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Advances in Tropical Acacia Research

Proceedings of an international workshop held in Bangkok, Thailand, 11–15 February 1991

Editor: **John W. Turnbull**

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Foreword

The genus *Acacia* has many native trees and shrubs with characteristics useful for industrial and community forestry. These nitrogen-fixing species grow in a variety of environments and produce a range of wood products, firewood, charcoal, building poles, tannins and fodder. In recent years fast-growing acacias have been used increasingly in the humid tropics to rehabilitate degraded grasslands and cutover rainforests. Extensive plantations have been established in Malaysia and Indonesia to provide timber and fibre for the pulp and paper industry. They are frequently planted around houses and along roads for shade, shelter and amenity.

ACIAR sponsored its first acacia workshop in Gympie, Queensland in 1986 to consolidate knowledge on the taxonomy, genetic resources, ecology, silviculture and utilisation of Australian acacias of interest to developing countries. This workshop highlighted important constraints to the greater use of acacias and identified research needs and priorities around which ACIAR could develop collaborative research projects. Since 1986, ACIAR-supported acacia research has included: reproductive biology; tree improvement; nitrogen fixation; selection of germplasm for acidic, saline and alkaline sites; and tannin and pulp properties.

The aims of this second workshop were to provide a forum for scientists in ACIAR-supported projects to interact with other scientists currently researching tropical acacias, to share new technology, and to identify areas of research which should receive priority.

ACIAR sponsored the workshop as part of its Forestry Program. The Centre wishes to thank the Royal Forest Department of Thailand for hosting the workshop and organising field tours. CSIRO Division of Forestry assisted in workshop organisation and the Faculty of Forestry, Universiti Pertanian Malaysia organised a post-workshop tour in Peninsular Malaysia.

The 60 participants came from Australia, People's Republic of China, India, Indonesia, Kenya, Laos, Malaysia, New Zealand, Pakistan, Sri Lanka, Thailand and Vietnam. Our thanks to those who prepared and presented the 49 papers — a clear indication of the interest in tropical acacia research and the application of research results to reforestation in developing countries.

The contribution of Janet Lawrence to the editorial direction and preparation of these proceedings is greatly appreciated.

G.H.L. Rothschild
Director
ACIAR

Recommendations for Research into Tropical Acacias

M.W. Haines, F.H. McKinnell, N.E. Marcar and J.W. Turnbull

The meeting divided into three subgroups to discuss major issues arising from the presentations. These were designated 'Biology and Ecology', 'Genetic Resources and Tree Improvement' and 'Silviculture and Utilisation'. The following recommendations were brought forward by each subgroup and approved by the final plenary seminar of the conference:

Biology and Ecology

Reproductive biology

a) Research should be continued on various aspects of basic biology (e.g. pollination mechanisms, pollen dispersal, vectors, microscopy techniques, isozymes) involved in understanding and controlling reproductive systems in such 'wet tropic' acacias as *A. aulacocarpa, A. crassicarpa, A. leptocarpa* and *A. cincinnata*. This is because reproductive biology appears to be species specific. Such activities are central to hybrid breeding programs and seed orchard management. Considerable advances have already been made in understanding these systems in *A. mangium, A. auriculiformis, A. melanoxylon* and *A. mearnsii.*
b) Research on the patterns of crossability in acacias should be undertaken because of the potential for the greater use of acacia hybrids in the future.
c) The potential for genetic engineering approaches to genetic improvement of acacia characters is very limited at this stage.

Vegetative propagation

Continuation of research into appropriate vegetative propagation procedures is essential to the preservation of rare and special genetic material (e.g. virus-free germplasm) and future genetic manipulation studies. Specific research activities should include:

a) Development of appropriate media for effective root initiation in selected species.
b) Scaling up large-scale micropropagation for hybrids and individual trees (e.g. maintenance of sterile conditions).
c) Assessment of the incidence and relative importance of somaclonal variation.

Adaptation to climate and soils

a) Considerable gains in our ability to predict likely performance of species and provenances over a range of climatic and soil conditions will be made by incorporation of trial data into PC and other databases (e.g. MPTDAT, TREDAT) using minimum data sets. Such efforts will need to be coordinated. Work on climatic matching needs to be extended to South Asia and Southeast Asia.
b) The understanding of mechanisms of adaptation of *Acacia* species to inhospitable sites (waterstressed, waterlogged, alkaline, saline, infertile) is incomplete. Some advances have now been made in glasshouse evaluation of species/provenances for salinity and acidity tolerance. There is a need for further research into physiological responses to these and other stresses and into water use under these conditions in order, for instance, to develop rapid screening procedures.

c) More information is needed on the nature of stress (e.g. nutrient imbalances, ECe levels etc.) actually encountered in the field for incorporation into data bases and to define screening media more accurately. Research is also required on below-ground processes (e.g. rooting patterns) involved in stress tolerance.
d) Research on the impact of environmental stresses on nitrogen fixation, and the effectiveness of rhizobial strain selection and mycorrhizal manipulation in moderating the impact of these stresses, is needed. Data on the net gains in soil nitrogen for acacia species are lacking.

Pests and diseases

Research needs to be intensified on the identification and methods of control on a range of fungal pathogens responsible for root diseases (heart rot, soft knot etc.) and insects e.g. stem borers.

Genetic Resources and Tree Improvement

Field guides

The recommendation of the ACIAR Acacia Workshop 1986 for the development of practical field keys for *Acacia* species is reiterated. There has been little progress and the need for this still exists.

Priorities for provenance research

Priority species should be expanded to include — *Acacia crassicarpa, A. aulacocarpa, A. holosericea, A. mearnsii* and other promising bi-pinnate acacias, *A. polystachya* and *A. cincinnata.*

Progress has been made with *A. auriculiformis* and *A. mangium. Acacia melanoxylon* is regarded as a lower priority in view of poor performance in tropical environments.

Seed supply

It was noted that purchasers of seed need to ensure the reliability of provenance information, because of doubt regarding the information provided by some seed merchants. It was recommended that the CSIRO Australian Tree Seed Centre (ATSC) approach suppliers in Australia to formulate a list of recognised suppliers.

For seed collection in Australia, collaboration between ATSC and developing countries is encouraged, e.g., participation by representatives from a developing country.

Species evaluation

a) There is need for practical information on experimental design, including unit plot size, field layout and replication, and this will be increasingly important with progress into family-in-provenance evaluation. It was noted that a forthcoming ACIAR publication will address this topic.
b) The involvement of biometricians at the design stage for implementing trials is encouraged.
c) There is a need to assemble the separate information from many countries to provide a review of species performance across countries and sites.
d) There has been a tremendous amount of data collected but not analysed.
e) In respect to recommendations made in 1986, ACIAR and participating countries are encouraged to include data in the TREDAT database.
f) Emphasis needs to be given to measuring characteristics other than growth, e.g. wood quality.
g) In view of the time required for wood quality assessment processes, development of rapid assessment techniques needs to be pursued.

h) It is recommended that trials of *Acacia* species, particularly those with a wide geographic distribution, should include provenances representative of different climatic regions within that range.
i) In species testing, exotics should not be used exclusively, and promising local species should be considered.
j) To evaluate species/provenances/family performance thoroughly, attention is drawn to the need for proper silvicultural practice to maximise growth.

Breeding

a) With current progress, there is need for the development of advanced breeding strategies in some countries.
b) Genetic variation with respect to resistance to pests and diseases needs to be examined.

Silviculture and Utilisation

Silviculture

There is a need for research on many aspects of silviculture in *Acacia* species. Some progress has been made in developing silvicultural techniques for industrial species but much more research is required to develop tree management systems appropriate for use by small farmers.

Research priorities identified at the acacia workshop in Gympie, Queensland, August 1986, are still relevant. These are:

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 species be evaluated for both individual and non-industrial products. Research priorities for industrial wood products include:

a) pulpwood studies
b) reconstituted wood panels
c) furniture products
d) tannin and tannin-based adhesives.

Identification and quantification of non-wood values of acacias require further attention, in particular:

a) fodder values
b) role of pollen in honey production
c) human food values of seed and gums
d) surveys of rural people to determine needs for tree-derived products and services.

The relationship of silvicultural practices to utilisation was also stressed. The need for early estimates of biomass production, the effects of wood-rotting fungi on wood and harvesting methods were identified.

Communication

The synthesis of information and its communication to researchers and managers is very high priority. A particular need was for the classification of *Acacia* species in terms of:

a) their suitability for various environmental zones and site conditions. For this there may well be information in existence, but it needs collation and publication.
b) their suitability for various timber end-uses. It was noted that the TREDAT and INSPIRE databases were quite deficient in this respect.
c) their suitability for non-industrial timber uses, such as handicrafts, tannins, pollen and nectar production, edibility for human consumption etc.

Methods of communicating the results of research are inadequate, although the efforts of ACIAR, through its publications, are appreciated in this regard. Databases such as TREDAT and decision support systems such as INSPIRE are potentially very useful, but need a great deal more data input and more system development. Continuation and refinement of these projects is highly desirable. The reported 10 years development time for TREDAT is of concern. There is value in having a database coordinator to facilitate uniform data collection and entry into the database.

Biology and Ecology

Role of Symbiotic Associations in Nutrition of Tropical Acacias

P. Dart*, M. Umali-Garcia** and A. Almendras***

Abstract

Nodulation and vesicular-arbuscular (VA) mycorrhizal associations contribute much to growth of *Acacia* species in unfertilised fields. Philippine soils vary a great deal in their populations of rhizobia nodulating *A. auriculiformis* and *A. mangium*. Some Australian acacias nodulate freely and fix nitrogen with a wide range of rhizobia strains isolated from different host *Acacia* species, while others nodulate only with a restricted range of strains. Only one of the 12 strains from the Philippines isolated from *A. mangium* nodulated effectively.

The best strains for both species came from northern Australia and Papua New Guinea. Large responses to inoculation were obtained in pot trials in soil and field trials in the Philippines for both *A. mangium* and *A. auriculiformis*. Twelve out of 22 *Acacia* species tested responded to inoculation when grown in an acidic yellow podsolic soil from Mt. Cotton near Brisbane.

In several pot and field trials in the Philippines large responses were obtained in nodulation and plant growth for both *A. mangium* and *A. auriculiformis* to P and sometimes K fertiliser addition but no response was obtained to trace elements. One year after outplanting at Carranglan, *A. auriculiformis* height was increased 80% and base diameter 120% by addition of 60 kg P/ha as single superphosphate.

Acacia forms both ecto- and endo-mycorrhiza. Several VA mycorrhizal species form symbiotic associations with *Acacia* species and, in field trials in the Philippines, *A. mangium* plants inoculated with a VA mycorrhizal strain survived, uninoculated trees died.

ALTHOUGH *Acacia* species have many uses and occupy important ecological niches, little is known of their symbiotic associations with *Rhizobium* bacteria or with mycorrhizal fungi. These associations are vital for the plant's nutrition, especially in soils poor in nutrients. Corby (1990) found that 37 species of *Acacia* occurring in Africa were nodulated and 17 of these dominated the communities in which they occurred, perhaps because of the competitive advantage derived from their nitrogen-fixing habit. Only three species were non-nodulating, and these belonged to a separate taxonomic group (Corby 1974). Beadle (1964) found that acacias growing in arid and semi-arid communities in Australia were nodulated. *Acacia* species in the Sudan grew, nodulated and fixed nitrogen at 35 °C root temperature (Habish 1970). Many plantings of *Acacia* occur on degraded land where the natural soil inoculum potential of these symbiotic micro-organisms is small. It is particularly in these situations that responses in plant growth have been obtained from inoculation.

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This review mainly covers the authors' experience under ACIAR Project 8371, which involved collaboration between the College of Forestry, University of the Philippines at Los Baños (UPLB), the Department of the Environment and Natural Resources of the Philippines (DENR), the Visayas State College of Agriculture and the University of Queensland. Related research by the National Institute of Biotechnology for the Philippines, UPLB (Biotech) and the CSIRO Division of Forestry is also covered.

Plant–Microbe Relationships

Acacia species from Africa are quite different taxonomically from those in Australia and a proposed new classification nominates three genera with six sections (Pedley 1987). We are examining whether there is a relationship between plant taxa and microbial symbiont. Habish and Khairi (1970) found that of 10 *Acacia* species occurring in Sudan, some were nodulated by *Bradyrhizobium* others by *Rhizobium* species. Some species nodulated freely with rhizobia isolated from other species, others only nodulated with a very restricted range of isolates. Dreyfus and Dommergues (1981) extended these observations, showing that some African species nodulated effectively only with slow-growing *Bradyrhizobium* strains (e.g. *A. albida*) whereas others only nodulated with fast-growing *Rhizobium* strains (e.g. *A. nilotica; A. raddiana; A. senegal*). *A. seyal* was effectively nodulated by both types of rhizobia. *A. sieberiana* nodulated effectively with some *Bradyrhizobium* strains but ineffectively with three out of five *Rhizobium* strains.

Similar patterns of specificity were obtained for introduced *Acacia* species of Australian origin. Roughley (1987) showed that a great deal of host species x strain specificity existed in Australian acacias, with some species being highly specific (only nodulating with a few strains isolated from those species) while others nodulated freely with strains isolated from a wide range of *Acacia* species nodules. Since many *Acacia* plantings are occurring in areas previously devoid of *Acacia* or related species, there is a possibility that effective populations of the microbial symbionts may be absent or in low numbers in these soils, and we are exploring the potential for inoculating *Acacia* in the nursery and amending soil nutrient deficiencies with fertilisers to enhance tree survival and growth.

Most of the nitrogen in forest ecosystems is derived from biological N_2 fixation. These systems are very efficient in recycling nitrogen leached to lower depths in the soil through uptake by deep roots and, through leaf fall, concentrating this N in the litter and upper soil horizons. Since the litter has a high C:N ratio, most of the N freed from plant material or fixed by microbes becomes tied up in the microbial biomass which slowly turns over to release nutrients such as N, P and S to the plant by the process of mineralisation of organic matter.

Disturbing this natural cycle that conserves scarce nutrients so effectively can lead to rapid loss of soil fertility. Maintenance of the litter layer as a soil mulch to reduce erosion is well as to conserve nutrients is a very important aspect of forest fertility.

Rhizobium ecology in soil

There are varying degrees of specificity in the *Acacia* species–*Rhizobium* strain interactions in nodulation and N_2 fixation, and there are even differences between provenances in their susceptibility to nodulation by *Rhizobium*. Soils contain several types of *Rhizobium*, and some soils may have too small a population of strains appropriate for a particular legume to develop adequate nodulation for good plant growth. Because of specificity in *Acacia* nodulation, strains for use in inoculants need to be selected for a particular species. This usually starts by assembling a collection of strains isolated from nodules, usually obtained from the legume under consideration, authenticating their ability to nodulate the legume in conditions which control contamination from other organisms, followed by an assessment of their ability to fix nitrogen in a strain trial in pots, using a rooting media which does not contain *Rhizobium*.

In order to estimate the populations of *Rhizobium* in soil, an indirect, most-probable-number (MPN) count is made because there is no selective medium for growing *Rhizobium* alone when agar plates are inoculated with a soil suspension. In the MPN count, soil is diluted with water, usually in a series of 10-fold steps until it is estimated that the suspension is too dilute to contain any rhizobia. Aliquots of this dilution series are added to plants of the legume under consideration growing under axenic conditions, often in a test tube culture system, and the plants left to grow for some weeks to form nodules. The pattern of nodulation is then recorded and a statistical probability table used to give the MPN estimate of the soil population. We developed techniques for counting rhizobia populations nodulating *Acacia auriculiformis* and *Acacia mangium* and showed that some lateritic soils from Carranglan, Nueva Ecija in the Philippines contained virtually no rhizobia nodulating these plants whereas soils from Cavinti, Laguna (pH 4.4), a clay soil contained 10^3–10^4 cells/g.

