic acrisols 37%, ferric acrisols 18%, dystric fluvisols 8%, gleyic acrisols 8% (FAO-Unesco). These soils are characterised by low fertilities, low cation exchange capacities and are moderately to strongly acid (Williams and Jamin 1983). Most of the land is free-draining; however low-lying areas are subject to periodic inundation during the northeast monsoon and this can affect survival in newly planted areas.

Vegetation

Much of the Bengkoka Peninsula has been subject to logging of the native forest, followed by slash and burn agricultural activity.

The generally low fertility soils and repeated burning, often as a result of fires escaping, has given rise to extensive areas of grassland and low scrub (*Imperata cylindrica* and *Eupatorium* spp.). These weed species make for low establishment costs but because of their competitiveness and the low soil fertility, the range of species that can be considered for planting is reduced.

Seed Supply

Seed supply of *A. mangium* is plentiful (the species seeds prolifically) but it is derived from a narrow genetic base. Much of the effort of an FAO project (MAL/78/009) based at Sepilok in Sabah,

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was directed at improving and broadening the genetic base of *A. mangium*.

New and improved seed supplies are still limited and most seed used in the Bengkoka project is derived from the original plantings in Sabah. Some of this seed shows some hybridisation effects with *A. auriculiformis*. Recently the project has procured seed supplies from Australia (Gap Creek) and Sabah Softwoods thinned provenance trials.

Nursery Practice

There were approximately 0.7 million *A. mangium* seedlings in the project nursery when the PMT arrived in June 1985. These seedlings ranged in age from 4 months to 8 months by the time planting began in mid September 1985.

In order to gather some cost/productivity/growth data and supplement numbers (after a rigorous culling of the nursery crop) the PMT grew an extra 170 000 seedlings, pricked out in September and November 1985.

A number of changes were effected to try and standardise nursery procedure and schedule the crop growing to fit with the weather and planting period:

1. Seed treatment as described by Bowen and Eusebio (1981) has been standardised and the numbers of seedlings per kilo pricked out has averaged 55 000 (range 36 000–71 000). Experience to date suggests that storage has not affected seed viability.
2. Soil collection has been standardised and is now collected from an area identified by the soil survey team. Previously soil was collected in a haphazard fashion from a number of locations. In nursery trials using the more uniform and fertile soil, versus the haphazardly collected soil, survival following pricking out was much improved and growth was marginally better after 3 months.
3. The polythene pot size has been reduced from ~700 cc soil volume to ~330 cc. Trials showed little difference in growth after 3 months and yet great savings accrue in soil collection, transport and planting costs.
4. Seedling growth has been monitored throughout the nursery growing phase. A target plant of 25 cm height in 12 weeks was aimed for. This was achieved with seedlings pricked out in September 1985. However seedlings pricked out in November 1985 did not follow the same growth curve.

Late December 1985 and January 1986 were particularly wet with many overcast days and frequent rains. We are unsure whether the growth reduction is due to poor light conditions, excess rainfall causing root anoxia, leaching of soil nutrients or a combination of these factors. Certainly *A. mangium* seedlings are strong light demanders as observations in the nursery showed seedlings at the eastern end of the beds grew faster in the September batch.

Foliar feeding was initiated earlier but it did not correct the growth rate until drier conditions prevailed again in February.

This result was similar to the findings of Jones (1984) and suggests that *A. mangium* seedlings are very sensitive to climatic influences early in life. Seedlings that reached target height in 12 weeks were culled and transported to the planting site. Though establishment and subsequent growth was good, the seedlings were 'soft' and easily damaged by handling and desiccation.

For later seedling production, the nursery growing period was extended by 3–4 weeks with one foliar feeding and reduced watering to 'harden' seedlings for transport and planting.

Growth in Field

Seedlings were monitored for height growth after a few months in the field. At 6 months the average height growth in the plantings is just over 120 cm though there is considerable variability about this mean. A nearby provenance trial of *A. mangium* had an average height growth of 3.7 m 12 months after planting with extra rock phosphate (50 g) and extra NPK (150 g) and very good weed control. It remains to be seen whether or not operational plantings will approach this height with less fertiliser.

Constraints

Many of the constraints on establishing *A. mangium* in a project of this nature are social rather than biological. The PMT spends considerable time on land disputes, incorporating kampong people into work programs, fire suppression, and ferrying people to medical facilities, in addition to normal planning and implementation of forest operations. There exists a dichotomy between the desire to create an efficient organisation and economic plantations and the pressure to create work and infrastructure for local people.

The hope is for a compromise to be reached, because if local people's needs are not satisfied, successful afforestation will not be achieved.

The dry months through the middle of the year create hazardous fire conditions in the project area. Young plantations of *A. mangium* are not resistant to fire and constant vigilance in the dry periods is necessary.

Variability in the nursery beds and young plantations could be attributed to a host of factors, environmental as well as human. The PMT is keen to broaden the genetic base in case inbreeding depression is contributing to variability.

Though SAFODA's research staff established a fertiliser trial within the project area in February 1986, many nutritional questions about *A. mangium* remain unanswered. More information is needed on critical nutrient levels for both the nursery and plantation phases. More foliar analyses and fertiliser trials as well as pot trials are necessary to build a complete picture of the nutritional requirements of the species.

Any planning in a project like this is ineffectual if the implementation on the ground is poor. Data collected, hectares planted and maintained to date has only been possible by effective on-ground management. The PMT is aware that skills are in short supply and on-the-job training is necessary in all aspects of forest management. Without this, projects of this nature will not be successful in the long term.

Acknowledgments

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Survival Rates of Direct Seeding and Containerised Planting of *Acacia mangium*

Rahim Sulaiman*

ACACIA MANGIUM was first introduced to Sabah from Queensland, Australia, in 1966. It was planted as a fire-break species for *Pinus caribaea* var. *hondurensis* in Ulu Kukut, an *Imperata cylindrica*-dominated area. The tree was later found to perform better than *Pinus caribaea*. Due to its fast growth and ability to thrive well on degraded soil, *A. mangium* was selected by Sabah Forestry Development Authority (SAFODA) to be the major species for its reafforestation program. The species is also used by Sabah Softwoods Sdn. Bhd. (SSSB) and Sabah Forest Industries in their plantations.

The trees are planted using containerised seedlings. These seedlings are raised in the nursery for a period of 3–4 months before they are planted out. This practise has been very successful in establishing good stocking of trees in the plantations in Sabah including the grassland areas.

Other methods of establishment for *A. mangium* have not been tried, although *Gmelina arborea* has been successfully raised and planted from cuttings. According to the National Academy of Sciences (1983), *A. mangium* can probably be established by direct seeding or vegetative propagation. In Sabah, it has been observed that natural regeneration takes place readily, especially after the site has been exposed to fire.

In view of the possibility of establishing plantations of *A. mangium* by direct seeding, an experiment was conducted in a grassland area after the site had been disturbed by the big fire of 1983. The objective was to determine the viability of direct seeding as a technique for reafforesting grassland area.

Materials and Methods

Plot Description

The experiment was conducted in the trial plantation area of the Forest Department at Sook, which has an elevation of 1000 m. The area lies in the Sook Plain which is approximately 40 km from Keningau. It is easily accessible by road from both Keningau and Pensiangan.

History, Vegetation and Soil

The plantation project area was opened up in 1970. In this area, much of the forest had been destroyed, possibly by fire, and had been replaced by lalang (*Imperata cylindrica*) and bracken (*Pteridium aquilinium*). *Baekia frutescens* is very common, together with a variety of sedges, orchids and the fern *Gleichenia*. Gallery forests still exist along the banks of the main rivers and *Dachrydium* species are common.

The main parent material is alluvium, which includes river and marine deposits ranging from fine-textured materials containing some weatherable minerals to coarse-textured materials which are largely composed of silica and the deposits may contain pebbles, stones and boulders (Bower et al. 1975).

The mean annual rainfall is 1915 mm. The mean monthly temperature is 25 °C, with a maximum temperature of 30 °C in the hottest month and 20 °C in the coldest month. Approximately 80% of the trial plots planted with various species were destroyed by fire in April 1983.

Plot Layout

The experiment was laid out in one of the burnt plots formerly planted with *Pinus caribaea* var. *hondurensis*. Altogether six plots of 1 ha each were randomly established with four plots of *A. mangium* direct-seeded and two plots containerised-planted in June 1983. The container stock was sown earlier in February 1983.