Sometimes soils contain strains which nodulate but which are not very effective in fixing nitrogen, and in these situations it is worth inoculating plants with a superior strain to see if it can supplant the indigenous soil population in forming the nodules. This is not easy because we usually can add only a small number of bacteria in the inoculum relative to a large soil population because soil volume is large. For example, a soil may contain 10^3 rhizobia of a particular strain per gram, and in the top 15 cm about 2 x 10^{12} rhizobia. Usually between 10^6 to 10^7 bacteria would be added as an inoculum to each plant. To overcome the competition from the indigenous population the inoculum strain thus needs to have an intrinsic competitive ability to form nodules, to be able to colonise root systems readily, and to move along the root system as it grows, so that the strain is present in the zone of the root susceptible to nodulation.

One way to assess the inoculum potential of a soil is to grow the test species in the soil (with basal fertiliser except N) in pots in a greenhouse and compare the growth of 1) uninoculated plants with those 2) inoculated with an effective strain of *Rhizobium* and 3) with an uninoculated control given a large amount of nitrogen fertiliser. Comparisons between treatments 1 and 2 indicate the need to inoculate, and between 2 and 3 the effectiveness of the soil population and/or the inoculum strain in providing the N required for plant growth. In a test of this nature with an acidic, yellow podsolic soil from Mt. Cotton near Brisbane, 12 out of 22 northern Australian *Acacia* species tested responded to inoculation.

Inoculum development

Acacia species appear to be nodulated by a diverse range of rhizobia which may be fast growing *Rhizobium* or slow growing *Bradyrhizobium* species. Some *Acacia* species are very specific, in that only a restricted range of rhizobia will nodulate them (e.g. *A. holosericea, A. cincinnata, A. polystachya*). Other species such as *A. auriculiformis* are more promiscuous in their nodulation habits, nodulating with a range of *Rhizobium* and *Bradyrhizobium* strains present in many tropical soils. Strains that infect and nodulate a particular *Acacia* species often vary a great deal in their effectiveness in fixing nitrogen. We conducted an experiment in which we tested 48 strains of rhizobia isolated from *Acacia* species from different countries for their effectiveness in nodulating and fixing nitrogen with *A. auriculiformis* and *A. mangium* in sand culture (Fig. 1).

We tested 12 strains isolated from *A. auriculiformis* grown in Philippine soils and found that they varied from being ineffective, fixing no nitrogen with *A. auriculiformis* (3 strains) to being moderately effective (7 strains producing 30–75% of the plant growth of the best strain), and 2 effective strains. None of the 12 strains isolated from *A. mangium* grown in Philippine soils nodulated *A. auriculiformis* effectively. The strains that fixed most nitrogen with both these acacias came from plants grown in northern Australia and Papua New Guinea. Strain PMA 311/1 was outstandingly effective on both, and is now our recommended inoculant strain. Strains from *A. ampliceps, A. mearnsii, A. melanoxylon, A. saligna, A. spectabilis, A. aulococarpa, A. holosericea* were ineffective or only partially effective (<51% of the dry weight of PMA 311/1).

A. mangium is much more specific in its *Rhizobium* affinities than *A. auriculiformis*. Only two of the 48 strains tested were effective (>75% of the growth with PMA 311/1) and most were quite ineffective. Only one of the 12 strains isolated from *A. mangium* and only one of 12 from *A. auriculiformis* grown in Philippine soils was even moderately effective (60% and 53% of the plant dry weight respectively with PMA 311/1). An earlier experiment with three acacia *Rhizobium* strains tested with 21 acacia species demonstrated marked strain specificity. Strain 14631.1 (or PMA 5/1) from *A. ampliceps* was moderately effective with 10 hosts while the other two strains were only effective on three hosts and failed to nodulate five hosts (Table 1). In an experiment growing plants in test tubes in a growth chamber, despite very slow growth rates, Galiana et al. (1990) also found that *A. auriculiformis* was more promiscuous than *A. mangium*, nodulating effectively with the eight *Bradyrhizobium* strains tested. *A. mangium* was ineffectively nodulated by two of these strains.

Millar et al. (1991) found that some Australian soils contained a varied population of strains capable of nodulating six temperate *Acacia* species whereas other soils contained more similar strains. Some soils supported good growth and nodulation; others only poor growth. For six tropical *Acacia* species, soils from 28 sites in northern Australia again varied in their effectiveness. Of the nodule bacteria populations *A. mangium* nodulated and fixed nitrogen poorly with two of the four strains tested; only three out of 33 isolates from different locations were effective. *A. auriculiformis* was nodulated more effectively. Out of the eight species tested, *A. torulosa, A. holosericea* and *A. mearnsii* were the most readily nodulated. Jisheng Sun et al. (1991) also demonstrated interactions between *Rhizobium* inoculant strains and *A. mangium* provenances, particularly with varying levels of phosphorus application. The large degree of interaction between soils, strains and host species indicates that selection of *Rhizobium* strains will be best done on a species by species basis.

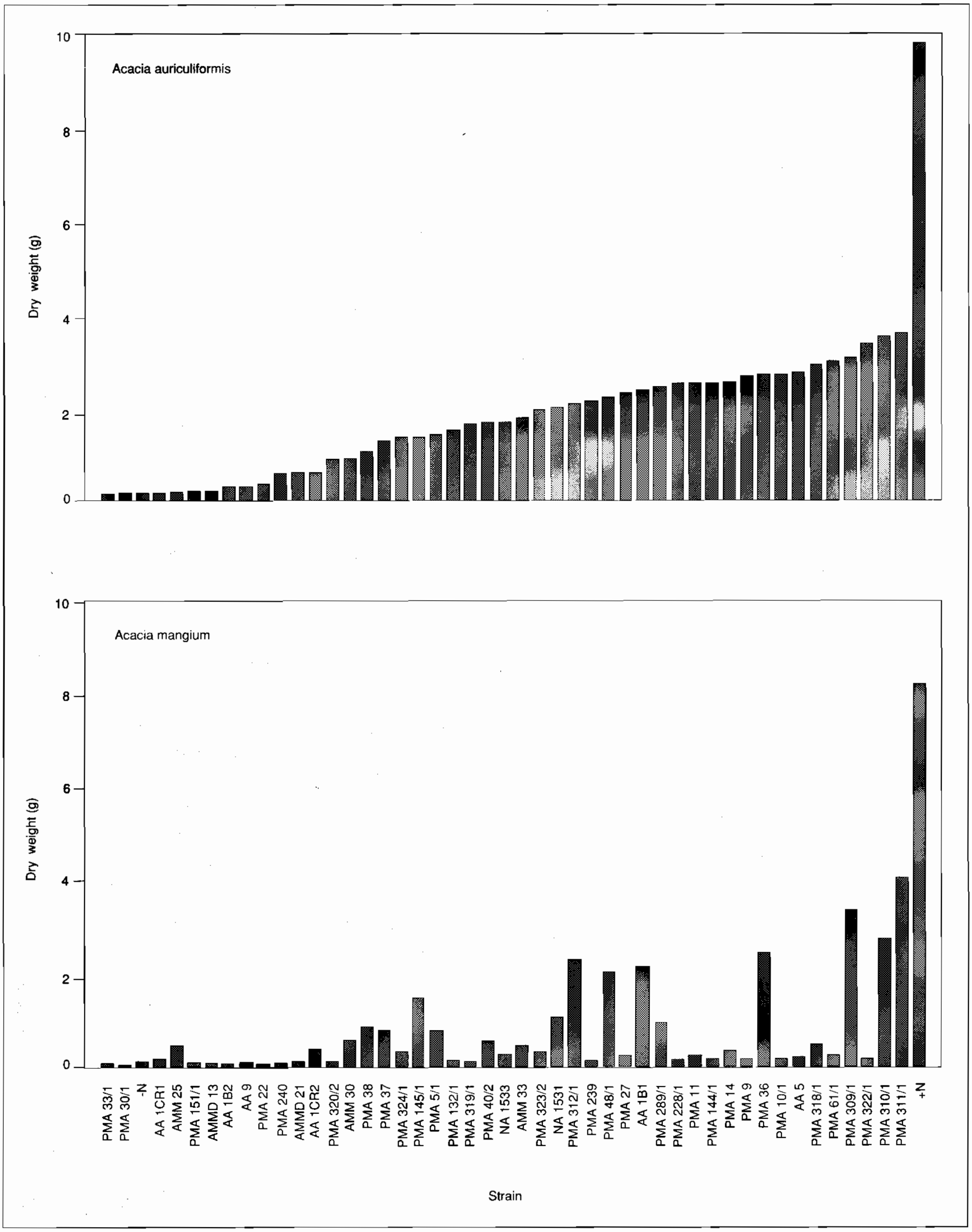

Fig. 1. Effectiveness of 48 *Acacia* isolates.

Table 1. Plant growth response of *Acacia* to *Rhizobium* inoculation in Philippine soils.

Species	Site	Growth parameter (% increase)*			
		Nodule weight/plant	Nodule number/plant	Plant height	Biomass
A. auriculiformis	Pantabangan				18
	Carranglan			53	109
	Cavinti		42	37	90
A. mangium	Pantabangan	1340	580	270	1120
	Carranglan		140	139	32
	Cavinti	148	509	64	180
	Rosario	50			39

* Plants were grown in a screen house and harvested at 3 months old. Only values significantly different to uninoculated plants recorded. Basal PK fertiliser added to all pots.

A series of pot and field *Rhizobium* inoculation experiments was conducted with *A. auriculiformis* and *A. mangium* in Philippine soils. Table 2 shows the response to inoculation for three soils in nursery experiments. Large increases in biomass (ranging from 18 to 1120%) and plant height (from 37 to 270%) were obtained for both species. Nodulation was also increased for *A. mangium* by inoculation.

Table 2. Nitrogen-fixing effectiveness of three strains of *Bradyrhizobium* against 21 *Acacia* species.

Species	PMA5/1	NA2534	TAL1522/1
A. leptocarpa	•••	•••	•••
A. cincinnata	•	•••	•••
A. holosericea	•	•••	•••
A. melanoxylon	•••	••	•
A. shirleyi	••	••	•
A. ampliceps	•••	•	•
A. crassicarpa	•••	•	•
A. dunnii	•••	•	•
A. maconochieana	•••	•	•
A. julifera	•••	•	o
A. mangium	•••	o	•
A. harpophylla	•••	o	o
A. tumida	•••	•	o
A. brassii	••	•	•
A. dimidiata	••	o	•
A. auriculiformis	••	o	o
A. rothii	•	•	•
A. aulacocarpa	•	•	•
A. simsii	•	•	•
A. plectocarpa	•	•	o
A. polystachya	•	o	o

••• = Fully effective •• = Partially effective
• = Ineffective o = No nodules

For *A. auriculiformis* increases in nodule weight per plant were not obtained consistently. However the inoculum strain may still have formed many of the nodules and if these were more effective in fixing nitrogen per unit of nodule weight than the native soil rhizobia, then plant growth would be increased.

In field trials at Cavinti and Carranglan responses to inoculation with *A. auriculiformis* were still evident 8 months after outplanting. For the Cavinti experiment, the increase in biomass dry matter at the nursery stage due to inoculation was 18%, and 8 months after outplanting the increase in plant height was 10%. The Carranglan results are still being processed.

For a series of 22 *Acacia* species grown in a yellow podsolic soil from Mt. Cotton near Brisbane (pH 4.5 in water), 12 of the species responded to inoculation with *Rhizobium* with plant top dry matter increases up to 380% for *A. mangium* and around 103% for *A. auriculiformis*. Basal fertiliser including trace elements was applied.

These *Rhizobium* inoculation experiments suggest that many of the strains naturally present in soils are only partially effective with many acacia species, and responses to inoculation can be obtained with young seedlings. After outplanting, the competition between inoculant strains and native rhizobia populations changes because the inoculant strains need to colonise the new roots formed, often a metre away from the stem. We do not know if such movement through soil along the roots is possible and experiments are in progress to test this. However, an experiment conducted at Tarlac, Philippines indicated that the increased plant vigour obtained in the nursery from inoculation of *A. mangium* persisted at least one year after outplanting.

Acidity tolerance

Acacias are often grown in adverse soil conditions and we are examining ways to select *Rhizobium* and host provenances tolerant of acidity and salinity. Appropriate methods are still to be developed for screening *Rhizobium* strains at pH measurements less than 4.9. However experiments conducted in two acidic soils maintained at different water potentials indicated large effects of soil moisture on nodulation in the acid soils and an interaction with species when lime was added. Nodulation and plant growth changes were smaller for *A. auriculiformis* than for *A. ampliceps* which is more tolerant of alkaline and saline conditions. Decreasing soil moisture to 0.8 M Pa soil moisture tension virtually eliminated nodulation for all species tested. Nodules were only formed at 0.08 M Pa in limed soil for *A. ampliceps* but a few were formed in unlimed soil at 0.008 M Pa. Nodulation of *A. auriculiformis* was decreased as soil moisture tension increased from 0.008 to 0.08 M Pa. Liming effects in both soils were more pronounced at the intermediate soil moisture tension (0.08 M Pa), with large differences between the two soil types.

Salinity tolerance

We have shown that there are differences between *Rhizobium* strains nodulating *Acacia* species in their tolerance of salinity. Strains isolated from nodules grown in saline soils were more tolerant in their growth on agar and in broth containing different salt levels than other strains. Some strains could grow in the presence of 2% salt. When *A. ampliceps* seedlings were grown in test tubes on agar slopes containing 0, 100 or 200 mM NaCl, inoculant strains tolerant of salinity in their growth in pure culture formed most nodules. We are now testing whether these strains are also more tolerant in their nodulation and nitrogen fixation when salt levels are gradually increased once the plants have established and nodulated in non-saline conditions, to simulate the effect of development of plants in a nursery followed by outplanting into saline soil. Our results to date suggest that selection of *Rhizobium* strains for improved symbiotic performance under saline conditions may be possible.

Salinity can affect the growth of *Rhizobium* in soil. When we tested the soil from saline sites near Korat, Thailand we found no rhizobia present. We are currently testing whether saline tolerant *Bradyrhizobium* strains inoculated into these soils can survive and multiply. It is possible that inoculant strains can grow on plant root surfaces in saline soil but not in the bulk soil.

Experiments conducted in collaboration with Dr. N. Marcar of the CSIRO Division of Forestry and Ms Colleen Sweeney of the Australian National University showed that nodulated *A. ampliceps, A. mangium* and *A. auriculiformis* differed in their response to introduction of 100, 200, 400 mM salt in the rooting medium. *A. ampliceps* was most tolerant, maintaining some nitrogenase activity even at 200 mM salt. *A. mangium* was least tolerant with growth and nodulation severely effected at 100 mM salt.

Nitrogen fixation

Using the ^{15}N natural abundance technique, Peoples et al. (1989, 1991) estimated that 52–66% of the nitrogen uptake of *A. auriculiformis* and *A. mangium* grown at Matalom in the Philippines was derived from N_2 fixation. Measurement of N-fixation by *Acacia* in the field by other methods has not been attempted.