Treatment

In both cases of direct-seeding and container-planting, the seeds used which came from one seedlot were pre-treated according to the method

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recommended by Bowen and Eusebio (1981), prior to sowing.

In the direct-seeding technique about 3–4 seeds were placed in each planting hole. These holes were spaced at 3 × 3 m. Each hole was cultivated up to a depth of 10 cm and cleared of grass in a circle of 15 cm diameter. No fertiliser was applied.

The container-grown stocks, while still in the nursery, were given NPK and steromeal fertiliser which were mixed with the topsoil at a ratio of 10:4:11 (10 wheelbarrows of top soil, 4 kg of NPK: 11 kg of steromeal). Normal silvicultural treatments such as watering and root pruning were given. These stocks were kept in the nursery for a period of 3–4 months until they attained a height of 15–20 cm and ready for planting.

Assessment

All seedlings were assessed concurrently with the weeding operations. Only survival rate was recorded for both cases. Visual observations on the general growth of the seedlings was also done. In the assessment, a similar procedure as that in counting the survival rate of the containerised stock was used for the direct-seeded plants, irrespective of the number of seedlings per hole that finally emerged. In other words, even if four seedlings were produced per hole, the survival count will still be one instead of four.

Results and Discussion

There were great differences in the survival rate for both treatments: Direct-seeding, 3 months after planting, 66% survived; after 6 months, 30%; for containerised planting, after 3 months, 97%; and after 6 months, 90% survived. There was a drastic decline of 36% in survival for the direct-seeded plots within 6 months after their establishment. However for the containerised planted plots, there was only a reduction of 7% in survival within the same period.

The high survival rate experienced by the containerised plants was probably due to their ability to adapt to the site and compete well with the grass, as a result of the silvicultural treatment given to them in the nursery. Prior to planting, these stocks undergo a 'hardening off' process which would enable them to withstand difficult conditions that may arise after establishment. The seedlings also have the height advantage to compete successfully for light with the grass in the site. The ball of earth (potting medium) which was planted together with the seedlings could serve as a reservoir of essential nutrients for their further growth. It is normal for the mortality rate to increase up to 10% (Tan and Jones 1982) especially in the grassland area. Those seedlings that failed to establish themselves were not able to adapt successfully to the site due to genetic and physiological factors.

The low survival rate for the direct-seeded plants was probably related to a number of factors such as soil, adaptability of the species and also competition. Even though the soil aeration may be increased as a result of cultivation, the podzolic soil appears to be unsuitable as a medium for germination of *A. mangium* seeds. This could be due to its failure to provide adequate moisture and nutrients needed for proper germination and further growth of the seedlings. Unlike the container-grown plants, the direct-seeded plants were not exposed to silvicultural treatment and process of hardening-off prior to their establishment in the field. As such their ability to withstand difficult conditions is much lower than the containerised plants. Furthermore, they do not have the height advantage and developed root system which would enable them to compete with the grass for nutrients, growing space and light. Competition between seedlings may occur if more than one seedling is occupying the same area. From visual observations, it was noted that most of the plants showed poor and non-uniform growth.

The fact that 66% of the plants survived in the first 3 months suggests the viability of the direct-seeding technique for reafforesting grassland areas. It is envisaged that with proper establishment and maintenance, the survival rate could be increased. It may be advantageous to sow only two seeds per hole to reduce competition that may occur between the seeds and seedlings later on. Addition of fertiliser may be useful to boost the growth of the seedlings. The rapid decline in survival of the direct-seeded plants after 6 months of establishment could be due to their inability to compete with the tall grass. Frequent weeding could alleviate the problem of high mortality of the seedlings. The disadvantage, however, lies in the cost of the weeding operation especially if it is done manually on a large area. Site cultivation and mechanical weeding may be the answer.

Conclusion

This simple experiment has yielded valuable information on the viability of the direct-seeding technique for establishing plantations of *A. mangium* in a grassland site. The survival rate of the direct-seeded plants is lower than that of the containerised-grown plants. Nevertheless this experiment suggests that direct seeding may be viable for developing plantations of *A. mangium* in the grasslands, provided adequate silvicultural treatments are applied. Further experiments to confirm this suggestion are needed.

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Field Trials of Fast-Growing, Nitrogen-Fixing Trees in Thailand

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THERE is worldwide concern over the problem of rapidly diminishing forest areas. For instance, Thailand is now confronted with a major complex problem caused by energy shortage, rural poverty, and depletion of forests. Available data on LANDSAT imageries taken in 1973 and 1978 showed a sharp decrease of forest area from 42% to 34%, amounting to 46 400 km^2. With an annual forest depletion rate of about 10%, deforestation is increasing suggesting that only 25% of the total forest area is now left, of which natural forest represents only 20%. The problem has been caused by shifting cultivation, land clearing, illegal cutting, and particularly by the increasing need for wood for energy and industrial uses. The destruction of the forests has resulted in reduced soil fertility caused by erosion, flood and low agricultural productivity, costly downstream flood control, and costly irrigation projects. These in turn impact on the economic, social and environmental conditions of the country. To overcome these problems and to cope with the human demands in upgrading the standard of living for rural poor, several attempts have been made to find ways to maintain the forest area and increase the forest plantation.

Methodology

The main experimental designs were planned to screen a wide range of 18 selected FGNFT species for their adaptability under the prevailing conditions at Chan Thuk[1] and Chumphon[2], including the investigations of suitable plant spacing and phosphate fertiliser requirements. The species are: (1) *Acacia auriculiformis*, (2) *Acacia mangium*, (3) *Albizia falcataria*, (4) *Calliandra calothyrsus*, (5) *Cassia siamea*, (6) *Casuarina equisetifolia*, (7) *Eucalyptus camaldulensis*, (8) *Gliricidia sepium*, (9) *Leucaena leucocephala*, (10) *Sesbania grandiflora*, (11) *Albizia lebbek*, (12) *Albizia procera*, (13) *Casuarina junghuhniana*, (14) *Albizia lebbekoides*, (15) *Enterolobium cyclocarpum*, (16) *Leucaena diversifolia*, (17) *Pithecellobium dulce*, and (18) *Samanea saman*. This was accompanied by analysis and testing of their multipurpose utilisation for firewood energy and industrial uses. In addition, detailed experiments were also conducted to study the plant-*Rhizobium* interaction, coppicing regrowth, lime requirements, mixed-species trial and germplasm (Yantasath 1983; Yantasath et al. 1984).

The experiments were designed as follow: Experiments at Chan Thuk and Chumphon (established in August 1982):

Species Trials Number of species: 18 (listed earlier), Design: augmented design with 6 replications consisting of species No. 1–10 and augmented with species No. 11–18; Plant spacing: 1 × 1 m; Plot size: 8 × 10 m^2 at Chanthuk and 6 × 10 m^2 at Chumphon.

Spacing Trials Number of species: 10 (No. 1-10), Design: split plot design, 2 replications, main plots = species No. 1-10 subplots = 6 spacings (1 × 0.5 m; 1 × 1 m; 1 × 1.5 m; 1 × 2 m; 1 × 3 m; 1 × 4 m); Plot size: 8 × 10 m^2.

Fertiliser Trials Number of species: 10 (No. 1-10 listed earlier), Design: split plot design, 4 replications, main plot = species No. 1-10, subplots = 4 levels of phosphate (18.75; 37.50; 75.0; 150.0 kg P_2O_5/ha), Basic fertiliser: ammonium sulphate (28 kg N/ha), potassium chloride (75 kg K_2O/ha), Plant spacing: 1 × 1 m, Plot Size: 4 × 10 m^2.

Germplasm Trials For the purpose of seed multiplication and germplasm collection, on-going species of NFT were planted at 1 × 1 m spacing, plus other collection of potential species and accessions.

[1] *Chan Thuk*, Nakhon Ratchasima: Sandy loam soil, with 1.32% organic matter; 9 ppm P; 108 ppm K; 0.114% total N; pH 5.5; 7.6 ppm Mn; 1.47 ppm Zn; 1.25 ppm Cu. Mean annual rainfall 1032 mm.

[2] *Chumphon*: Coastal sandy soil, with 1.01% organic matter, 10 ppm P; 22 ppm K; 0.087% total N; pH 4.3; 1.0 ppm Fe; 0.25 ppm Mn; 0.28 ppm Zn; 0.40 ppm Cu; 55 ppm Al. Mean annual rainfall 1170 mm.

Fertiliser (N:P:K = 9:24:24) of 312.5 kg/ha were applied in all plots at both sites. Lime at the rate of 1.56 tons/ha was applied at Chumphon only.

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Coppicing Regrowth Study Based on 1 year of data derived from the 'Fertiliser Trial' at Chumphon, in which there was no significant response of trees to phosphate applications, the fertiliser trial was therefore modified to superimpose a coppice regrowth study on one-half of each plot to allow collection of data on coppicing and biomass determination. Trees were harvested after age 15 months at the end of the rainy season in January 1984 and after age 24 months during the rainy season in August 1984 and weighed separately for leaves, branches and stem components. Twenty-five sample trees were used for biomass determination using allometric regression equation. The allometric regression equation $\log Y = \text{Log}\, a + b\, \text{Log}\, D^2H$, in which Y = weight; D = diameter at breast height (mm); H = height (cm) was used for biomass determination of each component of every species.

Additional Experiments in Khao Phu Luang (established in August 1984): Due to flood damage at Chanthuk in October 1983, repetition trials of NFT were conducted in August 1984 at Khao Phu Luang*, Amphoe Pak Thong Chai, Nakhon Ratchasima Province.

*Species Trial*** Number of Species: 6; Design: randomised complete blocks, 3 replications; Plant spacing: 1.5 × 1.5; Plot size: 10.5 × 13.5 m^2.

*Spacing Trial*** Number of species: 6; Design: Each species was planted separately in a completely randomised design with 3 replications, 3 spacing treatments (1.5 × 2 m; 1.5 × 3 m; 1.5 × 4 m); Plot size: 10.5 × 13.5 m^2.

Analysis and Testing Chemical analysis and in vitro dry-matter digestion for animal feed characteristics of leaf tissues and physical properties of the wood (moisture content, heating value, specific gravity, pulping and paper making characteristics) were undertaken from samples collected from experimental trials at Chumphon. Tissue samples were collected on a randomised basis from different trees of each species. Wood samples were collected from trees of different sections—basal, central and top.

* Khao Phu Luang Forest Reserve. Royal Forest Department. Sandy loam soil with 1.04% organic matter; 9 ppm P; 179 ppm K; 465 ppm Ca; 260 ppm Mg; 1.5 ppm Fe; 6.4 ppm Mn; 0.6 ppm Zn; 0.5 ppm Cu; 107 ppm Al. Fertiliser (N:P:K = 16:16:16), 312 kg/ha, was applied to all plots.

** Extension trial of selected species from Chan Thuk: (1) *Acacia mangium*, (2) *Albizia falcataria*, (3) *Eucalyptus camaldulensis*, (4) *Gliricidia sepium*, (5) *Leucaena leucocephala*, and (6) *Leucaena diversifolia*.

Results

Species Trials, Chumphon

After 3 years there were five species that adapted well to the site conditions: *Eucalyptus camaldulensis, Acacia mangium, Acacia auriculiformis, Albizia falcataria* and *Casuarina equisetifolia*, evidently due to their better tolerance to soil acidity. The biomass produced by these five species grown at 1 × 1 m spacing (10 000 trees/ha) was 63, 53, 52, 45 and 28 m^3/ha/year respectively. Other species produced less growth and biomass, particularly *Leucaena leucocephala* with only 3 m^3/ha/year, which was basically due to its sensitivity to soil acidity and increased susceptibility to nematodes that occurred widely in the trials.

Acacia mangium produced a good straight tree trunk with less branching, which thrived very well, and produced large amounts of nodules in roots. Seed was produced within 18 months even though the growth rate was relatively slow during the first year. *Gliricidia sepium* and *Calliandra calothyrsus* thrived well in the rainy season but were sensitive to drought that caused stem dying and biomass reduction.

Species Trials Chan Thuk

Data collection at the first year stage indicated that most of the tree species adapted well at Chan Thuk, particularly *Leucaena leucocephala, Eucalyptus camaldulensis, Enterolobium cyclocarpum, Leucaena diversifolia, Casuarina junghuhniana* and *Gliricidia sepium*. The 1983 flood damaged the experiments at Chan Thuk, and data collection was therefore limited to only 1 year. However, it was observed that the species tolerant to flood were *Acacia auriculiformis* (survived over 6 months of permanent flood), *Acacia mangium* and *Eucalyptus camaldulensis* (over 4 months), *Casuarina equisetifolia, Samanea saman, Albizia procera* (over 2.5 months with little damage). Other tree species were less tolerant and most of them were serverely damaged after 1.5 months flooding.

Spacing Trials

Data collection from 3-year-old trees showed an increase in height and diameter at breast height and biomass per tree with an increase of spacing. However, the total biomass production was higher with the closer spacing (higher plant density). The highest biomass was produced by *Acacia mangium, Eucalyptus camaldulensis* and *Acacia auriculiformis*; intermediate biomass productions were obtained from *Albizia falcataria* and *Casuarina equisetifolia*. Other species produced very low amounts of biomass due to their poor growing performance in acid soil.

Similar to the results in Chumphon, the Chan Thuk data collected at 9 months indicated an increase in height and diameter at base with an increase of spacing, and *Leucaena leucocephala* and *Eucalyptus camaldulensis* were the best-growing species.

Fertiliser Trial

Data collections of the trees every 3 months and after 1 year did not show any response of the trees to phosphate applications. The data obtained at Chan Thuk from 9-month-old trees did not show any response of the trees to phosphate applications.

Coppicing Regrowth

The coppicing regrowth data from the first cutting indicated the best coppicing percentages (95–87%) in *Gliricidia sepium, Cassia siamea, Leucaena leucocephala, Eucalyptus camaldulensis* and *Calliandra calothyrsus*. Lower coppicing percentages were demonstrated by *Albizia falcataria* (53%), *Acacia auriculiformis* (25%), *Acacia mangium* (10%) and *Casuarina equisetifolia* (2%).

The second cutting indicated the best coppicing percentages in *Cassia siamea* and *Eucalyptus camaldulensis* (95–87%). An increase of coppicing percentages was found in *Acacia auriculiformis* (71%), *Albizia falcataria* (74%) and *Acacia mangium* (22%). Less coppicing was found in *Leucaena leucocephala, Gliricidia sepium* and *Calliandra calothyrsus* (70–44%).

Additional Experiments in Khao Phu Luang

The repetition trial at Khao Phu Luang with six tree species indicated good growth for all the species tested. At 1 year of age, *Leucaena leucocephala* showed the best growth and biomass production and *Acacia mangium* had a slower growth than other species, which appeared to be a typical characteristic in the first-year period, but it would be expected to grow very rapidly in later years.

Analysis and Testing

Data on chemical characteristics and in vitro dry matter digestibility (IVDMD) indicated that *Leucaena leucocephala, Cassia siamea* and *Gliricidia sepium* were most suitable for use as ruminant feed due to their high IVDMD values, low crude fibre percentages and high protein contents. Though some other species, such as *Sesbania grandiflora, Calliandra calothyrsus, Albizia falcataria, Acacia auriculiformis* and *Acacia mangium* possessed high protein contents in leaf tissues, due to their moderate to low IVDMD-values and/or high crude fibre percentages, they were considered less suitable and need to be treated with water or some chemical treatments such as urea or sodium hydroxide in order to improve their IVDMD values.

The physical properties of tree species indicated high heating values of the woods, in which *Acacia mangium* had the highest (4903 kg cal/kg) and *Eucalyptus camaldulensis* had the lowest heating values (4603 kg cal/kg). The specific gravity of the woods ranged from 0.33 (*Albizia falcataria*) to 0.68 (*Leucaena leucocephala*) and the moisture content in woods was in the range of 34% (*Leucaena leucocephala*) to 57% (*Gliricidia sepium*).

Physical properties of the pulp from tree species at 15 and 24 months using two pulping processes (neutral sodium sulphate chemical-mechanical process and sulfate process) indicated the increase of wood properties especially the breaking length, tear factor, burst factor and folding endurance, brightness percentages and the pulping conditions of the 24 month tree compared to those of 15-month-old trees when the amount of sodium hydroxide used was increased from 12 to 15%. Also increasing were the yields of unbleached sulfate pulp for most of the species with the highest yield in *Acacia auriculiformis* (56.68%) and with an exception in *Albizia falcataria*, in which the yield was decreased. Values for the wood of 24- and 15-month-old trees were highest pulp properties of *Albizia falcataria* against its lower yield; the good qualities and yields obtained from *Leucaena leucocephala* and *Acacia mangium*; the increasing yield of *Eucalyptus camaldulensis* against its decreasing quality; and unsuitable qualities of *Calliandra calothyrsus* and *Gliricidia sepium* (Yantasath et al. 1985; TISTR 1985).