Mineral nutrition

In our experiments with *A. mangium* and *A. auriculiformis* in acidic soils from Cavinti, Carranglan and Matalom we obtained large responses to P fertiliser and sometimes to K fertiliser, but no response to trace elements. In Cavinti and Carranglan soil in a nursery trial, harvested 3 months after establishment, application of 60 kg P/ha as single superphosphate and 60 kg K/ha as KCl, when compared with 0 kg P and 60 kg K/ha doubled plant height and increased plant biomass production by 150–160%. Nodule number was increased by 170% in Carranglan soil. For the same comparisons with *A. mangium* in Cavinti soil, height was increased by 64% by addition of 60 kg P/ha, and biomass by 665%. For Carranglan the height increased by 37% and total plant dry matter by 96%. For both sites there was no significant difference between 30 and 60 kg P/ha addition, with 15 kg P/ha also giving a significant but smaller increase over the no P control.

At a more neutral site of Rosario (pH 6.5 in water), *A. auriculiformis* responded in the nursery to fertiliser addition in biomass production (38% increase with 60 kg P/ha) but there was no effect with *A. mangium*, probably because the *Rhizobium* population in the soil was ineffective for *A. mangium*. At Carranglan, one year after outplanting, plant height of *A. mangium* was 38% greater for 30 and 60 kg P/ha treatments than the no P control (1.04 m vs 0.76 m).

For *A. auriculiformis* one year after outplanting at Carranglan, addition of 60 kg P/ha as single superphosphate increased height by 80% and basal diameter by 120%. Addition of 60 kg P/ha as KCl further increased plant height by 17% (1.73 to 2.02 m). Growth of *A. auriculiformis* at Carranglan is relatively slow because of a long dry period of 6–7 months each year.

For soil from Matalom, Leyte in a nursery trial, the response to fertiliser addition was less dramatic but at 5 months after planting plant dry matter was increased by 44% by the addition of 120 kg P/ha. Nodule weight per plant was increased by 85%. For *A. mangium* the comparable response was a 14% increase in dry shoot weight and a 14.7% increase in nodule mass with the addition of K and P.

The implication of these results is that the growth and nitrogen fixing potential of *Acacia* may only be realised in many soils if adequate fertiliser, particularly P, is applied. The added P stimulates nodulation and thereby N fixation and plant growth. In some soils K may also be deficient. In alkaline soils response to S may be obtained, but no reports, apart from our ACIAR results, are known to us of the effects of fertiliser addition.

Mycorrhiza

The response to P fertiliser suggests that the mycorrhizal development on these acacias may be restricted. Acacia species can form both ecto- and endo-mycorrhizal associations (Reddell and Warren 1987). The ectomycorrhizal fungus *Thelephora* spp. forms a beneficial association in promoting growth of *A. auriculiformis*. *Glomus etunicatum* followed by *G. macrocarpum* and *Gigaspora margarita* were the most effective vesicular arbuscular mycorrhiza (VAM) isolates for *A. auriculiformis* and *A. mangium*. For *A. mangium* the response to inoculation with *G. etunicatum* in the nursery persisted into the field 2 years after outplanting at Pantabangan (tree height 1.36 m). Uninoculated trees all died (R. de la Cruz, pers. comm.).

VAM inoculant granules providing 30–50 spores per plant were sufficient to give plant growth responses. These granules after air drying and storing at room temperature for one year were still able to increase height growth of *A. mangium* threefold in a pot experiment (R. de la Cruz, pers. comm.).

Conclusion

Microbial amendments can have a significant impact on *Acacia* growth in the nursery. Effective inoculant strains for some species are available. Methods for selecting *Rhizobium* for acidity and salinity tolerance are under development. Large growth responses can be obtained for *A. mangium* and *A. auriculiformis* in the nursery and in the field from addition of P fertiliser. Defining appropriate and economic fertilising regimes for particular soil and climatic zones is likely to have a large impact on *Acacia* production.

References

Beadle, N.C. 1964. Nitrogen economy in arid and semi-arid plant communities. 3. The symbiotic nitrogen fixing organisms. Proceedings of the Linnean Society of New South Wales, 89, 273–286.

Corby, H.D.L. 1974. Systematic implications of nodulation among Rhodesian legumes. Kirkia, 9, 301–329.

1990. The incidence of rhizobial nodulation among legumes dominant in the flora Zambesiaca area of Africa. Kirkia, 13, 365–375.

Dreyfus, B.L. and Dommergues, Y.R. 1981. Nodulation of *Acacia* species by fast- and slow-growing tropical strains of *Rhizobium*. Applied and Environmental Microbiology, 41, 97–99.

Galiana, A., Chaumont, J., Diem, H.G. and Dommergues, Y.R. 1990. Biology and Fertility of Soils, 9, 261–267.

Habish, H.A. 1970. Effect of certain soil conditions on nodulation of *Acacia* spp. Plant and Soil, 33, 1–6.

Habish, H.A. and Khairi, Sh. M. 1970. Nodulation of legumes in the Sudan II. *Rhizobium* strains and cross-inoculations of *Acacia* spp. Experimental Agriculture, 6, 171–176.

Jisheng Sun, Simpson, R.J. and Sands, R. 1991. Studies with seedlings of provenances in *Acacia mangium*. In: Richardson, A.E. and Peoples, M.B. ed., 9th Australian Nitrogen Fixation Conference, Australian Society Nitrogen Fixation, Canberra, 118–119.

Millar, A.H., Snoad, N.P., Watson, J.M. and Gibson, A.H. 1991. Host x strain relationships in *Acacia* species. In: Richardson, A.E. and Peoples, M.B. ed., 9th Australian Nitrogen Fixation Conference, Australian Society Nitrogen Fixation, Canberra, 126–127.

Pedley, L. 1987. Australian Acacias: taxonomy and phytogeography. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. Canberra, ACIAR, 11–16.

Peoples, M.B., Faizah, A.W., Rerkasem, B., and Herridge, D.F. 1989. Methods for Evaluating Nitrogen Fixation by Nodulated Legumes in the Field. ACIAR Monograph No. 11, vii + 76 p.

Peoples, M.B., Bergersen, F.T., Turner, G.L., Nurhayati, D.P. and Suratmini, P. 1991. Methods to measure symbiotic N_2 fixation in tree legumes. The use of ^{15}N natural abundance. In: Richardson, A.E. and Peoples, M.B., eds., 9th Australian Nitrogen Fixation Conference, Australian Society Nitrogen Fixation, Canberra, 124–125.

Reddell, P. and Warren, R. 1987. Inoculation of Acacias with mycorrhizal fungi: potential benefits. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. Canberra, ACIAR, 50–53.

Roughley, R.J. 1987. Acacias and their root-nodule bacteria. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. Canberra, ACIAR, 45–49.

Factors Limiting Seed Production in *Acacia mearnsii*

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Abstract

Data are presented that suggest that the lack of pollinators, number of polyads reaching the stigma or ratio of male to normal flowers cannot explain the low pod and seed production. As at least 37% of the stigma receive a polyad the possibility of selfing was examined. Although there is a gap between the female stage and pollen shed in an individual flower, there is considerable overlapping of receptive stages on a branch with the chance of selfing high. As a single polyad fits neatly into the cup-shaped stigma, it appears that once a polyad is fixed onto the stigma it can act as a physical barrier to other polyads. The number of pollen grains (16) is greater than the number of ovules (12–14) so only one polyad is required for pollination.

Results are presented that indicate that artificially-selfed flowers rarely initiate pods and that the site of incompatibility is within the ovary. There is further evidence that selfing is a major limitation to seed yields, in that no pods matured following artificial self-pollination and the level of outcrossing was high (94%). The results are discussed in relation to management of seed orchards.

IN tree breeding the function of a seed orchard is to provide a reliable source of genetically improved seed for plantations. Phasing out the use of seed from natural populations in favour of that from seed orchards has been shown to increase yields in forestry (Matheson 1990). However there are several factors potentially limiting the quantity and quality of seed produced in seed orchards. These factors can be broadly grouped as environmental and biological. Environmental factors limiting seed production could be soil type, water and sunlight. With *Acacia* species in early stages of domestication, the relative importance of these factors is largely unknown. In this paper we report on a study of some biological factors determining seed production in *Acacia mearnsii*.

To obtain maximum benefit from a seed orchard requires a recognition of the limitations on seed production imposed by the biology of a species. Knowledge required of aspects of the reproductive biology of acacias include levels of pollination and effective outcrossing, mechanisms of incompatibility and factors limiting pod and seed yields. For instance, in natural populations of eucalypts significant inbreeding can occur which reduces yields (Eldridge and Griffin 1983) whereas significantly less inbreeding may occur in well designed seed orchards (Moran et al. 1989).

Further, if vegetative propagation and controlled pollinations are not feasible for acacias, a breeding strategy based on progeny from open pollinated seed needs to be considered (Raymond 1987). Thus it is vital to have information about the reproductive biology of the particular acacia species in order to develop a breeding strategy for it.

Acacia mearnsii is grown commercially for the tannin in its bark, for fuelwood, charcoal, construction timber and for pulp. About 10 000 ha have been established in 10 Chinese provinces with an annual planting rate of about 3300 ha. There is currently a large and increasing demand for seed of known and good quality to meet the seed requirements for establishing new plantations during 1991. China plans to import seed from either Brazil or India. A breeding program was recommended by ACIAR to overcome the problems associated with present poor seed of unknown origin (Raymond 1987). It was reported that in some areas in China *A. mearnsii* will flower well but no seed is set. Poor and variable yields have also been reported in natural stands in Australia (Thomson pers. comm.).

In this paper we summarise results of three years' observations on floral development, pollination and pod and seed yields in a natural stand of *A. mearnsii*

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growing in southeast New South Wales, Australia. The aim of the study was to determine what factors at what stages during reproductive development have detrimental effects on the quantity of seed produced.

Methods

The study area is located 16 km northeast of Bungendore, New South Wales lat. 35°10'S: long 149°35'E: alt. 800 m (for detailed site descriptions and data collection see Moncur et al. 1989). The site, 150 x 150 m, is undulating, partly cleared land with scattered trees of *Eucalyptus dives, E. pauciflora* and *Allocasuarina littoralis* amongst the *A. mearnsii*.

Racemes were randomly collected, fixed in 1:2 lactic acid:ethanol for three days and then transferred to 70% ethanol. For controlled pollination, racemes were bagged prior to flowering. Bags were inspected at regular intervals and flowers in the female phase were pollinated with polyads collected from a range of trees, using the method described in Moncur et al. (1989). For detection of polyads on the stigma and the detection and measurement of pollen tubes in ovaries, the flower parts were stained in 0.1% decolorised aniline blue, squashed and observed under fluorescence microscopy.

Results

Breeding system

The inflorescence consists of a large number of globular flower heads, borne in axillary racemes, with each head having up to 50 creamy-yellow flowers which are strongly scented. Each flower is perfect, containing a single ovary with style and stigma and about 40 anthers (Table 1). Each anther is two-lobed, each lobe consisting of four locules which split open at anthesis exposing a single polyad. Pollen in acacias is dispersed as a polyad (Fig. 1a), all individual grains being from one paternal sporogenous cell. The number of pollen grains per polyad in individual species is usually reasonably constant but can range from 4 to 32 between species (Knox and Kenrick 1983). About 90% of Australian species of acacias, including *A. mearnsii*, have 16-grain polyads. In *A. mearnsii* each polyad is approximately the same size as the stigma (Fig. 1b) and the number of pollen grains is always greater than the number of ovules (12–14 in *A. mearnsii*). Thus only one polyad is required for pollination. It has been hypothesised that within a single seed pod all the ovules may be fertilised by the same father (Muona et al. 1991).

At flower opening the sepals and petals separate slightly, the style pushes through the opening and straightens (Fig. 1c). The small stigma is covered with stigmatic fluid (Fig. 1d) and appears shiny. It is now receptive and will remain so for about 24 hours. After this time the filaments unfold and exert outwards until the anthers are nearly at the same height as the stigma (Fig. 1e). The head is now a bright yellow ball, the colour coming from the filaments not the petals. The stigma is no longer receptive (not shiny) and the style slowly turns brown and withers (Moncur et al. 1989). The anthers split open exposing the polyads (Fig. 1f). Normally within a flower there is no overlap between stigma receptivity and polyad appearance. The polyads are not ejected and remain exposed on the anthers for 2–3 days. The flowers have no nectaries.

Table 1. Floral organs in *A. mearnsii**.

Organ	Number
Heads/raceme	61.5 ± 29.7
Flowers/head	27.9 ± 5.6
Anthers/flower	37.8 ± 3.9
Polyads/anther	8.0
Polyads/flower	300
Polyads/head	840

* Source: Moncur et al. (1989)

Phenology

In the study all flowers in a single globular head opened almost simultaneously and took 4–5 days to complete the cycle from sepal opening to pollen shed. Each raceme, consisting of up to 100 globular heads, had individual heads flowering over a period of 14 days, though the majority completed their sequence within 7 days.

In the population of 70 trees studied, the mean flowering time of each tree was about 20 days. Trees which commenced flowering earliest flowered longest. Trees flowered in a similar order each year but there was annual variation in the time flowering commenced.

Pollinators

A wide range of insect species were captured on the flowers. The honey bees (*Apis mellifera*) had the most polyads on their bodies and spent considerably longer foraging than other species. A range of birds were seen in the trees but only the yellow-rumped thornbill (*Acanthiza chrysorrhoa*) continually came in contact with open flowers. A number of these birds were caught by mist netting and found to have

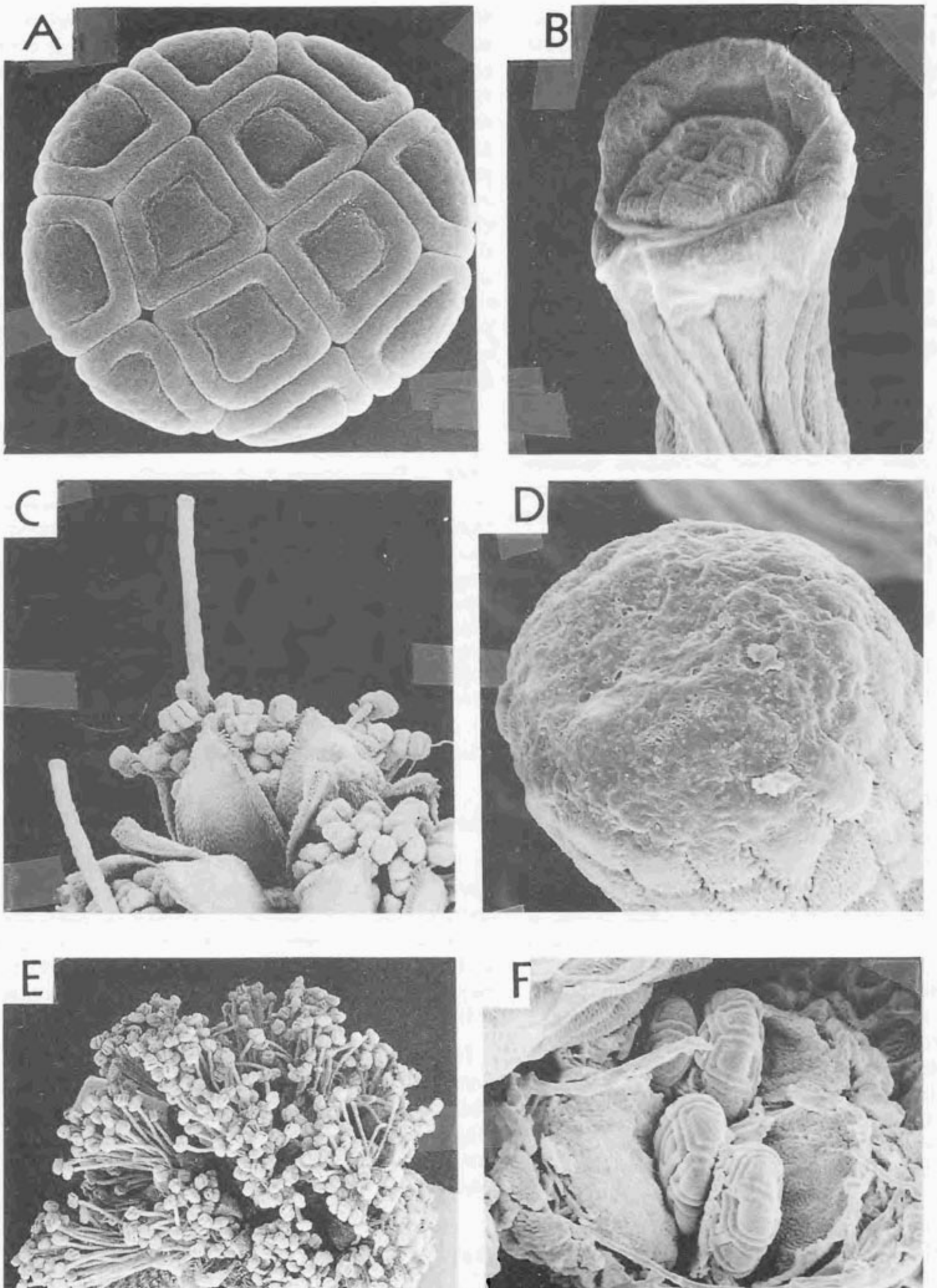

Fig. 1. Scanning electron micrographs of *A. mearnsii* flowers and polyads.

polyads on the beak and forehead. Following medium to strong winds, a small number of polyads were collected in pollen traps downwind from trees in full flower. A high percentage of the polyads stained red with 1% acetocarmine, indicating a high percentage of viable pollen grains.