The complete tabular data for the chemical characteristics, the physical properties, and pulping and digestibility experiments will be published by the Thailand Institute of Scientific and Technological Research, Bangkok.

Future Development and Applications

Based on the results obtained from the experiments under different environmental conditions which demonstrated a wide range of adaptability of the species *Acacia mangium* and *Acacia auriculiformis*, it was considered that these tree species have good prospects for: reforestation; commercial-scale cultivation for lumber for furniture, plywood, structural members, firewood, high heating value charcoal; and good quality paper pulp. Besides, the trees could be added to or substituted for a few fast-growing tree species being promoted for large-scale cultivation throughout Thailand and other countries (see March, April and May 1985 issues of the TISTR Research News for more information).

Realising that *A. mangium* and *A. auriculiformis* have been cultivated in many countries, with several provenances and wide genetic bases, it is considered that future development should lie in the testing of these tree provenances and improvement through a selection and breeding program, to find out how good these trees are for future seed production.

Leucaena leucocephala and *Leucaena diversifolia* are also thriving at Chan Thuk and Khao Phu Luang, as well as in many other places, where the soils are not acidic. Although *L. leucocephala* has been cultivated widely for its use as animal feed and for other purposes, little research work on this species has been undertaken in Thailand. As well, very little research has been done on *L. diversifolia* or their hybrids, which seem to be tolerant to acid soil.

The most prominent and interesting species in this study, both for its adaptability and agroindustrial uses, is *Acacia mangium*. Though its growth rate was rather slow during the seedling and establishing period, it grew very quickly thereafter, and produced high levels of biomass and seeds within 2 years. Its wood has higher calorific value than other species tested and suitable quality for paper pulp production and the lumber industry (e.g. furniture, plywood and construction materials). Additionally, *A. mangium* has been classified as a fast-growing, nitrogen-fixing tree with the ability to produce large numbers of *Rhizobium* nodules. Though growing well in non-acid soil conditions it was able to adapt itself to thrive satisfactorily in acid soil.

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Performance of Australian Acacias in Hawaiian Nitrogen-Fixing Tree Trials

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NITROGEN-FIXING trees deserve premium consideration for tropical agroforestry, since N is often the major limiting factor in tropical soil fertility. Over 650 species of trees and shrubs are known to fix nitrogen, and many others are believed to fix but have not been verified (Halliday 1984). These species can satisfy most tropical fuelwood needs, and often serve as significant sources of pulp- or postwood, and of fodder or green manure. The species of *Acacia* and *Leucaena* are among the most widely deployed of N-fixing genera, and are the subject of the following comparisons.

The genus *Leucaena* has long been the subject of our research in Hawaii, focused on the major commercial species *L. leucocephala*. At least 11 other species are recognised in the genus (Brewbaker 1986), and all tested have proven to be cross-fertile with *L. leucocephala* (referred to as "LEU" in this paper), despite major differences in morphology, chromosome number, etc. Self-incompatibility characterises diploid taxa in the genus, while most polyploids are self-fertile. The most interesting of these polyploids is *L. diversifolia* subsp. *diversifolia*, a self-fertile $2n = 104$ subspecies of this large and widespread $2n = 52$ species. Referred to as "DIV" in this paper, it is from midlands and highlands of Eastern Mexico at 20°N lat, with significant tolerance to cold, to soil acidity, and to the psyllid insect. Hybrids of LEU and DIV have been extremely vigorous and are the source of active current breeding in our program.

Fuelwood trials have been established in Hawaii since 1978 to evaluate tropical trees for their potential in dense fuelwood plantations. We are broadly interested in all the tropics, and in employing Hawaii as a unique living greenhouse to conduct trials and breeding research relevant to most of the tropics. Our focus has been on N-fixing trees, including 18 species of the genera *Acacia, Albizia, Calliandra, Casuarina, Dalbergia, Enterolobium, Gliricidia, Leucaena, Prosopis, Samanea* and *Sesbania* (Brewbaker et al. 1982). Among these were three species of the genus *Acacia* that are the subject of the present paper—*auriculiformis, mangium* and *mearnsii*. In contrast to the leucaenas, these acacias have higher acid soil tolerance and fit ecological niches to which commercial leucaenas appear less well adapted.

Tree trials are expensive to establish and of long duration, and we have sought to exploit small-plot, high-density plantings and more efficient experimental designs to minimise these costs.

Materials and Methods

Data are summarised for the following five species:

LEU *Leucaena leucocephala*, cv. K8, from Moyahua, Zacatecas, Mexico (elev 1100 m): $2n = 104$, self-fertile

DIV *L. diversifolia*, cv. K156, from Fortin des Flores, Vera Cruz, Mexico (elev 1225 m): $2n = 104$, self-fertile

AUR *Acacia auriculiformis*, cv. N5 (NFTA), Taiwan Forest Res. Inst. #80006: $2n = 22, 26$, cross-pollinating

MAN *A. mangium*, cv. N6 (NFTA), U.S. Forest Service, Agana, Guam (ex Malaysia): $2n$ = unknown, cross-pollinating

MEA *A. mearnsii*, cv. N163 (NFTA), from Olinda, Maui, Hawaii (elev 1400 m), introd. c.1900: $2n = 26$, self-sterile.

The experimental design for all trials was the augmented randomised complete blocks design of Federer and Raghavarao (1975), incorporating several species in all reps and other species in one rep only. Replicated species in all trials included LEU, DIV and AUR, while MAN was replicated only at Waimanalo and MEA was unreplicated in all trials (with yields adjusted as necessary to the mean of the replicated entries in the pertinent block). Three

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or four blocks were used, normally including five replicated entries and 3–6 unreplicated entries for a total of <10 plots per block. The plots were small, 4 × 7 m (6 × 7 at the Haleakala site), with 28 trees on a 1 × 1 m grid, permitting the blocks and the associated error variances to be correspondingly small. All trials were prepared by ploughing and occasionally with herbicide applications, but no fertilisation (although some were on former crop land and none were P-limited). Seedlings were grown for 3–4 months from scarified, rhizobia-treated seeds, prior to transplanting. Water was provided to ensure good seedling establishment on dry sites, and the Molokai trial was drip-irrigated throughout the trial. Data recorded included individual tree heights, basal diameters (at 10 cm) for 1.5 years, and breast height diameters from 1 year onward. Where multiple co-dominant stems occurred, a single combined value (geometric average) was calculated.

High-density legume tree plantings grow in much the same manner as do high-density crop plantings. Canopy closure is early, weeds are suppressed, and slow-growing plants reduce overall yield insignificantly as their neighbouring plants compensate. The 10 measured trees per plot were taken from the core two rows bordered on all sides by the same species. This sample size is perhaps too small for heterogeneous cross-pollinated species, but it is fully adequate for the self-pollinated leucaenas (Van Den Beldt 1983a). MacDicken (1983) and MacDicken and Brewbaker (1984) analysed trials for sample size effects on estimated standard errors. Among the conclusions were that increased sample size from 10 to 20 trees would reduce SE values only 8–30% for height and 6–10% for basal area and wood volume. Thus the small plots are unusually land-efficient, particularly viewed from the perspective of multi-location trials.

Of the seven sites chosen for our trials, four were part of the Benchmark Soils Project network of experiments (Ikawa et al. 1985; Silva 1985). A summary of early tree growth at these sites was presented by MacDicken in Silva's (1985) review. Three sites (Waimanalo, Molokai and Haleakala) were managed independently, with assistance from the U.S. Soil Conservation Service and NifTAL. The sites ranged from 21 °N to 3 °S lat, with elevations from sea level to 600 m, providing a wide range of climates and soils. Mean annual temperatures ranged from 19.4 to 28.6 °C, with annual solar insolation values ranging from 379 to 476 cal/cm^2/day. Rainfall became limiting at two locations—Waimanalo and Waipio—notably late in the second year of growth, after El Nino. Exemplary annual rainfall data are the following from Waimanalo; 1981 = 1211 mm, 1982 = 1729 mm, 1983 = 503 mm. The Nakau, Indonesia, site also went through drought in growth period 6–12 months. The driest site, Molokai, was drip-irrigated for the trial. Acid soils characterised most sites, although base saturations and calcium levels were good, and exchangeable Al was low in surface soils. However, the Haleakala, Iole and Nakau sites have subsoils low in bases, highly Al-saturated, and generally hostile to crop plants.