Pod and seed yields

Mean pod and seed yields over three years (Table 2) were low considering the vast numbers of flowers formed (Fig. 2). Moreover, differences in yield were small both between years and between flowering seasons, e.g. 1987–88 and 1989–90 were heavy flowering seasons whilst 1988–89 was a light flowering season. Factors contributing to low pod and seed yields could include: low levels of pollinators; few stigma being pollinated; the proportion of effective flowers; level of inbreeding and incompatibility within or between trees; insect damage. We examined these in some detail and the results are detailed below.

Table 2. Pod and seed yields for *A. mearnsii* between 1987 and 1990.

	Flowering season		
	1987–88	1988–89	1989–90
Total racemes*	150	135	120
Total heads	9228	1332	8166
Functional female flowers	19 932	19 180	
Pods initiated	117	187	242
Pods matured	113	26	54
Seeds matured	532	137	313
Seeds/pod	4.71	5.27	5.80
Heads/pod (initiated) (%)	1.27	14.04	2.96
Heads/pod (matured) (%)	1.22	1.95	0.66
Functional female flowers/ pods initiated (%)	0.59	0.97	

* 15 racemes from the same 10 trees were selected and tagged each year

Numbers of pollinators

Although a wide range of insect species were observed they were few in number. In an attempt to increase pollinators we introduced bee hives onto the site during flowering in years 1988–89 and 1989–90. The 12 hives placed at the site represent about 400 000 potential pollinators. Although the bees worked the flowers and collected large amounts of pollen (hives were fitted with pollen traps) there was no significant increase in pod set (Moncur and Somerville 1989).

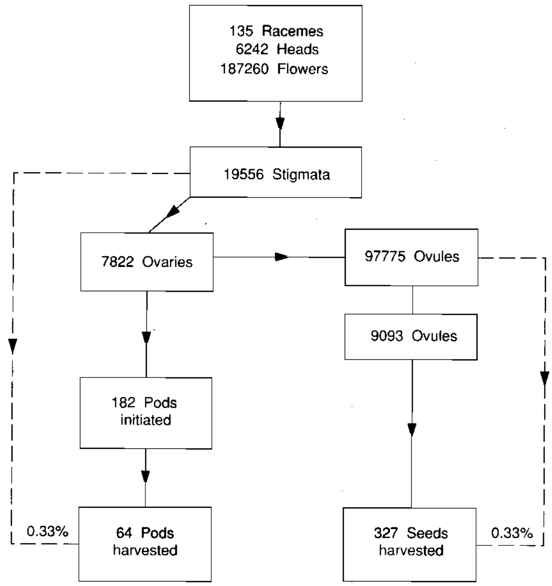

Fig. 2. Loss of reproductive material over time in *A. mearnsii.*

Lack of pollination

About 37% of the stigmas had at least one polyad, but no increase was noted with the introduction of honey bees.

Male vs hermaphrodite flowers

Although the number of heads differed between years the total number of normal hermaphrodite flowers was relatively constant. Male flowers refer to flowers that have little female organ development and are functionally male only. In the 1987–88 flowering season 93% of flowers were male, compared with only 52% in the lighter flowering season of 1988–89. Thus number of male flowers was lower in low flowering years.

Incompatibility/outcrossing

Results from controlled pollinations indicate that for crosses between trees 21% of the heads initiated a pod compared to 0.5% with artificial self-pollination (Table 3). No pods from self-pollinations survived to maturity. The heads that initiated a pod under natural pollination represented 1.3% of the population. Levels of outcrossing measured at the germinated seedling stage from isozyme analysis were 94% for both the 1987 and 1988 seed crops.

Table 3. Comparison of artificial pollinations in *A. mearnsii**.

Method	Heads	Pods (initiated)	Heads with pods (%)
Crosses	297	63	21.2
Selfing	2000	10	0.5
Natural	8968	117	1.3

* Source: Moncur et al. (1989)

Selfing

When examining flowers from self and natural pollinations we found that the number of pollen tubes that were physically able to grow down a style did not seem to be limited to the number of ovules or the number of pollen grains in a polyad. In one instance 33 pollen tubes were counted in a self-pollinated style that had been pollinated by three polyads. The average for the self-pollinated flowers was 11.9 pollen tubes/style compared with 8.7 tubes/style for the open-pollinated flowers.

From observations of the stained and squashed self-pollinated ovaries it appeared that most pollen tubes were bunched and turned back on themselves at the top of the ovary, and of these some had distorted or swollen tips. Rarely could pollen tubes be seen entering the embryo sacs. When open-pollinated flowers were observed, ovaries that had pollen tubes bunched at the top of the ovary were thought to be the result of self-pollination. In addition pollen tubes were visible inside some embryo sacs and appeared to have discharged their gametes. In such ovaries there were usually several ovules with pollen tubes inside.

Discussion

From these observations it appears that the lack of pollinators, number of polyads reaching the stigma or ratio of male to normal flowers cannot explain the low pod and seed production. As at least 37% of the stigmas received a polyad the possibility of selfing was examined. Although there is a gap between the female stage and pollen shed in any individual flower there is considerable overlapping of receptive phases within a raceme. Considering the vast number of flowers and thus polyads on a branch the chance of selfing is high. As a single polyad fits neatly into the cup-shaped stigma and the number of pollen grains (16) is greater than the number of ovules (12–14) only one polyad is required for pollination. In the Bungendore population in the 1988–89 flowering season only 9% of the stigmas had multiple polyads. Thus it appears that once a polyad is fixed onto the stigma it can often act as a physical barrier to other polyads.

Current results indicate that the site of incompatibility in *A. mearnsii* is within the ovary and the self-incompatible pollen tubes rarely enter the ovule. Artificially selfed flowers rarely initiate pods (Kenrick and Knox 1989; and this data) so that even when a self pollen does enter an ovule, maturation of pods does not occur.

In *A. retinoides*, where the site of the incompatibility is the nucellus (Kenrick et al. 1986), the number of the ovules from self-pollinated flowers that are fertilised is similar to that (data not presented) for *A. mearnsii*. For *A. retinoides* the fraction of ovules fertilised was 1.45% in 1983 and 2.9% in 1984, while for *A. mearnsii* in this study the figure was 1.89%. For artificial cross-pollinations in *A. retinoides* 16% (range 12–20%; Kenrick et al. 1986) of ovules were fertilised while for *A. mearnsii* in this study the open-pollinated ovules fertilised were 9.3% (range 8.0–10.8%). This lower figure for open pollinated material is expected as self pollen and outcross pollen are likely to be competing for stigmas. Further evidence that selfing is a major limitation to seed production is the fact that no pods reached maturity following artificial self-pollination and the level of outcrossing is very high.

The research has pinpointed stages of the reproductive life cycle at which factors operate to affect the quantity and quality of seed produced in *A. mearnsii*. On the positive side it has been shown that most of the viable seed produced is outcrossed. It has also been shown that a large fraction of stigmas are not pollinated. If pollination could be significantly increased then it might result in a significant increase in the quantity of seed produced in seed orchards. The fact that a significant fraction of the stigmas are self-pollinated implies, however, that this fraction of the flower crop cannot be easily manipulated in a seed production program. If self-pollination can be controlled to some extent either by genetic engineering or by the use of gameticides (gameticides can terminate pollen development if applied at meiosis) the opportunities for cross-pollination increase. Honey bees could play an important role in increasing pod set by increasing the flow of pollen between trees, where pollen numbers have been artificially reduced. However, the potential for seed production gains would appear to be greatest if the level of pollination could be significantly increased. There is also the possibility of increasing quantity, if not quality, of seed produced by having larger orchards.

References

Eldridge, K.G. and Griffin, A.R. 1983. Selfing effects in *Eucalyptus regnans*. Silv. Genet., 32, 216–221.

Kenrick, J., Kaul, V. and Williams, E.G. 1986. Self incompatibility in *Acacia retinoides*: site of pollen tube arrest is in the nucellus. Planta, 169, 245–250.

Kenrick, J. and Knox, R.B. 1989. Quantitative analysis of self-incompatibility in trees of seven species of *Acacia*. Journal of Heredity, 80, 240–245.

Knox, B.R. and Kenrick, J. 1983. Polyad function in relation to the breeding system of *Acacia*. In: Mulcahy, D.L. and Ottaviano, E., ed., Pollen: Biology and Implications for Plant Breeding. Elsevier, Amsterdam, 411–417.

Matheson, A.C. 1990. Breeding strategies for MPTs. In: Glover, N. and Adams, N., ed., The improvement of multipurpose species. Winrock, Washington, 67–100.

Moncur, M.W., Moran, G.F., Boland, D.J. and Turner, J. 1989. Floral morphology and breeding systems of *Acacia mearnsii* De Wild. Proceedings of Workshop, 'Use of Australian trees in China'. Guangzhou.

Moncur, M.W. and Somerville, D. 1989. The use of honey bees for pollen transfer and increased pod set in black wattle (*Acacia mearnsii*). Australasian Beekeeper, 91, 73–89.

Moran, G.F., Bell, J.C. and Griffin, A.R. 1989. Reduction in levels of inbreeding in a seed orchard of *Eucalyptus regnans* F. Muell. compared with natural populations. Silv. Genet., 38, 32–36.

Muona, O., Moran, G.F. and Bell, J.C. 1991. Hierarchical patterns of correlated mating in *Acacia melanoxylon*. Genetics (in press).

Raymond, C.A. 1987. *Acacia mearnsii*. A breeding plan for China. CSIRO, Canberra.

Comparison of Floral Morphology, Flower Production and Pollen Yield of *Acacia mangium* and *A. auriculiformis*

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Abstract

Despite the extensive planting of *Acacia mangium* currently and the longer preference for *A. auriculiformis* in Malaysia, little is known about their floral morphology. This paper compares the floral morphology of the two species and estimates their flower production and pollen yield. Correlation of the structural and functional aspects of the floral morphology with the breeding system is also described.

ACACIA mangium Willd. is the most widely planted Australian acacia in Malaysia and other developing countries such as Thailand, Philippines and Indonesia. In Malaysia, about 61 000 ha of *A. mangium* plantations have been established (Anon. 1990). By the year 2000 it is estimated Malaysia will have about 575 000 ha of *A. mangium* plantations (Wan Razali 1990). *A. auriculiformis* A. Cunn. ex Benth., on the other hand is planted widely in Malaysia as an ornamental but has potential as an industrial species. Hybrids of these two species have a potential role in plantations.

Little is known on the flowering morphology and flowering behaviour of *A. mangium* and *A. auriculiformis*. This paper compares the floral morphology of *A. mangium* and *A. auriculiformis* and estimates of their flower and pollen production. An attempt is also made to relate some of the structural and functional aspects of the floral morphology to the breeding system.

Morphological Characteristics

The floral morphology of some *Acacia* species has been described by several authors (e.g. Newman 1933, 1934a, 1934b; Cookson 1954; Ford and Forde 1976; Kenrick and Knox 1979, 1981, 1982; Buttrose et al. 1981).

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The floral morphological characteristics of *A. mangium* and *A. auriculiformis* are well documented. Pedley (1975, 1978), Verdcourt (1979) and NAS (1983) have given brief descriptions on the inflorescences of *A. mangium* and *A. auriculiformis*. General descriptions on the floral morphology of *A. mangium* and *A. auriculiformis* grown in Sabah were provided by Bowen (1981).

Inflorescence description

The inflorescence of both *A. mangium* and *A. auriculiformis* consists of numerous flowers borne on a loose pendulous spike. The flowers are arranged spirally along the spike. When in full blossom, the inflorescences resemble bottle brushes. The number of inflorescences per phyllode axil range from three to eight. In *A. auriculiformis*, most axils have one pair of inflorescences. The inflorescence of *A. mangium* is longer and has more flowers than *A. auriculiformis* (Table 1).

Flowering is conspicuous and, during peak flowering season, the entire crowns of *A. mangium* and *A. auriculiformis* are covered with inflorescences.

Floral morphology

The flowers of both species are regular in symmetry consisting of five sepals, five petals, numerous stamens and one gynoecium. *A. mangium* has larger flowers than *A. auriculiformis* (Table 1).

The bright yellow of the *A. auriculiformis* flower arises from the colour of the petals, filaments and anthers. In the case of *A. mangium*, the creamy white flower is from the white petals and filaments and the yellow anthers.

Flowers of both *A. mangium* and *A. auriculiformis* are scented with a mild sweet fragrance. The fragrance is particularly distinct in the early morning in times of full bloom.

Microscopic examination of the stigmata of *A. mangium* and *A. auriculiformis* shows the receptive surfaces have a flat appearance. In both species they measure about 63 microns in diameter and form a cup-shaped depression at the tip of the solid style. Since the style and the surrounding filaments are of the same length, the stigma lies on the same plane as the anthers. Exudate is present on the stigma, giving a glistening appearance when observed under a dissecting microscope.

The anthers of *A. mangium* and *A. auriculiformis* are bilobed structures set terminally on their filaments and measuring 183 and 213 microns, respectively. Each lobe has four separate loculi. Each loculus encloses a polyad (composite pollen grains). In both species, the polyad is spherical in shape with a diameter of about 30–40 microns.

The ovary of *A. mangium* and *A. auriculiformis* is sessile with minute hairs. Table 1 summarises the morphological characters of *A. mangium* and *A. auriculiformis* inflorescences and flowers.

Generally the flowers of *A. mangium* and *A. auriculiformis* are hermaphrodite. However, in some inflorescences, staminate flowers are also present. The incidence of staminate flowers is as low as 4.0% in *A. mangium* and 0.4% in *A. auriculiformis*, from 9730 flowers and 5279 flowers observed in *A. mangium* and *A. auriculiformis*, respectively. The number of staminate flowers per inflorescence ranges from 0 to 46 in *A. mangium* and 0 to 8 in *A. auriculiformis*.

The staminate flowers occurred randomly in any position of the inflorescence. Microscopic investigation revealed that the ovary in the staminate flower was either completely absent or vestigial.

Flower and pollen production

The estimate of inflorescences per branch is the product of the average number of inflorescences per twig and the average number of twigs per branch; the estimate of flowers per branch is the product of the average number of inflorescences per branch and the average number of flowers per inflorescence. The polyad production per branch is estimated by multiplying the average number of flowers per branch by the average number of stamens per flower, and by the number of polyads per anther (8 for both species).

Table 2 shows the estimate of inflorescences and flowers per branch of *A. mangium* and *A. auriculiformis*. Inflorescence production per branch of *A. mangium* is 46.6% higher than *A. auriculiformis*. In flower production per branch, the estimated production of flowers per branch for *A. mangium* and *A. auriculiformis* is about 53 000 and 15 000 respectively. This represents about 70% difference in flower production per branch between *A. mangium* and *A. auriculiformis*. The polyad production per branch in *A. mangium* exceeds that of *A. auriculiformis* by 72.0%.

Discussion

The structure and functional aspects of flowers have determinative roles on the mode of pollination (Frankel and Galun 1977). Authors such as Proctor and Yeo (1972), Frankel and Galun (1977), and Faegri and Van der Pijl (1979), have given detailed accounts of causal interactions between flower structure and pollination mechanisms.

Generally, the inflorescences and flowers of *A. mangium* and *A. auriculiformis* are morphologically similar. The main distinctive morphological feature between the flowers of the two species is their colour. Both species have small flowers with bright colour and have high flower number per inflorescence. The inflorescences are very conspicuous as they are in abundance and clearly displayed on the periphery of

Table 1. Morphological characters of *A. mangium* and *A. auriculiformis* inflorescences and flowers.

Character	*A. mangium*	*A. auriculiformis*
Inflorescence length	97 mm	70 mm
Flowers per inflorescence	195	105
Flower size	4.9 × 4.6 mm	3.8 × 4.1 mm
Anthers per flower	115	109
Ovules per ovary	12–14	12–14
Pollen grains per polyad	16	16
Pollen-ovule ratio	1.23	1.23

Note: Figures represent average values

Table 2. Estimates of flower production in *A. mangium* and *A. auriculiformis*.

	A. mangium	*A. auriculiformis*
No. of twigs with inflorescence buds per branch	10	9
No. of inflorescences per twig	27	16
No. of inflorescences per branch	270	144
No. of flowers per branch	53 000	15 000
No. of polyads per branch	47.6 million	13.2 million

Note: Figures represent average values

the crown. The conspicuous spatial arrangement of the inflorescences in the crown increases the likelihood of insects visiting the flowers. This allows more flowers to be revisited per unit time (Heinrich 1983) and reduces the frequency of foraging mistakes (Paton and Ford 1983).

With reference to the definition of sex expression of the individual flower (Frankel and Galun 1977), the flowers of *A. mangium* and *A. auriculiformis* are either hermaphrodite or staminate. With such flowers present on the plants, both *A. mangium* and *A. auriculiformis* plants are classified as andromonoecious. Andromonoecy, which is a spatial separation of sex organs as an outbreeding device, has been observed in other acacias (Newman 1933; Wickens 1969; Guinet and Vassal 1978; Zapata and Arroyo 1978; Tybirk 1989).

In both *A. mangium* and *A. auriculiformis*, the overall occurrence of staminate flowers was very low when compared to others such as *A. nilotica* (Tybirk 1989). In *A. nilotica*, Tybirk estimated that about 71.4% of the flowers observed were staminate. However, this phenomenon is not observed in *A. mangium* and *A. auriculiformis*. Therefore, if andromonoecy is to provide the floral mechanism to promote outcrossing (Sedgley 1987), the efficiency of andromonoecy in *A. mangium* and *A. auriculiformis* is questionable and needs to be evaluated.

The morphology of the polyads of *A. mangium* and *A. auriculiformis* has an adaptive significance in pollination. Kenrick and Knox (1982) suggested that the size of the polyad fitted well onto the stigma which would help to ensure seed set following a single pollination event. In both *A. mangium* and *A. auriculiformis* the size of the polyads is about 30–40 microns which fits neatly into the stigma cup which measured about 63 microns. Crudent (1977) advocated that the pollen-ovule ratio can provide an indication of breeding systems in flowering plants. The pollen-ovule ratio of 1.23 in both *A. mangium* and *A. auriculiformis* signifies a moderate efficiency of pollen transfer.

Both *A. mangium* and *A. auriculiformis* are species with a high density of flowers. This could attract potential pollinators and so conform to the optimal foraging theory (Charnov 1976) as cited in Paton and Ford (1983), in which increase in foraging effort (visits per flower) should be proportional to the increase in the rates at which nectar or pollen can be harvested. When plants have more flowers, pollinators may visit and revisit more flowers per unit time, which reduces frequency of foraging mistakes. This applies particularly to plants with a high density of flowers and convenient spatial arangement.

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References

Anon. 1990. Research Report 1989. Forest Research Institute Malaysia, Malaysia. 165 p.

Bowen, M.R. 1981. A note on seed collection, handling and storage techniques including some experimental data and information on *Acacia auriculiformis* hybrid. Seed Series No. 3. FAO/UNDP-MAL/78/009. Forest Research Centre, Sabah, 18 p.

Buttrose, M.S., Grant, W.J.R. and Sedgley, M. 1981. Floral development in *Acacia pycnantha* Benth. in Hook. Australian Journal of Botany, 29, 385–395.

Charnov, E.L. 1976. Optimal Foraging: The Marginal Value Theorem. Theoretical Population Biology, 9, 129–136.

Cookson, I.C. 1954. The Cainozoic occurrence of *Acacia* in Australia. Australian Journal of Botany, 2, 52–59.

Crudent, R.W. 1977. Pollen-ovule ratio: a conservative indicator of breeding systems in flowering plants. Evolution, 31, 32–46.

Faegri, K. and van der Pijl, L. 1979. The Principles of Pollination Ecology. Pergamon Press, Oxford, 248 p.

Ford, H.A. and Forde, N. 1976. Birds as possible pollinators of *Acacia pycnantha*. Australian Journal of Botany, 24, 793–795.

Frankel, R. and Galun, E. 1977. Pollination Mechanisms, Reproduction and Plant Breeding. Monographs on Theoretical and Applied Genetics 2. Springer-Velag, Berlin Heidelberg, 281 p.

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

Heinrich, B. 1983. Insect foraging energetics. In: Jones, C.E. and Little, R.J., ed., Handbook of Experimental Pollination Biology. Van Nostrand Reinhold, New York, 187–214.

Kenrick, J. and Knox, R.B. 1979. Pollen development and histochemistry in some Australian species of *Acacia*. Australian Journal of Botany, 27, 413–427.

1981. Structure and histochemistry of the stigma and style of some Australian species of *Acacia*. Australian Journal of Botany, 29, 733–745.

1982. Function of the polyad in reproduction of *Acacia*. Annals of Botany, 50, 721–727.

National Academy Science 1983. Wood Products and Uses. Mangium and Other Fast-Growing Acacias for the Humid Tropics. National Academy Press: Washington D.C., 21–23.

Newman, I.V. 1933. Studies in the Australian acacias, II. The life history of *Acacia baileyana* F.v.M. Part 1. Some ecological and vegetative features, spore production and chromosome number. Journal of Linnean Society London, Botany, 49, 145–171.

1934a. Studies in the Australian acacias, IV. Life history of *Acacia baileyana* F.v.M. Part 2. Gametophytes, fertilisation, seed production and germination and general conclusions. In: Proceedings of Linnean Society New South Wales, 59, 277–313.

1934b. Studies in the Australian acacias, III. Supplementary observations on the habit, carpel, spore production and chromosomes of *Acacia baileyana*. In: Proceedings of Linnean Society of New South Wales, 59, 237–251.

Paton, D.C. and Ford, H.A. 1983. The influence of plant characteristics and honeyeater size on levels of pollination in Australian plants. In: Jones, C.E. and Little, R.J., ed., Handbook of Experimental Pollination Biology. Van Nostrand Reinhold, New York, 235–248.

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

1978. A revision of *Acacia* Mill. in Queensland. Austrobaileya. 1(2), 75–234.

Proctor, M. and Yeo, P. 1972. The Pollination of Flowers. Taplinger Publishing, New York, 418 p.

Sedgley, M. 1987. Reproductive biology of *Acacia*. In: Turnbull, J.W., ed., Proceedings of international workshop on Australian acacias in developing countries, Gympie, Qld, Australia, 4–7 August 1986. ACIAR Proceedings No. 16, 154–156.

Tybirk, K. 1989. Flowering, pollination and seed production of *Acacia nilotica*. Nordic Journal of Botany, 9, 375–381.

Verdcourt, B. 1979. Manual of New Guinea Legumes. Botany Bulletin No. 11. Kristen Press, Madang, Papua New Guinea, 645 p.

Wan Razali Wan Mohd 1990. Sustainable forest management in ASEAN with special reference to sustainable timber production in Malaysia. FRIM-IDRC Internship Report, 101 p.

Wickens, G.E. 1969. A study of *A. albida* Del. (Mimosoideae). Kew Bulletin, 23, 181–203.

Zapata, T.R. and Arroyo, M.T.K. 1978. Plant reproductive ecology of a secondary deciduous tropical forest in Venezuela. Biotropica, 10, 221–230.

Floral Development of *Acacia auriculiformis*

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Abstract

This study investigated basic information on floral development in *Acacia auriculiformis*. Its flower is perfect, comprising calyx, corolla, androecium and gynoecium. Floral buds were initiated in summer between late June and late August through to flowering.

Floral development was studied from floral initiation to anthesis or flowering. During the early stage of stamen development, the anther primordium differentiated to form the anther wall and sporogenous cells. During the late stage, the sporogenous cells produced the microspore mother cells and successively formed the polyads. At the stage of microsporogenesis, the pistil primordium enlarged and enfolded to form an ovary. Ovule primordia arose internally from the margin so the pistil contained 14 ovules. Each ovule initiated a megaspore mother cell. At anthesis, these megaspore mother cells produced the megaspores, which formed the embryo sac with 8 nuclei. There are three antipodals in the chalazal end, two polar nuclei near the centre and two synergids and egg in the micropyle end. The complete development process of the floral bud up to the flowering time took about 50 days.

Acacia auriculiforms A. Cunn. ex Benth. is a fast-growing tree and an exotic in Thailand. It has a perfect flower which is borne upon a rachis, in a spike with 100–120 individual flowers. The rachis is 6–7 cm long, paired on the upper axil of the phyllode. The flowers occur from late June to late August.

This study was conducted to describe the morphological and anatomical features of floral development of *A. auriculiformis* from floral initiation to anthesis.

Materials and Methods

Flowers of *A. auriculiformis* at different stages of development were collected from Muak Lek, Saraburi, Thailand and fixed in FAA. Dehydration and infiltration was carried out through TBA series and the materials were embedded in paraffin wax at 56–58 °C. Sections were cut with the rotary microtome to 10–15 micron thickness and stained with safranin-aniline blue combination (Johansen 1940).

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Observations

Inflorescences appeared in leaf axils of new shoots. Most of the inflorescence buds were initiated between June and August, and developed into flowers in August and September. The six stages of floral development are described in Table 1.

The flowers are arranged in a spike and each individual flower bud is surrounded by bracts. At the early stage, each flower consists of five sepals and five petals around a dome of tissue — the primordia of stamens and the pistil. The sepals and petals develop concurrently as the pistil primordium enlarges in the centre, surrounded by the stamen primordia. Each stamen differentiates from the central primordia and elongates to form a filament and anther primordium. The anther primordium develops into four locules. Each locule appears somewhat squarish. These cells differentiate and form a primary sporogenous cell and the anther wall. The sporogenous cells increase in mass as a result of the formation of microspore mother cells. These microspore mother cells undergo meiosis to give the polyads, which are surrounded by the exine. During the development of the microspore mother cell stage, the tapetum and the middle layers are crushed by developing microspores.

Table 1. Stages of flower development in *Acacia auriculiformis*.

Stage	Description	Duration (days)
1	A protruberance of inflorescence bud about 0.5 cm long appears in leaf axils of new shoots	0
2	The rachis elongates and the individual flower buds are clustered	0–15
3	The rachis elongates to full size (6–7 cm) and the individual greenish flowers are separated	15–30
4	The individual flowers turn yellow	30–40
5	The flowers open	40–45
6	Some flowers produce fruit (green pod 0.5 cm) but others abort	45–50

The pistil primordium appears on the centre of the dome. It enlarges by cell division that causes the pistil primordium to enfold and form a longitudinal groove. This enfolding continues until the margins meet to form an ovary. Ovule primordia arise internally from each margin. At the same time, cell division appears in the apex of the pistil to expand the tissue, thus forming a style and a stigma. The receptive surface of the stigma has no protuberances.

When the ovule primordium increases in size, the primordium of integument is initiated from the epidermal layer at the base of the ovule primordium. The integuments grow in a ringlike belt enclosing the nucellus but leave a small pore at the apex of the nucellus to form a micropyle at the anthesis period.

The ovule emerges as a tiny protruberance on the placenta with the hypodermal archesporial cell. It functions as the magaspore mother cell and divides to form a megaspore dyad and a linear tetrad of megaspores. One of the megaspore tetrad cells is functional and successive mitosis divisions result in the formation of an embryo sac with eight nuclei. The egg apparatus consists of an egg cell and two synergids in the micropylar end, two polar nuclei near the centre, and three antipodals in the chalazal end. The duration of flower development until anthesis is approximately 45–50 days.

Discussion

Flower buds initiate between late June and late August. Maximum production of flower buds takes place in July. The flower buds develop and most abort in late August. This reduction in bud development corresponds with growth of the seed pod, which matures to shed seed in October (Pukittayacamee and Hellum 1988).

The flower buds initiate in the leaf axil of the new shoots. Most of the inflorescences are paired but occasionally three inflorescences arise on the axil. The reason for this is unknown, but it may be a mechanism of cell division in the transition from vegetative to reproductive tissue. The individual flowers are at different stages in the inflorescence. The lower flowers develop faster than the upper, however the individual flowers over the entire rachis open at approximately the same time.

References

Johansen, D.L. 1940. Plant microtechnique. McGraw-Hill, New York.

Pukittayacamee, P. and Hellum A.K. 1988. Seed germination in *Acacia auriculiformis*: developmental aspects. Can. J. Bot. 66, 388–393.

Multiplication of *Acacia mangium* by Stem Cuttings and Tissue Culture Techniques

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Abstract

Acacia mangium can be easily propagated by stem cuttings and tissue culture techniques. Single internode stem cuttings with one phyllode or half-cut phyllode taken from 6- to 12-month-old seedlings produced high rooting percentages (65–76%). Cuttings taken from 24-month-old seedlings and cuttings without phyllode and without hormone treatment gave lower rooting percentages (12–15%). For tissue culture, nodal explants of aseptically germinated seedlings cultured on MS basal medium supplemented with 3% sucrose (w/v), 0.6% bacteriological agar (w/v) and 0.5 mg/l 6-benzylamino purine induced a higher shoot multiplication with an average 25.4 shoots per explant. For root formation, excised micropropagated shoots were treated with a hormone rooting powder (Seradix 3).