Results

Height and Diameter Growth

Height (H) and DBH values (diameter at breast height) of the five measured species at the seven sites are summarised below. The data are discussed here in the order of sites listed in Table 1.

Table 1. Estimated wood yields (t/ha/yr fresh).

Site	Mean temp.	Age	Species				
			LEU	DIV	AUR	MAN	MEA
Waimanalo, Hawaii	23.9	3.0	44.4	26.6	20.1	28.1	—
Waipio, Hawaii	24.2	2.5	30.0	23.2	12.8	16.3*	45.2*
Molokai, Hawaii	23.4	2.8	81.9	46.0	18.3	16.7*	81.6*
Haleakala, Hawaii	19.4	2.0	2.7	18.4	14.8	17.1*	65.0
Iole, Hawaii	20.1	2.5	2.8	24.9	12.2	37.8*	107.4*
Davao, Philippines	28.1	2.0	97.6	89.9	38.1	28.2*	—
Nakau, Indonesia	28.6	1.7	11.9	12.0	27.5	—	—

* Unreplicated entries.

Waimanalo (planting date 15 Jan 81) is considered a site with no major growth-limiting factors. It is at sea level with gentle tradewinds, mean temperature 24 °C, average 1380 mm rain. Early tree growth to 1.5 years was more or less typical, but then slowed markedly due to drought (Fig. 1). LEU and DIV were nearly similar and MAN and AUR performed similarly, with MAN filling out better in diameter. A severe psyllid attack from 1984–85 slowed leucaena growth, and by 1986 (5.5 years) the five species were nearly identical in height and DBH (10 m, 10 cm).

The Molokai site (Soil Conservation Service, USDA, planted 5 Sep 81) was also a non-limiting lowland site, 23 °C mean temperature, high solar insolation, strong winds, and provided with drip irrigation. At this site also, LEU was a top performer, with DIV similar in height but lower in DBH. Among the acacias, MEA (one rep) was excellent, while MAN and AUR were nearly identical and low in yield.

The Waipio site (planted 10 Nov 81) is drought-prone (avg 700 mm annual rainfall, but much less in second year of this trial), with generally good environment. Under this drought stress, all species performed poorly, with MEA (one rep) outstanding, LEU and DIV similar and the other acacias surviving well but poor in growth.

Haleakala and Iole stations are similar cool highland sites (about 20 °C annual avg) that are moist with acid soils of low base saturation but adequate levels of Ca in surface soil. LEU failed at both sites and DIV (a highland species) performed reasonably well, showing its combined tolerances of acid soil and low temperature. In contrast, MEA (one rep) was exceptional at each site, achieving 8 m heights in 2 years. AUR failed much like LEU at both sites. However, the results with MAN were enigmatic; it performed quite well at Iole, but would be considered unadapted at Haleakala. Since the MAN plots were unreplicated, the latter data are to be treated with caution, but suggest intrinsic differences.

The two remaining sites, Davao (Philippines) and Nakau (Sumatra), were part of the Benchmark ultisol network (Silva 1985); both are hot and wet. A transient drought, soil acidity and low base saturation were limiting factors at Nakau. Growth at Davao exceeded that of all other trials, with LEU and DIV impressively superior (to 12 m in 2 years) to the acacias AUR and MAN. Regrettably, *A. mearnsii* was not included in this trial. The Nakau ultisol, formerly in rubber, was evidently too acid (with low base status and low Ca) to support the leucaenas, but the poor performance of the acacias was unexpected.

The sigmoidal height growth patterns in all trials appeared similar, tapering off after 2 years, as DBH values continued to increase. In our experience with leucaena at 1 × 1 m spacing, mean annual volume increments are very similar over a 4- to 5-year period, then abruptly taper off. MEA is similar, but AUR and MAN grow to greater heights and DBHs, tapering off in MAIs in about 8 years at Waimanalo.

Wood Properties and Volumetric Growth

Specific gravity and moisture contents were calculated for 2-year-old trees from several trials (top, middle and bottom samples), and weighted averages are summarised below (SpGr = specific gravity as dry matter/displacement volume, MC = percent moisture content on fresh weight basis: LEU, SpGr .55, MC39; DIV, .49, 47; AUR, .51, 45; MAN, .53, 44; MEA, .47, 57.

High densities characterised all species, and moisture contents were relatively high only in *A. mearnsii*. These values can be modified by changes in weather. Van Den Beldt's (1983b) averages for LEU of .434 SpGr, 48.1 for MC and 838 kg/m^3 represent many more data, and were used to calculate yields that follow.

Volumetric equations are well established for few N-fixing tree species. In LEU the volumes over a wide range of ages and sites have been approximated remarkably well by the simple equation V (m^3/tree) = .5H$(DBH)^2$, where H is in m and DBH in cm (Van Den Beldt 1983a,b; Kanazawa et al. 1982). Yantasath et al. (1985) and others prefer a log transformation of this formula, that tends to draw in extreme values, and employ the full regression equation, log Yield = log a + logH$(DBH)^2$. The a values are often small for fast-growing trees (Van Den Beldt 1983a,b). Formulae also employing basal diameters have been evaluated by MacDicken (1983) and others, that may add refinement but are usually less directly interpretable.

The volumetric formula used here for LEU was derived by Van Den Beldt (1983a,b) from 260 harvested trees of 1.5 to 4 years of age. Formulae for other species were derived from measures of 2-year-old trees of DIV and AUR (replicated) and MAN and MEA (unreplicated) at three sites, with totals of 60, 20, 4 and 9 harvested trees. The following equations were calculated (together with R values as percents for goodness of fit), where Y = weight in kg/tree, H = height in m, and d.b.h. = diameter in cm:

LEU $Y = 0.500 + .0465\,H(d.b.h.)^2$
$R = 98\%$ (260 trees)
DIV $Y = 0.715 + .0416\,H(d.b.h.)^2$
$R = 98\%$ (60 trees)
AUR $Y = 2.756 + .0353\,H(d.b.h.)^2$
$R = 83\%$ (20 trees)

MAN $Y = 2.789 + .00905\ H(d.b.h.)^2$
$R = 38\%$ (4 trees)
MEA $Y = 2.316 + .0488\ H(d.b.h.)^2$
$R = 78\%$ (9 trees)

These regression values were applied to calculate expected yields (Table 1) using height (H) and diameter (d.b.h.) data from the final collections. The MAN formula was based on too few trees for reliability, so the AUR formula was applied to MAN data for Table 1. Yields ranged from negligible to more than 100 tons/ha/year (fresh weight). MEA was outstanding at the four sites studied. LEU and DIV were similar except in the highlands, where LEU fails. MAN and AUR were steady performers at all sites, but never outstanding. It is clear that hybrids of LEU and DIV provide unusual germplasm for extending adaptability of the genus in fuelwood use, as also do hybrids of AUR and MAN.

Discussion

Tree form was generally satisfactory for fuelwood in all these five species. Multiple stems were infrequent at the 1 × 1 m density, except at the (cool) Iole site for AUR and MAN. Average numbers of stems (final ages) from six trials were—LEU 1.10, DIV 1.14, AUR 1.30, MAN 1.32 (1.1 if Iole trial is ignored) and MEA 1.01. Bole shape varied greatly, but from a forester's perspective, empirical ratings were LEU good, DIV very good, AUR fair (irregular), MAN excellent, and MEA fair (often spiralled).

Genetic variation was very high in the *Acacia* spp., outcrossing diploids, and low for the leucaenas, self-fertilising polyploids. This was evident in plot CV's, not shown, of MacDicken (1983) and Van Den Beldt (1983a,b), and expressed often by overtopping of slow-growing trees within 2 years. Selective thinning does not pay in the homogeneous leucaena stands, but would seem wise, depending on economics, for the acacias.

The provenances we chose in 1980 were from a limited available selection, and improved provenances are now generally available. K8 LEU is being replaced with K636 and others of better form, but K156 has remained an outstanding DIV. We have no basis for considering the N5 AUR, N6 MAN and N163 MEA provenances atypical, although collections now available might provide better yields.

Border effects with all species were very large. Unbordered trees achieved diameters greatly in excess of the measured trees. All species appeared highly light-invasive and responsive, the crowns expanding rapidly to invade illuminated areas. Species elimination trials with the small 4 × 7 m plots used here are effective for only about 3 years, when border effects become too large. Coppicing observations made on our felled trees confirm those of Yantasath et al. (1985) that leucaenas coppice almost 100%, while the acacias coppice more or less poorly, ranging from less than 20% for MAN to 40% for MEA.

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Use of Acacias in Fiji

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THE climate of Fiji is largely influenced by the trade winds which affect the group from the East to Southeast. The resultant cloud and rainfall pattern produces an extended rain shadow area affecting the west to northwest side of the larger islands, and the smaller outer islands in the lee of these islands.

The vegetation cover is reflective of these climatic influences with tropical rain forest predominating on the southeastern side and grasslands with wooded gullies predominating on the northwestern side of the main islands. This grassland ecosystem also prevails on many of the smaller islands within the Fiji group away from the major influence of the larger islands.

The soils in Fiji are generally of volcanic origin and can be broadly categorised into four major groups: (a) humic latosols in the wetter south east; (b) nigrescent soils; (c) ferruginous latosols in the drier northwest; and (d) red-yellow podzolic soils which are usually found on rolling and hilly land derived from quartz-rich parent material of acidic composition. There is a generalised geological link between the first three soils categories in that increased weathering can be followed from nigrescent soils, through humic latosols then ferruginous latosols for soils derived from parent material of basic composition (Twyford and Wright 1965a,b).

Acacia Trials in Fiji

The introduction of acacias into Fiji by the Ministry of Forests occurred in the late 1960s with three species: *Acacia mangium, A. auriculiformis* and *A. melanoxylon*. The species introductions were pursued as part of on-going evaluations of potential plantation species that could be used to enrich or replace logged-over and unafforested areas.

As well as these recent trials with exotic acacias there is also considerable potential for development of known indigenous acacias in Fiji, such as *A. richii*.

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Acacia melanoxylon was planted at three sites between 1969 and 1970 using seed from Tanzania. Whilst early initial growth was significant especially on the cooler upland trial site where after 9 months some trees were 1.5 m in height, there were no live trees past 3 years of age in the mensuration plots.

Acacia auriculiformis was planted at six sites between 1969 and 1970 and three sites in 1982. Growth rates recorded in the wetter rain forest areas were of the order 7.5–9 m in height and 7.5–10 cm in diameter at age 30 months, whilst growth on the dryland sites was approximately 4 m in height and 4 cm in diameter at age 30 months. A tropical cyclone in 1972 destroyed the 1969–70 series plots producing evidence of the instability of *A. auriculiformis* in windy areas. These plots were subsequently written off, however continued observation of the remaining stand has strengthened evidence of the inability of this species to withstand wind.

Another factor of concern in regard to this species has been its ability to encroach into surrounding sites from the original plots. Considerable regeneration is now evident up to 300 m away from the original 1970 plot at Drasa, located in the dry grassland area. This pattern has not been observed in the wetter rainforest areas which may be due to the more vigorous competition that exists on these sites.

Acacia mangium has been used only recently in trials in Fiji, with the first plots being established in 1981 as part of a fuelwood evaluation. Sites selected for these trials include the true nigrescent soils which have in the past yielded poorer-than-average growth of *Pinus caribaea* var. *hondurensis*. Growth in these areas relates to the growth of *A. auriculiformis* on the ferruginous latosols, i.e. about 4 m in 30 months.

A provenance trial of *Acacia mangium* has just been established in the wetter rain forest area outside Suva, using 11 Queensland provenances, one from PNG and two from Indonesia. At the time of writing only the initial post planting seedling height measurements were available.

Other known Acacia introductions include *Acacia curassavica, A. farnesiana* and *A. polystachya*.

Of this group *A. farnesiana* is significant in that it was accidentally introduced instead of *A. arabica*, and has now been declared a noxious weed as a result of its impact in laying to waste thousands of hectares of pastoral land (Mune and Parham 1967).

Properties of Indigenous Acacias

Acacia richii, or Qumu as it is known in Fiji, resembles Tasmanian blackwood (*Acacia melanoxylon*) in appearance but is somewhat heavier, with an air dry density of 830 kg/m^3. It shows the typical *Acacia* sheen and with its superior hardness lends itself to decorative flooring. Other suggested uses include furniture, panelling, building and construction timber (Alston 1982).

Acacia simplicifolia or Tatagia is a small tree up to 12 m high with broad phyllodia 5–12 cm long and 4–8 cm wide. It occurs commonly near the seashore and survives well in poorly structured sands. It has a hard wood and appears stable under cyclonic wind conditions (Parham 1972).

Acacia mathuataensis is a relatively uncommon species with phyllodia much smaller than those of *A. simplicifolia* (Parham 1972).

Fuelwood Profile

The problem of fuelwood availability in Fiji is already becoming evident, especially in the drier climatic zones and on the small outer islands (Siwatibau 1981).

Fuelwood usage in Fiji includes domestic fuel for cooking and heating purposes, commercial fuel for industrial heating and to a lesser degree fuel for power generation.

Domestic Use

The fuelwood requirement for people living in the rural areas of Fiji in particular, is critical to their continued existence, whilst maintaining their cultural identity. The increasing shortage of wood, especially on the smaller outer islands in the lee of the main islands such as the Yasawa Group, is an area requiring immediate attention. Many of the people living on these islands are collecting timber substantial distances from the village and are required in some cases to climb 300 m high up basalt ridges to collect adequate supplies to provide daily needs.

The development of a fuelwood resource in these situations has, to date, rested mainly with *Pinus caribaea*. This arises from past emphasis of the Ministry of Forests on extension developments with an 'eye' to possible commercial conversion. There is evidence that *Pinus caribaea* will survive and grow on these degraded grassland slopes, with many similar sites already established as commercial plantations on Viti Levu by the Fiji Pine Commission and Ministry of Forests.

Commercial Usage

The cost of producing and reticulating electricity to the industrial development areas in the Fiji islands in many cases prohibits its use as a major source of energy. The alternative use of fuelwood to produce heat for industrial processing is widely applied. Usage includes processes such as distillation of spirits, extracting and processing raw sugar, heat for kiln drying sawn timber and preheating prior to electrical induction heating of steel for 'rolling.'

Power Generation

The commercial generation or cogeneration of electricity using fuelwood inputs in the major industrial areas of Fiji is common. Despite the introduction of hydroelectric power into Fiji in 1984, power costs have remained high (approximately A$0.22 per kwh).

The Fiji Electricity Authority has adopted a program to address the problem of rural electrification based on small auto-generators and solar power units, however, it is not considered by most people living in these rural and island areas as a high priority for attention. They appear content with small petrol-driven generators to service village community centres and benzine lamps for other lighting purposes.

Soil/Site Conservation

Stabilisation and shelters of coral island sand beaches and foreshore areas around basalt island outcrops are of significant importance, especially in the wake of cyclones that repeatedly damage village communities in these areas.

A recent trial, established in 1983 on a coral sand island just off Viti Levu using five species of casuarinas and three species of acacias was intended to evaluate the potential of various species in both control of coastal erosion and sheltering of bures from high winds. The area was struck by the devastating cyclones of 1985 and the performance of the surviving species assessed only recently. Because of the young age of the trees. All those in exposed sites were blown over and destroyed by the cyclones. Some of the casuarinas on the more protected sites, behind permanent structures such as buildings (bures) survived. None of the acacias were in the surviving group. The most hardy of the trial survivors was *Casuarina equisitifolia*. The indigenous *Acacia simplicifolia* on the island appeared to have weathered the repeated cyclonic winds well and as such may be well worth consideration as a rehabilitation and protection species in other situations and further trials.

Construction and Roundwood Uses

There is a moderate demand for durable hardwoods in the drier and less wooded regions of the Fiji Islands for both in-ground and above-ground construction purposes, as a result of continued cutting for construction and fuelwood.

Traditional housing or bure construction has in many cases given way to concrete block and galvanised iron due to the unavailability of suitable timbers in the form of small-diameter durable roundwood.

Whilst a properly constructed bure will survive well under cyclone conditions, the natural durability of available timbers used in some cases means that the expected life of the building may also be considerably shortened.

The traditional bures are labour-intensive in construction and have a relatively high maintenance component, however they require limited capital investment which is an important factor with isolated communities.