VEGETATIVE propagation, either by stem cuttings or tissue culture techniques, is becoming an important tool for forest tree improvement activities and for the establishment of clonal plantations. Its value in the forestry sector has been proven with the success of clonal forestry practices of *Eucalyptus* spp. in Aracruz, Brazil. In fact, it is considered an excellent approach for reducing time to implement tree improvement activities and for immediate mass production of high quality and genetically uniform planting stocks of selected superior individuals.

In recent years considerable efforts have been made in many tropical countries to develop proper vegetative propagation techniques of tree species for improvement and reforestation programs. In the case of Malaysia, studies on the possibility of using *A. mangium* stem cuttings and tissue culture techniques for production of genetically improved planting stock for a large-scale planting program have been conducted with good success.

In this paper the effects of age of stock plants, phyllode number, and growth substances on rooting of *Acacia mangium* stem cuttings are reported. Also the effect of cytokinins on shoot multiplication in vitro and the effect of growth substances on ex vitro rooting of excised shoots are highlighted.

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Stem Cuttings

Experiment 1: The effect of age of stock plants on rooting ability of *A. mangium* stem cuttings

Cuttings were taken in batches at age 6, 12, 18 and 24 months from healthy potted seedlings. They were cut into single internode cuttings, around 4–5 cm long and 0.5–1.5 cm in diameter, depending on the age of the seedlings. They were then treated with Seradix 3 (commercial hormone powder) then inserted into rooting medium (1:1 Irish sphagnum peat and sand). Intermittent mist sprayers controlled by an electronic leaf were used to maintain a high humidity (about 80%) inside rooting chambers. Observations were carried out three months after planting.

The results of this study clearly illustrated that the percentage of rooting is sharply decreased with the increase in age of the stock plants (Table 1). A statistical test revealed that cuttings taken from 6- and 12-month-old stock plants were equally good in their rooting percentages, and that they were significantly different compared to those from older stock plants.

The decline in rooting percentage of *A. mangium* stem cuttings taken from older stock plants may be due to anatomical features such as thickening of sclerenchymatous cells which become a barrier for root initiation. These characteristics are often present in older trees and may cause difficulty in rooting

(Komissarov 1964; Nanda et al. 1969). Histological examinations of 1-year-old *A. mangium* seedlings clearly showed that a continuous layer of sclerenchymatous cells was present (Darus 1989a). Although this layer did not affect the rooting of one-year-old *A. mangium*, possibly with increase in age it becomes thicker and forms a barrier for emergence of adventitious roots.

Table 1. Rooting percentage of *A. mangium* stem cuttings in relation to the age of stock plants.

Age of stock plants (months)	Rooting (%)
6	71.3 ± 4.6 a
12	65.0 ± 5.2 a
18	31.3 ± 2.1 b
24	15.0 ± 1.7 c

Means sharing a common letter do not differ significantly ($p = 0.05$)

Experiment 2: Effect of phyllode number on rooting ability of *A. mangium* stem cuttings

Cuttings were obtained from 1-year-old healthy potted seedlings. They were cut into several one-internode and two-internode cuttings and then divided into four groups: 1) two-internode stem cuttings with two phyllodes; 2) one-internode stem cuttings with one phyllode; 3) one-internode stem cuttings with the phyllode cut transversely into half; 4) one-internode cuttings without a phyllode. All cuttings were also treated with Seradix 3 and planted into similar rooting chambers as described in Experiment 1.

The results indicate that the presence of a phyllode on *A. mangium* stem cuttings was very important. However, when the phyllode was cut transversely into half, the rooting percentage was higher than cuttings with 1 or 2 entire phyllodes. The leafless cuttings gave very low rooting percentage (Table 2).

Table 2. Rooting percentage of 1-year-old *A. mangium* stem cuttings in relation to phyllode presence.

Phyllode number	Rooting (%)
Cuttings with 2 phyllodes	46.0 ± 2.4 a
Cuttings with 1 phyllode	66.0 ± 9.3 ab
Cuttings with ½ phyllode	76.0 ± 7.5 b
Cuttings without phyllode	12.0 ± 2.1 c

Means sharing a common letter do not differ significantly ($p = 0.05$)

It has been reported that the presence of leaves is essential to stem cuttings in order to produce and supply carbohydrate to those stem tissues involved in root formation. Leakey et al. (1982) reported that a lower rooting percentage of *Triplochiton scleroxylon* leafless cuttings was clearly caused by the depletion of carbohydrate content.

Experiment 3: Effect of growth substances on rooting of *A. mangium* stem cuttings

Alpha-naphthalene acetic acid (NAA) and indole-3-butyric acid (IBA) were used at concentration levels of 500, 1000, 1500 and 2000 ppm. Single-internode cuttings of 1-year-old healthy potted seedlings were treated by dipping the basal end (about 1–2 cm) into solution for about 30 seconds before inserting them into a rooting medium containing equal parts of Irish sphagnum peat and sand. Some cuttings were treated with Seradix 3 and for controls, they were treated with distilled water.

The results indicate that IBA, NAA and a hormone rooting powder greatly improved rooting percentage of *A. mangium* stem cuttings. However, the degree of response and effectiveness of these substances to induce rooting are largely dependent on types as well as concentration levels (Table 3). The best treatment was 500 ppm IBA. However, a statistical test indicates that there was no significant difference in rooting percentage of cuttings treated with 500 ppm IBA and the other treatments, except cuttings treated with 2000 ppm NAA and the control.

Table 3. Rooting percentage of 1-year-old *A. mangium* stem cuttings with and without hormone treatments.

Treatment	Rooting (%)
Control	36.0 ± 2.3 bc
Seradix 3	66.0 ± 8.9 ac
500 ppm IBA	76.0 ± 6.5 a
1000 ppm IBA	68.0 ± 3.6 a
1500 ppm IBA	60.0 ± 8.6 ac
2000 ppm IBA	46.0 ± 7.3 ac
500 ppm NAA	50.0 ± 5.2 ac
1000 ppm NAA	60.0 ± 12.8 ac
1500 ppm NAA	52.4 ± 4.7 ac
2000 ppm NAA	34.0 ± 6.5 ab

Means sharing a common letter do not differ significantly ($p = 0.05$)

Tissue Culture Techniques

Experiment 4: Effect of cytokinins on shoot multiplication

Nodal explants of 1-month-old aseptically germinated seedlings were cut into pieces 2–4 mm in length and were then cultured in full-strength MS basal medium (Murashige and Skoog 1962) supplemented with 3% sucrose (w/v), 0.6% bacteriological agar (w/v) and cytokinins at different concentration levels. The cultures were then incubated in a controlled growth room (room temperature 20 ± 3 °C, 18 hours photoperiod and a light intensity of 30 000 lux). Observations were carried out on 2-month-old cultures and all developed shoots were carefully excised and counted.

Shoots started to develop within two weeks of inoculation. They were healthy, green in colour and with small juvenile compound leaves. Of the two cytokinins tested for their ability to induce multiple shoot formation, 6-benzylamino purine (BAP) was the most effective. The highest number of shoots per explant was obtained from MS basal medium supplemented with 0.5 mg/l BAP, with an average of 25.4 shoots per explant. For kinetin, the optimum concentration for multiple shoot induction was 4.0 mg/l, with an average of 12.3 shoots per explant (Table 4).

Table 4. Effect of BAP and kinetin concentration levels on shoot multiplication (n = 20).

Concentration levels of BAP or kinetin (mg/l)	No. of shoots produced per explant in MS + BAP	No. of shoots produced in MS + kinetin
0.00	1.2 ± 0.4 a	1.2 ± 0.4 e
0.10	4.6 ± 1.1 ab	—
0.25	7.1 ± 1.7 b	—
0.50	25.4 ± 6.0 c	2.0 ± 1.4 e
1.00	24.6 ± 4.1 c	2.6 ± 0.8 e
2.00	19.3 ± 2.5 d	4.5 ± 2.8 e
4.00	15.8 ± 4.6 d	12.3 ± 4.6 f

Means sharing a common letter do not differ significantly (p = 0.05)

The success of multiple shoot formation appears to be controlled by the growth substances and their concentration levels. In this study, it was observed that the BAP at 0.5 mg/l was the best for nodal cultures of aseptically germinated *A. mangium* seedlings. In fact, it has been frequently reported that BAP always induces better shoot multiplication than other cytokinins. Its effectiveness has been demonstrated in cultures of other woody species such as *Calophyllum, Eugenia* and *Fragraea* (Rao and Lee 1982) and *Eucalyptus* (Gupta et al. 1981). However, when the nodal explants are taken from older seedlings the level of BAP has to be increased. For example, Darus (1989b) reported that the optimum BAP concentration for nodal cultures of 8-month-old seedlings was slightly higher, i.e. 1.0 mg/l of BAP was needed to produce the maximum number of shoots, 16.9 per explant.

Experiment 5: Effect of growth substances on rooting of excised shoots

Shoots more than 0.5 cm long were used for ex vitro rooting. Three different types of auxins viz. indole-butyric acid (IBA) and alpha-naphthalene acetic acid (NAA) at different concentration levels and Seradix 3 were used. Excised shoots were treated with NAA and IBA by dipping the base into freshly prepared solution for about 5 seconds before inserting them into the misted rooting chambers containing a 1:1 mixture of Irish sphagnum peat moss and sand. For the control treatment, the shoots were dipped into distilled water for about five seconds before planting them into the rooting medium.

The results indicated that the different types of growth substances and their concentrations influenced the root formation of the excised shoots. Seradix 3 was found to be the best at inducing root formation and giving the highest rooting percentage (Table 5). Treatment with NAA at higher concentrations (500 and 1000 ppm), with lower concentration of IBA (100 ppm) or without any hormone treatment produced lower rooting percentages.

Table 5. Rooting percentage of excised shoots with and without growth substance treatments in misted rooting chambers.

Treatment	Rooting (%)
Control	17.5 ± 3.1 ae
Seradix 3	85.0 ± 2.5 b
100 ppm NAA	40.0 ± 2.5 c
250 ppm NAA	35.0 ± 4.7 cde
500 ppm NAA	22.5 ± 2.5 ade
1000 ppm NAA	12.5 ± 0.0 a
100 ppm IBA	17.5 ± 3.1 ae
250 ppm IBA	32.5 ± 5.0 cde
500 ppm IBA	40.0 ± 6.1 c
1000 ppm IBA	37.5 ± 5.6 cd

Means sharing a common letter do not differ significantly (p = 0.05)

It was found that the general requirements for rooting of micropropagated shoots in misted rooting chambers were similar to those for stem cuttings of *A. mangium* seedlings. The growth substances and their concentration levels were also important for rooting micropropagated shoots. It was interesting to note that a hormone rooting powder (Seradix 3) induced a higher rooting percentage of micropropagated shoots, while for stem cuttings of 1-year-old *A. mangium* seedlings, IBA at 500 and 1000 ppm was the most effective at inducing high rooting percentages.

Conclusions

These studies demonstrated that under favourable environmental conditions, using suitable rooting hormones at optimum concentrations and young stock plants, *A. mangium* could be easily mass propagated by stem cuttings. It also shows that micropropagation techniques of *A. mangium* can be utilised for vegetative propagation on a larger scale.

References

Darus Haji Ahmad 1989a. Anatomical study on root formation in *Acacia mangium* stem cuttings. Journal of Tropical Forest Science 2(1), 20–24.

1989b. Rapid propagation of *Acacia mangium* plantlets using micropropagation techniques. Paper presented at The Regional Symposium on Recent Development in Tree Plantations of Humid/Subhumid Tropics of Asia, UPM, Serdang, Malaysia. 5–9 June 1989.

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

Komissarov, D.A. 1964. Biological basis for propagation of woody plants by cuttings (Trans. by Shapido, Z. 1969). Israel Program for Scientific Translations, Jerusalam.

Leakey, R.R.B., Chapman, U.R. and Longman, K.A. 1982. Physiological studies for tropical tree improvement and conservation. Factors affecting root initiation in cuttings of *Triplochiton scleroxylon* K. Schun. Forest Ecology Management, 4, 53–56.

Murashige, T. and Skoog, F. 1962. A revised medium for rapid growth and bioassays with tobacco tissue cultures. Physiol. Plant., 15, 473–495.

Nanda, K.K., Anand, V.K. and Kumar, P. 1969. Rooting ability of cuttings of forest tree species and its relationship with tissue characteristics, nutrients and auxins. Second World Consultation on Forest Tree Breeding, Washington, 7–16 August 1969.

Rao, A.N. and Lee, S.K. 1982. Importance of tissue culture in tree propagation. In: Fujiwara, A., ed., Plant Tissue Culture. The Jap. Assoc. for Plant Tissue Culture, Tokyo, 715–718.

Vegetative Propagation of *Acacia auriculiformis*

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Abstract

Vegetative propagation by means of air-layering of *Acacia auriculiformis* was found to be profoundly affected by season and tree age. Rooting in the rainy season was more than 80%, while in the dry season rooting was only 10%. Furthermore, younger trees (4–8 years) rooted more readily than older trees (15 years and above). Air-layers of young trees had a rooting rate of 60–80%, while for older trees the rate was less than 25%.

In cutting experiments, epicormic shoots from pollarding gave a higher rooting percentage (90%) than branch cuttings (70%). It was found that the commercial preparation "Seradix" No. 3 containing 0.8% indolebutyric acid (IBA) gave best results.

A FEASIBILITY study on vegetative propagation of *Acacia auriculiformis* was carried out in 1988 by the author. The results, presented at the National Forestry Conference, Royal Forest Department, Bangkok in 1989, indicated that it was highly feasible to propagate *A. auriculiformis* vegetatively through air layers, grafts and cuttings using hormone treatments and mist spray facilities.

However, it was considered that further in-depth studies were needed to establish practical methods for field operation. ACIAR scientists suggested that these studies should cover various aspects such as:

- seasonal variation in rooting ability;
- variation of rooting ability between trees;
- effect of height on rooting ability;
- comparison of rooting ability of cuttings from epicormic shoot and branch cuttings;
- effects of tree age on rooting ability.

These studies were carried out in experimental plots of Sakarat Environmental Research Station and demonstration plots of Thai-Japan Research and Training in Re-afforestation Project, Pakchongchai District, Nakorn Ratchasima Province.

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Materials and Methods

Effect of seasonal variation and individual tree variation on rooting ability of air-layers

These studies were carried out between January 1989 through September 1990. Five vigorously growing 4-year-old *A. auriculiformis* trees were selected. In each tree, 10 branches were selected for air-layering experiments in both dry and wet seasons. The selected branches were chosen to represent the whole crown of tree. Selected branches were 8–12 months old.

Five branches were air-layered in January 1989. Each branch was girdled (approximately 2-cm section), the cambium scraped and a solution of Seradix No. 3 applied to the wound. When it dried completely, wetted coconut husk approximately 150 cc in volume was wrapped around the wound and covered with clear plastic tightened with rope to secure the material and prevent evaporation.

The air-layered branches were inspected after 60 days. Rooted branches, which were easily observed through clear plastic, were cut to examine and count the number of roots. These procedures were duplicated in 1990.

Rooting ability of epicormic shoots compared to branch cuttings

These studies were carried out using 8-year-old *A. auriculiformis* which had an average height of 14.5 m and diameter at breast height of 27.3 cm. Five vigorously growing trees were selected in May 1989.