Summary

The potential use of acacias in Fiji and on surrounding islands has in no way been explored to its fullest potential to date.

Whilst there is recognition that acacias could potentially have a place in fuelwood programs in the South Pacific, there is a need to ensure that the species introduced to the area are initially appraised of their potential to: (i) survive in the cyclone-affected climatic conditions; (ii) service the needs of fuelwood and protection; (iii) offer alternative utilisation options (e.g. construction); (iv) generate a possible future source of income to these developing communities; and (v) not impact, as a result of massive regeneration, on the respective cultural values and agricultural needs that are zealously guarded by the more isolated island communities.

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Seed Production and Silvicultural Trials of Acacias in Papua New Guinea

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THE Papua New Guinea *Acacia* program is very recent. Although the Brown River provenance of *A. auriculiformis* has been planted extensively in small areas since the 1960s and seed of an unknown Queensland provenance of *A. mangium* was introduced to the Bulolo Research Station in 1978, no major work was carried out until the 1980s.

Seed collections in 1980 and 1982 (Doran and Skelton 1982; Skelton 1983; Turnbull et al. 1983) resulted in provenance seedlots of the following acacias being made available: *Tree species: A. aulacocarpa, A. auriculiformis, A. crassicarpa, A. leptocarpa, A. mangium*; and *Shrub species: A. simsii.*

Papua New Guinea is committed to the FAO Global Programme for Improved Use of Genetic Resources, therefore the Department of Forests has initiated a program of seed production, form and vigour observation, provenance expansion and improvement and local species and provenance trials for the above species except for *A. leptocarpa* and *A. simsii.*

Seed Production of Routine Material

Owing to the very expensive seed reconnaissance and collection expeditions, the occurrence of other useful species in Papua New Guinea requiring exploration, the Department of Forests very limited staff resources and the high demand for seed of tropical subhumid *Acacia* species, provenance seed production areas are being established.

Commencing in 1984, isolated 4 ha blocks of the four Papua New Guinea (sub) provenances of *A. mangium* have been established near Madang (north coast Papua New Guinea at approximately 5 °S and 60 m elevation) to supply routine provenance seed. An equal number of offspring from each mother tree were planted at 8 m square spacing to encourage broad crown development and each tree was randomly located on the planting grid, labelled and mapped. The older trees have flowered extensively (September–December 1985) but fruit has not yet set. The original (sub) provenance collections were based on vegetation type and three were relatively close to one another (20–40 km). As there is probably no break in their distribution on the Oriomo Plateau, a fifth 'mixed transFly' provenance seed production area is to be established. This will comprise an equal representation of all half-sib seedlots collected (approximately 130) and its offspring are intended for progeny testing (because of its increased genetic base) and further general seed production. Additional seed production areas are to be established at Bulolo (see below).

Isolated seed production areas of all large tree species of *Acacia* are being established at the National Tree Seed Centre at Bulolo (at about 7 °S and 700 m). These are being set up on 'advancing front' bases so that material from additional collections of existing provenances can be appended to the provenance blocks. Currently 9 out of the 14 provenances of all species collected to date have been established in blocks which are at present of 1–2 ha in size. The identity of the families has been maintained in the field.

Some of the 1982 provenance collections of *A. aulacocarpa, A. auriculiformis* and *A. crassicarpa* (Turnbull et al. 1983) had a basic minimum of mother trees (as little as 5) therefore it is planned to make more collections of existing provenances as well as identifying and collecting new provenance material.

Species and Provenance Testing

Randomised Blocks Factorial trials have been established in the Gogol Valley near Madang. Nine

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provenances of *A. mangium* (the four Papua New Guinea (sub) provenances plus five Australian provenances, supplied by CSIRO, which represent the full latitudinal range) and 'controls' of well-known Papua New Guinea plantation species, *Eucalyptus deglupta* and *Acacia auriculiformis* (Brown River provenance) were planted simultaneously on three sites (ex-forest, hill, imperfectly drained; ex-forest, re-cleared regeneration, flat, poorly drained; and *Imperata cylindrica* grassland, hill, imperfectly drained). Preliminary results from 1985 (age 2.5 years) are shown in Table 1. In general the Papua New Guinea provenances are performing better (in height growth) although to date only one provenance (Walsh's Pyramid from Australia) is showing significantly poorer growth. All three sites were significantly different especially the *Imperata* site which is exhibiting very poor growth. Diameter growth shows similar trends on the ex-forest sites, however the trees on the *Imperata* site are too small to measure. This result is surprising in view of the success of *A. mangium* on *Imperata* sites in Sabah (Tham 1979). Similar slow growth has also been noted on some grassland sites at Bulolo. Ineffective mycorrhizae and rhizobia are suspected and this is to be investigated.

In February 1986, Papua New Guinea provenances of *Acacia* species (3 of *A. aulacocarpa*, 3 of *A. auriculiformis*, 4 of *A. crassicarpa* and one of *A. mangium*—a 'control' to link results with earlier trials) were planted simultaneously in a Randomised Block Factorial on two sites (ex-forest, hill, imperfectly drained and *Imperata cylindrica* grassland, hill, imperfectly drained). A further *A. mangium* trial of Indonesian provenances and Sabah softwoods routine and seed stand material is planned for late 1986.

Tree Improvement

Specific programs will be devised upon the outcome of species and provenance trials and when seed is available for pilot plantations. Half-hectare provenance observation stands are, however, planned to record form and vigour of individual offspring from the natural mother trees. Equal numbers of seedlings from each mother tree will be randomly located on the planting grid and after stem form selection the stands will be thinned to become seed stands–selects.

Acacia auriculiformis Brown River provenance suffers from very poor form but no attempt has been made to improve it pending results of new provenance trials. Poor selection of mother trees during the original collections may have contributed to this poor form.

Silviculture

Acacia auriculiformis Brown River provenance has been widely planted in small areas throughout Papua New Guinea. The largest surviving areas are in the Gogol Valley and, like elsewhere, poor form has limited its greater use. Most Papua New Guinea research into the species was ad hoc and centred on the Sepik Plains. These grasslands were formed by continuously clearing forest for subsistence agriculture many thousands of years ago resulting in degradation of the fragile, very poorly drained soils.

Lamb (1975) has described these plantations and Luton (1980) gives more recent growth data. He also describes widespread mortality of *A. auriculiformis* at the same physiological age in two successive years (1978 and 1979). No pathological evidence was found and waterlogged soils suggest a

Table 1. Mean provenance height by site for 1982 *A. mangium* provenance trial, 1985 age 2.5 years.

Provenance or species	Ex-forest imperfectly drained	Ex-forest poorly drained	*Imperata* imperfectly drained	All sites
Balamuk, PNG	12.4	10.6	2.2	8.4*
Toko (Tokwa), PNG	12.2	10.1	2.5	8.3
Oriomo, PNG	11.0	10.3	3.2	8.2
Iokwa, PNG	11.0	10.4	2.4	7.9
Claudie River, Aus.	10.9	9.6	2.2	7.6
Abergowrie, Aus.	11.2	9.7	1.4	7.4
Daintree, Aus.	9.3	9.5	0.7	6.5
A. auriculiformis, PNG	9.7	8.3	1.3	6.4
Eucalyptus deglupta, PNG	10.1	6.8	1.2	6.0
Walsh's Pyramid, Aus.	8.0	6.3	1.1	5.2

* Provenances connected by a bar are not significantly different by Tukey's Test at $p < 0.05$.

probable cause. Natural stands in Western Province can withstand flooding but it is thought the deeply saturated sepik soils (in the wet season) have a very low oxygen content preventing root development past a point which allows continued survival beyond age 6.5 years. Ineffective mycorrhizae and rhizobia may also be a factor. Most of the remaining plantations were destroyed by a severe fire in August 1984 but prolific natural regeneration occurred after the first rains in November.

An attempt to study form in a 1979 spacing trial was abandoned after pigs continuously uprooted seedlings, destroying the trial. No plantations of *A. mangium, A. aulacocarpa* and *A. crassicarpa* have yet been established although, to date, form of *A. mangium* in the provenance trials (trees planted at 3 m square spacing) appears to be better than in excess stock block plantings (planted at 4 m square spacing) in the Gogol Valley. One stand of *A. auriculiformis* (planted at 4 m square spacing) in the Gogol Valley shows improved stem form but its growth is poorer than elsewhere. Both *A. auriculiformis* and 'giant' *Leucaena leucocephala* (both Mimosaceae) appear to have better form with slower growth. The good stem form of many naturally occurring trees is probably due to fire killing and subsequently burning lower branches.