Trees were either pollarded or girdled 30 cm above ground level. Branches from pollarded trees with a diameter of 10–15 mm were selected and cut into 30 cm pieces. Five branches from pollarding of each tree were placed in coarse sand in a plastic tunnel to stimulate epicormic shoot development.

In July 1989, 10 epicormic shoots from pollarded branches were selected from each tree. These epicormic shoot cuttings were dipped in Seradix No. 3 powder and placed in 10 × 15 cm polyethylene bags filled with coarse sand. At the same time, branch cuttings from selected trees were also given the same treatments as epicormic shoot cuttings.

All cuttings in polyethylene bags were arranged in trays in a lath house with intermittent mist spray facilities and 50% shading. This experiment was carried out with five replications. Observations of rooting were undertaken periodically. These cuttings had rooted after 40 days of treatment. Rooted cuttings were removed from mist spray facilities, placed in ordinary cutting beds and watered twice daily. Final observations on rooted cuttings were made in September 1989. This experiment was duplicated in 1990.

Girdling treatment in this experiment failed to produce epicormic shoots.

Effect of tree age on rooting ability

This study was carried out from June to September 1989. Three age classes of *A. auriculiformis* were selected for this study — 15, 8 and 4 years old. Five vigorously growing trees in each age classification were chosen. In each tree, five branches in the upper portion of the crown were selected and treated with air-layering techniques described earlier. Inspection of rooting took place in September 1989.

Results and Discussion

Effect of seasonal variation and individual tree variation on rooting ability of air layers

The results of these studies indicate that rooting ability of *A. auriculiformis* is highly dependent on the season, and is by far the best during the rainy season (Table 1). Furthermore, individual trees showed no significant variation in rooting ability in the rainy season. Statistical analyses showed that there was a significant difference in rooting ability between seasons, but rooting ability from year to year showed no significant difference.

Rooting ability of epicormic shoots and branch cuttings

In these studies, pollarding treatment succeeded in producing epicormic shoots while girdling treatments failed. Therefore, the studies were able to compare only epicormic shoot cuttings from pollarding treatment with branch cuttings.

The studies showed that there was a significant difference in rooting ability between epicormic shoot and branch cuttings (Table 2). Rooting ability of epicormic shoots was far better than those from branch cuttings. Furthermore, cuttings from epicormic shoots produced better plants than those from branch cuttings, both in appearance and vigour.

Effect of tree age on rooting ability

The result of this study showed that rooting ability was not significantly different between 4 and 8 year old trees but there was a highly significant difference in rooting ability between these and 15-year-old trees

Table 1. Seasonal and individual variation of rooting ability of air layers on 4-year-old *A. auriculiformis*.

Tree No.	No. of air layers	Year							
		1989				1990			
		Dry season (Dec.–Feb.)		Rainy season (May–July)		Dry season (Dec.–Feb.)		Rainy season (May–July)	
		No. of rooted branches	% rooted	No. of rooted branches	% rooted	No. of rooted branches	% rooted	No. of rooted branches	% rooted
1	5	1	20	5	100	0	0	5	100
2	5	1	20	4	80	1	20	5	100
3	5	0	0	4	80	0	0	4	80
4	5	0	0	5	100	0	0	5	100
5	5	0	0	4	80	0	0	5	100

(Table 3). Furthermore, roots produced by 4-year-old trees were better than those produced by 8- and 15-year-old trees, both in size and in appearance.

In addition, close observation on the unrooted branches in the 15-year-old class showed no callus formation, while those unrooted branches in the 8- and 4-year-old classes showed callus tissue. It is possible that with time that callus would develop into roots.

Table 2. Variation in rooting ability between pollarded shoot and branch cuttings.

		Pollarded shoot	Branch cutting
Tree No.	No. of cuttings	% rooted	% rooted
1	10	100	80
2	10	90	60
3	10	70	60
4	10	100	70
5	10	100	80

Table 3. Rooting ability at different ages of *A. auriculiformis*, using the air-layering technique.

Tree No.	No. of branches	4 years % rooted	8 years % rooted	15 years % rooted
1	5	100	80	40
2	5	80	60	40
3	5	80	80	20
4	5	100	80	0
5	5	80	40	40

Conclusions

From these studies, vegetative propagation of *A. auriculiformis* was possible both with the air-layering technique and cuttings, provided that the tree was less than 10 years old. Epicormic shoot cuttings from pollarding would provide the best, most practical method to mass propagate *A. auriculiformis* vegetatively. Air-layering, though less practical, would also provide a suitable alternative.

Tissue Culture of *Acacia auriculiformis*

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Abstract

Tissue culture of *Acacia auriculiformis* is directly related to its improvement program. Buds from mother trees were sterilised in chlorox 5% for 45 minutes. Multiple-shoot induction was obtained through culturing on MS (1962) basal medium + 10 μM BAP and 0.5 μM IBA. Root induction, both in vitro and with microcutting methods, was carried out. Rooting media consisting of White (1963) basal medium + 2 μM IBA + 1 μM IAA or White (1963) basal medium + 1 μM IBA + 2 μM NAA were appropriate media for root induction. The microcutting method, however, still gave poor results due to difficulties in handling techniques and establishing proper environmental conditions.

ACACIA auriculiformis was introduced to Thailand over 50 years ago as an ornamental tree. It can grow well throughout Thailand even in poor soil and open forest. Although *A. auriculiformis* can grow on hot, dry sites, it is also adaptable to humid climates with an annual rainfall up to 1800 mm. *A. auriculiformis* can be used for pulp, fuelwood and construction timber. *A. auriculiformis* is also used to protect against soil erosion and in forest land rehabilitation. Therefore, this species is widely chosen to plant in watershed or water catchment areas, shifting-cultivation areas and forest plantations.

A. auriculiformis is not widely used for construction due to its crooked stem and short clear bole. However, good form trees of this species with a long, straight clear bole and light crown were found in some areas in Thailand. It was also observed that most of the good form trees produce very small amounts of seed, which might be because of their small crown and few branches. Therefore, regeneration of these good form trees is still a problem for large-scale plantation establishment. Tissue culture techniques might be a way to alleviate this problem.

Furthermore, vegetative propagation has an advantage in that genetic variation of the tree is minimal while seed propagation is subject to a high degree of variation. For these reasons, tissue culture of *A. auriculiformis* is a possible alternative regeneration method.

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Material and Methods

The micropropagation of woody species can be carried out with three approaches; enhancing axillary bud break, adventitious bud formation and somatic embryogenesis (Rao 1987).

Explants

Buds and branches were collected from selected plus trees and were used as explants which divided into three types.

Type I Bud from plus tree
Type II Bud from branch-cutting seedling and
Type III Sprouting bud from stem cutting

The buds were cut into approximately 1 cm lengths.

Sterilisation

The small pieces of bud were sterilised with chlorox 5% reagent as follows:

	Pretreatment	Time in reagent (min)
Bud Type I	1. fungicide 1% 30 min + detergent 30 min	30
	2. —	30
	3. running water 12 h	30
Bud Type II	4. detergent 15 min	45
Bud Type III	5. detergent 30 min	45
	6. —	45

Schedules 2 and 3 were subjected to an ultrasonic cleaner + shaker (15 + 15 min) during chlorox treatment. After sterilisation, all buds were rinsed 2–3 times with sterilised water.

Multiple shoot induction

The sterilised buds were cultured in medium. MS 1962 was used as basal medium (Murashige and Skoog 1962) and supplemented with 10 μM 6-benzylaminopurine (BAP) +0.5 μM indole-3-butyric acid (IBA) + 3% sucrose and 0.8% agar, pH 5.6–5.8. The buds were kept in a culture room which was 25±2°C, photoperiod 12/12 h.

Root induction

Multiple shootlets were separated and transplanted for root induction. Both in vitro and microcutting methods were employed.

In vitro root induction.

A combination of basal media, cytokinin and auxin was employed to induce root formation. The media were mixed as follows:

1. MS 1962 basal medium added with different concentrations of naphthaleneacetic acid (NAA) 0, 0.1, 1, 10 and 100 μM and BAP 0, 0.1, 1, and 10 μM.

2. MS 1962 basal medium added with BAP and indole-3-acetic acid (IAA) at the level of 0, 5, and 10 μM.

3. White (1963) macroelements mixed with MS 1962 microelements, organic compounds and iron constituted the basal medium. IBA and IAA were combined at the level of 0, 1 and 2 μM.

4. The same basal medium as No. 3 mixed with IBA and NAA 0, 1 and 2 μM.

All media were supplemented with 3% sucrose and 0.8% agar. Ten shootlets were usually cultured, except on the second medium where 5 shootlets were transplanted.

Microcutting methods

The separated shootlets were transplanted into media such as sand and vermiculite. After being sprayed with water, plastic bags were used to keep moisture in the media. There were 293 separated shootlets.

Results and Discussion

Sterilisation

Bud type I Buds and branches from the mother tree were found to be highly contaminated. The percentage of contamination in each treatment did not differ. About 95% of explants were contaminated (Table 1).

Table 1. Percentage contamination of *Acacia auriculiformis* after sterilisation.

Explant	Sterilisation method	No. of explants	Contamination (%)
Bud type I	1	352	93.31
	2	728	95.19
	3	560	96.96
Bud type II	4	116	12.93
Bud type III	5	132	100.00
	6	123	33.33

Bud type II Shaking the bud from branch-cutting in detergent for 15 min and sterilising in chlorox 5% for 45 min was the appropriate method to sterilise the explants. Only 12.9% of explants were contaminated.

Bud type III The sprouting buds from stem cutting sterilised in chlorox 5% at 45 min showed lower contamination than pretreating the explants with detergent. About 33% of sterilised buds with no pretreatment explants were contaminated, while all of sterilised buds with pretreatment explants were contaminated.

Buds from branch-cuttings and sprouting buds from stem cuttings were in the best condition for micropropagation. However, the sprouting buds from stem cuttings were useful in the case of collecting explants from field trials.

Multiple shoot induction

The explants culturing in MS (1962) +10 μM BAP +0.5 μM IBA +3% sucrose and 0.8% agar could produce multiple shootlets in 3–5 months.

Buds from branch cutting (bud type II) cultured in this media could produce shootlets around 98 days after culture initiation. Approximately 63% of explants produced axillary buds. A range of 1–3 shoots were obtained from each explant. The average of multiple shoots was 1.57 shoots/explant (Table 2).

Subculturing was also undertaken. It was found that 74% of separated shootlets produced multiple shootlets 3 months after subculturing. Each shootlet produced 1–10 shoots with a final average of 2.6 shoots per plant.

Table 2. Percentage of multiple-shoot inductions, number of shootlets and average of shootlets per explant after culturing on MS (1962) + 10 μM BAP + 0.5 μM IBA after 3-5 months.

Explant	Sub culture	Period (month)	Multiple-shoot (%)	No. of shootlets	Av. no. of shootlets per explant
Bud type II	1	3	63.2	1–3	1.57
	2	3	73.9	1–10	2.59
Bud type III	1	5	76.8	1–4	1.73
	2	3	81.1	1–7	2.34

Sprouting buds from stem cuttings (bud type III) were slow to develop. Due to weak condition and small size, the explants took 5 months after culture initiation to recover and sprout new buds. The first culture showed that approximately 77% of explants produced multiple shoots with 1–4 shootlets. The average number of multiple shoots was 1.7 per explant.

Results from sub-culturing showed that 81% of shoots formed multiple shoots with a range of 1–7 shootlets/shoot. It was also observed that a shorter period of time was taken for subculturing. Approximately 3 months was needed for subcultured shoots to produce shootlets, with the average 2.3 multiple shoots per shootlet.

Lim and Gavinlertvatana (1989) reported that modified media and types of explants affected bud break and shoot growth. The explants had the maximum bud break (75%) in media with 2.25 mg/l (10 μM) BAP, 0.1 mg/l (0.5 μM) IBA and 80 mg/l adenine sulphate. For explants, presence or absence of a subtending leaf also had an effect on shoot growth. In the absence of a subtending leaf, the multiplication rate was higher. For terminal buds with leaf attached, roots formed quite well.

In vitro root induction

Combinations of cytokinin and auxin were less effective in inducing root than using auxin alone. Media containing NAA alone with concentration of 0.1–1 μM could induce root formation (Table 3). However, the medium containing BAP 1 μM and NAA 1 μM could also induce 40% of separated shootlets to produce roots.

Combinations of BAP and IAA were less effective. Only 10% of shootlets cultured on MS + 5 μM BAP and IAA 0 or 10 μM could produce roots.

Combination of auxins had a definite effect on root induction. White (1963) basal medium consisting of 2 μM IBA with 0 or 1 μM IAA were the best media for rooting (Table 4). However, the root system obtained from media supplemented with 2 μM IBA and 1 μM IAA was the best for producing a strong, healthy root system.

Table 3. Percentage of *A. auriculiformis* rooting 3 months after culturing on MS (1962) + 0–10 μM BAP + 0–100 μM NAA.

BAP (μM)	NAA (μM) 0	0.1	1.0	10	100
0.0	10	40	40	30	—
0.1	20	—	30	30	—
1.0	10	10	40	—	—
10.0	—	—	—	—	—

Table 4. Percentage of *A. auriculiformis* rooting 1 month after culturing on White (1963) with IBA and IAA 0–2 μM.

IBA (μM)	IAA (μM) 0	1	2
0	100	40	90
1	80	80	60
2	90	80	100

Combinations of IBA and NAA also affected root system development. The shootlet culturing on White (1963) basal media + 1 μM IBA + 1–2 μM NAA could produce roots better than on other culturing media (Table 5). NAA especially at the level of 2 μM gave a strong, healthy root system.

Table 5. Percentage of *A. auriculiformis* rooting 1 month after culturing on White (1963) with IBA and NAA 0–2 μM.

IBA (μM)	NAA (μM) 0	1	2
0	50	90	50
1	90	100	80
2	100	70	100

Microcutting

A number of shootlets were transplanted to plastic boxes filled with fine sand or vermiculite and kept in high moisture conditions. It was found that only 38% of shootlets produced roots after 90 days.

Conclusions

Tissue culture of *A. auriculiformis* was undertaken to increase the availability of trees with good stem form for timber. Buds from branch-cuttings or sprouting buds taken from stem cuttings were used as explants. Chlorox 5% for 45 min was the best treatment for sterilisation. After that, the explants were cultured on MS (1962) basal media + 10 μM BAP and 0.5 μM IBA to induce and multiply shoots. Both in vitro rooting and microcutting were carried out. The media consisting of White (1963) + 2 μM IBA + 1 μM IAA or White (1963) + 1 μM IBA + 2 μM NAA were highly effective for root induction. However, the microcutting method proved unsatisfactory and environmental conditions were thought to be the major cause of low rooting percentage.

Lim and Gavinlertvatana (1989) were able to induce rooting in vitro. They found that rooting was increased with the addition of auxins (IAA and NAA). The number of rooted plants and quality of roots depended on the combination of IAA and NAA. The optimum concentration was 2.0 mg/l (11.42 μM) IAA and 1.5 mg/l (8.06 μM) NAA which could produce 70% rooted shoots.

References

Lim, T.W. and Gavinlertvatana, P. 1989. In vitro propagation of mature *Acacia auriculiformis* A. Cunn. ex. Benth and *Acacia mangium* Willd. Presented at the Seminar on Winrock Project, Singapore, 17–18 August 1989. 9 p.