Pests and Diseases

On ex-forest sites *A. auriculiformis* is susceptible locally to root rot by *Ganoderma* and *Phellinus* species, and in one study area rot has spread between trees resulting in an approximate 10% annual mortality (Arentz, F., unpublished data). *Acacia mangium* deaths in seed production areas and provenance trials have also been attributed to these diseases.

At Bulolo *A. auriculiformis* apical shoot damage has been caused by *Mictis profana* (F) and the larva of a species of scarabaeid beetle has damaged roots and caused mortality. Severe mortality of planted seedlings of all *Acacia* species has recently occurred, but the cause has not yet been identified.

Growth

Data are available for *A. auriculiformis* from a number of countries and for *A. mangium* from Sabah, but since climate, site and provenance are quite different, comparison of figures would mean little without careful analysis.

However, *A. mangium* provenance trial data recently made available show very similar growth on sites in the Philippines (Petterson and Havmoller 1984), Sabah, Malaysia (Sim 1984) and Papua New Guinea.

By coincidence the previous vegetation at three earlier trials in Sabah (Sim 1984) corresponds to the previous vegetation on the sites of the Papua New Guinea 1982 trial. Only Daintree provenance, however, is common to both trials and the results show similar growth except for the particularly poor performance on the Papua New Guinea *Imperata* site.

Future Seed Availability

Seed from the October 1986 collection will be made available through the FAO program. The joint Department of Forests/CSIRO, Canberra expedition is expected to collect *A. mangium* and *A. auriculiformis* provenance seed although species actually collected will depend on the status of fruiting. Stocks from previous collections are now virtually exhausted but when the seed production areas are fruiting larger quantities of seed should be available. This will be advertised in the FAO Forest Genetic Resources Information occasional papers.

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Australian Acacias in Kenya

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KENYA is situated in East Africa, between Lake Victoria and the Indian Ocean, and has a total land area of 570 000 km^2 The country rises gradually from the sea in the east to about 1800 m 500 km inland where the Great Rift Valley divides it from north to south. The valley is about 60 km wide and 300 m deep, with precipitious walls in some parts.

More than half the area of the country, in the north and northeastern parts and in the southern parts of the Rift Valley floor, is arid or semi-arid. The higher land from 1400 m to 2830 m in the central part of the country enjoys a good rainfall and is fertile. On the mountain slopes and other areas of high rainfall, dense natural high forest occurs.

Kenya has a wide range of climatic conditions. The rainfall varies in a general way from extremely dry conditions to the north and east, where the rainfall is scanty and erratic and as low as 250 mm/annum, to the high moisture conditions of the Lake Victoria region with rainfall of 1500–2000 mm.

As a result of these wide-ranging conditions, the soils of Kenya are extremely variable. Likewise the vegetation is very varied with the main types including forests of various forms, mountain grassland, savanna and semi-arid grassland to desert shrubs and grass.

Forestry Practice in Kenya

The diversity of the land mass has a great influence on forestry practice in Kenya. Systematic forestry management began at the end of the 19th century. The first foresters found closed forests in widely scattered blocks and separated by great expanses of thinly populated grassland and open bush country. They pursued a vigorous policy of exploration and reservation of the scattered forests they found, and by 1915 most substantial forests had been reserved as government forest areas. Most, if not all, of these reserves were in the areas with great agricultural potential. So from the beginning forestry was concentrated in these zones.

While a few indigenous species in these forests produced excellent quality timber, a majority produced hard heavy timbers difficult to work and were difficult to regenerate. So introduction of exotic species started quite early. The first species to be introduced for trial had been tried in South Africa and found to be very productive. These included the gum *Eucalyptus saligna* and the wattles *Acacia decurrens* and *A. mearnsii*, and from India teak, *Tectona grandis* and *E. globulus*. The gums and wattles were so outstandingly successful that by 1910 an extensive series of species trials had been embarked on (Dyson 1974).

From the very first, emphasis was placed, in Kenya, on the establishment of regular plantations and on the use of exotics. The first plantations for fuel were of indigenous species, but these were soon replaced with *Eucalyptus* spp. and wattle (*A. mearnsii* and *A. decurrens*) which had proved very successful in trials.

Silviculture of Some Acacias

The normal system of making plantations in Kenya is by the shamba system, a highly developed form of the 'Taungya' cultivation. Resident labourers enter into a 3-year agreement with the Forest Department, under which they are allocated annual areas for cultivation of agricultural crops. They clear the land, allocated at the rate of 0.5–1 ha/labourer, and burn all rubbish. The land is cultivated and food crops are grown. During the second year more food crops are grown and tree seedlings planted after staking. Cultivation for food crops continues in the third year and sometimes in the fourth year until the trees grow so big that food crops cannot be grown economically. The shamba system has served Kenya forestry extremely well and continues to do so. It also reduces establishment costs drastically.

Nursery practice in Kenya depends on availability of the soil ingredients, and where the plants, when

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ready, would be planted. *Acacia* seed is pre-treated by scalding it in boiling water and left to cool.

Sowing in situ often results in poor emergence, if not total failure, and planting established seedlings is worth the extra cost. The procedure usually followed is to sow 3–6 seed per clear polythene tube (diameter 10 cm layflat and 15 cm deep) if plants are expected to be planted on a difficult site. Seedlings are grown in tubes for about 6 months.

Sometimes seed is sown in plant trays or seedbed and the seedlings pricked into transplant beds. The beds 1 m wide are revetted with 15 cm wide boards and filled with a soil mixture of good top soil, farm manure, peat and chopped gravel. The seedlings are root-pruned by cutting with a knife along the length and breadth of the beds and length-wise with a piano wire to stop the roots going below 15 cm soil mixture. Seedlings raised in this way are lifted with a block of soil around the roots and are usually planted in areas with good rainfall.

The nursery procedure described above has been used for raising *Acacia melanoxylon* (blackwood) seedlings, the only *Acacia* species that has been tried in Kenya for the production of saw timber. The practice is to plant at an espacement of 2.7 × 2.7 m with 1372 stems/ha or at a wider spacing of 3 × 3 m with 1111 stems/ha. Weeds are a nuisance in tropical countries, and the plants must be kept free of climbers and grasses until properly established.

The importance of blackwood as a timber tree in Kenya has declined since the mid 1960s in favour of the quick-growing softwood species. No pruning and thinning schedules have therefore been developed. It is, however, normal practice to prune to 10 m height the final crop of about 300 stems/ha at age 20 years.

The wattles *Acacia mearnsii* and *A. decurrens* are used for fuel production, as they have been used since they were first introduced in Kenya. The largest plantations are at an altitude of about 1900 m and receive about 1300 mm of rainfall/year. *Acacia mearnsii* is the most commonly used species for tan-bark. Plantations of this species have largely replaced those of *A. decurrens* and *A. pycnantha*, formerly cultivated, because it produces a preferred kind of tan extract.

After the initial establishment through planting, and clear-felling at a rotation age of 10 years, regrowth is achieved through natural regeneration from seed. The crop is reduced to final stocking of 2000 stems/ha by thinning heavily when height approximates 3–4 m, or 2–3 years after germination.

New *Acacia* Species

During the past 10 years or so there has been a tremendous increase in forestry activities in Kenya. The President has been in the forefront urging people to plant more trees every year. In response to this, the government Forest Department, several international aid organisations and numerous non-government organisations (NGOs) have all made contributions. There has been an increase in the demand for seed, and Australia has been a very good source. The acacias particularly suitable for semi-arid zones have been imported. To date about 40 different *Acacia* species have been imported and tried in Kenya. Out of these about 30 have come in during the last 5 years.

Largely as a consequence of growing human and animal populations, in Kenya, there has been an increase in deforestation and general land degradation. Not only in marginal lands but, in many cases, existing cultivated areas are rapidly declining in productivity.

The consequent acute food and fuelwood supply problems are well known. These necessitate intensive counter measures, among which tree-planting programs are in the forefront both for environmental protection or enhancement on the one hand, and for renewable energy supplies on the other. There is a growing awareness that the woody perennials can and must play a prominent role not only in maintaining the sustainability of Kenya land-use systems but in offsetting farm fuelwood needs. It is in these roles that the Australian acacias will be expected to contribute.

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