Murashige, T. and Skoog, F. 1962. A revised medium for rapid growth and bioassays with tobacco tissue cultures. Physiologia Plantarum, 15, 473–497.

Rao, A.N. 1987. Multipurpose tree species and their propagation by in vitro method. In: Rao, A.N. and Aziah Modh. Yusoff, ed., Proceedings of the Seminar on Tissue Culture of Forest Species. FRIM and IDRC. 93–103.

White, P.R. 1963. The Cultivation of Plant and Animal Cells. The Ronal Press Co. New York.

Coppicing Ability of Some Australian Tree Species in Thailand

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Abstract

The coppicing ability of some Australian tree species in Thailand was investigated between August 1989 and July 1990. It was carried out in a 1985 species trial at Chantaburi province. Block number 1 was assigned as the control plot. Blocks number 2 and 3 were cut at a height of 1 m above ground level. Sample sizes of each seedlot were between 26 and 50 samples. The result showed that most of the Australian and local tree species could coppice well in the first month after cutting but *Acacia aulacocarpa* (13866) produced maximum average number of bud clusters the second month after cutting. However, *A. auriculiformis* (local 6) had the best coppicing capability compared with other seedlots of the species from Australia.

MANY Australian tree species have played an important role in reforestation programs in developing countries in Asia, Africa and South America for over 100 years. Demand for Australian tree species has been increasing because Australia has a wide range of tree species distributed naturally from cold temperate to hot tropical climatic conditions. Australian tree species are also unique and well adapted to nutrient-deficient sites and seasonally dry condition in the tropics. The CSIRO Australian Tree Seed Centre in Canberra has a world-wide reputation for providing samples of authentic seed and supply of information on species and provenance details. Often the results of trials established with this seed are not published so it is difficult to obtain accurate information on the performance of Australian tree species overseas.

Fortunately, many Australian tree species from various seedlots have been tested in field trials since 1985 at several sites in five countries (China, Kenya, Thailand, Zimbabwe and Australia) under collaboration with the ACIAR Forestry Program. These experiments were systematically planned and covered a wide range of climates and soil types.

The field trials in Thailand have been assessed for growth and survival (Boland and Pinyopusarerk 1987; Puriyakorn et al. 1988; Chittachumnonk 1988; Pinyopusarerk 1989) and an above-ground biomass of selected promising species (Chittachumnonk 1988).

As mentioned earlier, there are many ACIAR field trials in several countries. It would be beneficial to the project to study coppicing in all countries. To begin these studies the trials in Thailand were selected for intensive investigation.

The aim of this paper is to present data on coppicing ability for Australian tree species and local tree species established in the 1985 field trials in Thailand. While substantial information exists on the coppicing capacity of eucalypts, little information is available for the lesser-known Australian species being tested in the CSIRO/RFD trial. If these species are found to coppice it should not be assumed that the benefits of managing them under a coppice system will be the same as for eucalypts. In order to determine their potential for management under a coppice system, information was needed on the dormant and adventitious bud characteristics of different species and the seasonal variation of coppicing abilities.

Materials and Methods

Location

Khao Soi Dao Seed Orchard is located at Pong Nam Ron district, Chantaburi province, Thailand. The area is 200 m above mean sea level. The soils are grey

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podzolics with a sandy loam or sandy clay loam texture and pH 6.5. Total average annual rainfall is 1300 mm.

Selection of sample trees

The coppicing ability of the Australian and local tree species trial at Chantaburi province was investigated between August 1989 and July 1990. It was carried out in a 1985 CSIRO/RFD trial plot. The trial design was randomised complete blocks with three replicates. Each plot with a block contained 25 trees at 2 × 2 m spacing. The trees in two replicate blocks were cut at 1 m above ground level and all side branches removed. The third block was untreated and designated a control. Sample sizes of each seedlot were between 26 and 50 trees. If the tree had several stems of approximately the same size arising from below 1 m all were cut at 1 m. Monthly observation of coppicing ability was recorded for one year from the time of bud appearance. The number of bud clusters and the distance of each bud cluster from ground level were recorded.

Results

Timing of coppicing ability

The study showed that the coppicing of 19 Australian tree species produced the maximum average number of bud clusters the first month after cutting. *Acacia aulacocarpa* (13866), however, coppiced the second month after cutting. Generally, the average number of bud clusters was three times more in the first month than in the second (Table 1). There was a tendency for the average number of bud clusters to decrease with time after cutting.

In the acacia group, in the first month after cutting *Acacia polystachya* (13871) had the best sprouting capabilities, while *A. holosericea* (14660) had the poorest. In the eucalypt group, *Eucalyptus pellita* (12013) produced a maximum average number of bud clusters which slightly differed from the other three *Eucalyptus* spp. For casuarinas, *Casuarina cunninghamiana* (13514) had greater coppicing capability than provenances 13148 and 13519 (Table 1).

Table 1. Average number of bud clusters of 20 Australian tree species and four local tree species each month after cutting.

			Month after cutting				
Lot	Species	Species No.	Aug. 89	Sep. 89	Oct. 89	Nov. 89	Dec. 89
13653	*Acacia leptocarpa*	A1	23.2	3.3	0.1	—	—
13680	*A. crassicarpa*	A2	15.7	2.8	0.1	0.1	—
13683	*A. crassicarpa*	A3	11.8	2.6	0.4	—	—
13684	*A. auriculiformis*	A4	7.5	4.0	1.4	0.2	—
13688	*A. aulacocarpa*	A5	6.0	1.8	0.2	—	—
13689	*A. aulacocarpa*	A6	12.3	1.5	—	—	—
13691	*A. leptocarpa*	A7	31.3	0.9	0.3	—	—
13846	*A. mangium*	A8	15.7	5.2	2.1	—	—
13854	*A. auriculiformis*	A9	33.2	4.7	2.3	0.7	0.4
13861	*A. auriculiformis*	A10	24.0	3.4	0.6	0.3	—
13866	*A. aulacocarpa*	A11	7.8	23.0	2.9	1.0	0.4
13871	*A. polystachya*	A12	59.5	7.5	1.4	0.7	0.2
14660	*A. holosericea*	A13	0.03	—	—	—	—
13148	*Casuarina cunninghamiana*	C1	79.2	29.0	1.9	0.5	—
13514	*C. cunninghamiana*	C2	97.3	19.4	3.3	4.1	0.7
13519	*C. cunninghamiana*	C3	40.8	36.6	8.4	5.6	1.0
12013	*Eucalyptus pellita*	E1	22.4	1.6	0.1	—	—
14106	*E. camaldulensis*	E2	13.3	1.0	0.0	—	—
14130	*E. torelliana*	E3	15.5	5.8	1.4	0.3	0.3
14537	*E. camaldulensis*	E4	18.7	1.3	0.0	—	0.2
local2	*Melia azedarach*	L1	18.9	0.7	—	—	—
local3	*Peltophorum dasyrachis*	L2	37.9	0.6	0.1	0.1	0.2
local5	*Cassia siamea*	L3	37.1	3.2	0.4	0.4	0.2
local6	*Acacia auriculiformis*	L4	37.5	4.6	1.1	0.1	0.1

Remark : — : No bud cluster

On the other hand, all four local tree species especially *Peltophorum dasyrachis, Cassia siamea* and *A. auriculiformis* sprouted well in the first month after cutting similar to Australian tree species (Table 1).

Level on stump vs coppicing ability

The study showed that *Acacia, Casuarina* and *Eucalyptus* species could coppice at every level on the stump in the trial, except *A. holosericea* (14660) (Table 2). The tendency was for coppicing abilities of all Australian tree species to decrease with decreasing stump height level until at the base of stump it produced only a few bud clusters (Fig. 1). Average number of bud clusters in the acacias was found to be the highest in 90–100 cm above ground level. Casuarinas and eucalypts produced maximum bud clusters at a height of 80–90 cm on the stump (Table 2).

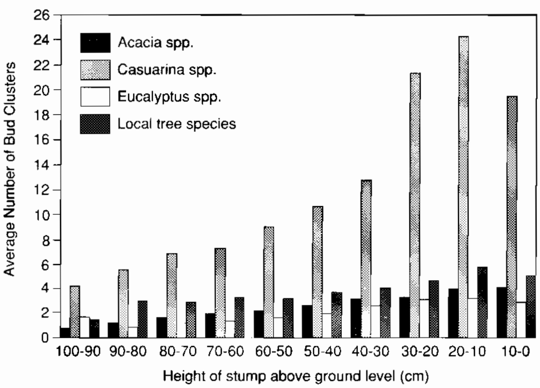

Fig. 1. Average number of bud clusters on each level of stump height of 20 Australian tree species and 4 local tree species.

Eleven Australian tree species could sprout well at stump height of 80–90 cm above ground level, 5 species at 90–100 cm above ground level and 2 species at 70–80 cm above ground level. However, *A. mangium* could shoot well at stump height of 40-50 cm above ground level (Table 2).

Furthermore, the study showed that *A. polystachya* (13871) produced the highest sprout (71.9 bud clusters/stump) in the acacia group. Other species that produced bud clusters in decreasing order were *A. auriculiformis* (13854), *A. aulacocarpa* (13866), *A. leptocarpa* (13691) and *A. auriculiformis* (13861) respectively. *A. holosericea* had the lowest coppicing ability in 70–80 cm above ground level by producing only 0.03 bud clusters/stump (Fig. 2). For eucalypts, *E. pellita* (12013) coppiced very well, producing 23.9 bud clusters/stump which was similar to *E. torelliana* (23.3 bud clusters/stump). Furthermore *E. camaldulensis* (14537) could sprout better than *E. camaldulensis* (14106).

In the casuarinas, *Casuarina cunninghamiana* (13514) had the best average number of bud clusters by producing 139.0 bud clusters/stump. Average number of bud clusters of *C. cunninghamiana* (13148) and *C. cunninghamiana* (13519) were 125.6 and 103.0 bud clusters/stump respectively (Fig. 2).

The maximum average number of bud clusters in the four local tree species was found 80–90 cm above ground level. Their coppicing abilities tended to decrease with decreasing stump height down to the base of stump. There was only one species, *Peltophorum dasyrachis*, which could sprout well at 10–20 cm stump height.

The maximum average number of bud clusters of *Cassia siamea, Acacia auriculiformis* and *Melia azedarach* were in 90–100, 80–90 and 70–80 cm stump height level, respectively (Table 2).

Moreover, the study showed that local *A. auriculiformis* had the highest coppicing ability in this species but there was no significant difference between the average number of bud clusters of *Peltophorum dasyrachis, Cassia siamea* and *A. auriculiformis* (13854) (Fig. 2).

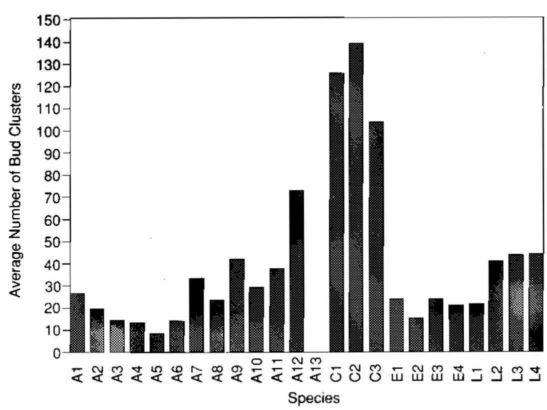

Fig. 2. Average number of bud clusters/stump of each Australian and local tree species (species numbers correspond to lists in Tables 1 and 2).

Coppicing abilities compared

The highest average number of bud clusters per stump was 123.0 in casuarina, which was considered

Table 2. Average number of bud clusters of 20 Australian tree species and four local tree species at each level on the stump above ground.

Lot	Species	Species No.	Stump height above ground level (cm) 100–90	90–80	80–70	70–60	60–50	50–40	40–30	30–20	20–10	10–0
13653	*Acacia leptocarpa*	A1	2.7	3.5	4.1	4.3	3.5	2.6	2.2	1.4	1.1	1.2
13680	*A. crassicarpa*	A2	2.9	3.8	3.0	2.6	2.1	1.7	1.2	1.0	0.6	0.1
13683	*A. crassicarpa*	A3	3.5	2.6	1.9	2.0	1.6	1.1	1.0	0.6	0.2	0.0
13684	*A. auriculiformis*	A4	1.7	3.0	2.0	2.1	1.4	0.9	0.9	0.6	0.2	0.1
13688	*A. aulacocarpa*	A5	1.1	1.4	1.2	1.3	1.4	0.7	0.4	0.3	0.1	0.1
13689	*A. aulacocarpa*	A6	2.0	2.6	2.2	2.1	1.9	1.4	1.0	0.4	0.2	0.0
13691	*A. leptocarpa*	A7	3.6	5.5	5.6	5.5	3.3	3.1	2.4	1.5	1.3	0.7
13846	*A. mangium*	A8	2.2	2.6	2.2	2.9	2.7	3.0	2.4	2.8	1.8	0.4
13854	*A. auriculiformis*	A9	6.4	5.2	5.1	5.1	4.5	3.8	4.1	3.7	2.7	0.7
13861	*A. auriculiformis*	A10	5.5	4.5	4.1	3.1	2.9	2.7	2.5	2.2	0.9	0.1
13866	*A. aulacocarpa*	A11	12.7	6.7	4.0	3.1	3.0	1.8	1.9	1.4	0.9	0.9
13871	*A. polystachya*	A12	9.6	10.9	9.5	7.9	6.9	5.6	5.9	5.1	5.8	4.7
14660	*A. holosericea*	A13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13148	*Casuarina cunninghamiana*	C1	14.8	31.4	14.7	11.3	11.5	11.3	10.9	9.0	6.0	4.7
13514	*C. cunninghamiana*	C2	24.7	21.1	34.1	14.6	11.0	8.4	6.4	7.2	6.4	5.1
13519	*C. cunninghamiana*	C3	19.3	20.9	16.0	12.8	9.9	8.0	4.7	4.5	4.1	2.9
12013	*Eucalyptus pellita*	E1	2.7	3.0	3.0	2.7	2.6	2.4	1.8	1.6	1.1	3.1
14106	*E. camaldulensis*	E2	2.7	2.9	2.6	2.2	1.2	0.7	0.6	0.6	0.3	1.1
14130	*E. torelliana*	E3	3.6	4.0	3.8	3.0	2.3	1.8	1.5	1.0	1.1	1.2
14537	*E. camaldulensis*	E4	2.7	3.1	3.1	2.8	2.1	1.9	1.4	1.3	0.7	1.3
local2	*Melia azedarach*	L1	2.2	3.3	3.4	2.8	2.3	1.7	1.6	1.5	1.5	1.0
local3	*Peltophorum dasyrachis*	L2	4.0	4.2	3.3	3.4	3.3	3.9	4.3	4.1	6.5	3.2
local5	*Cassia siamea*	L3	8.2	8.9	6.1	4.9	4.5	3.3	3.1	1.9	1.4	0.6
local6	*Acacia auriculiformis*	L4	5.7	6.8	5.8	5.0	5.1	4.1	3.9	3.7	2.6	0.8

the maximum coppicing ability. The following groups in descending order were the local tree species, acacias and eucalypts, with average numbers of 37.0, 25.3 and 20.6 bud clusters/stump respectively.

Performance of four seedlots of *A. auriculiformis*

A. auriculiformis produced the maximum average number of bud clusters the first month after cutting. Seedlot number 6 (local) could sprout well at 80–90 cm stump height (Table 2), and there were 43.7 bud clusters/stump (Fig. 2). *A. auriculiformis* (13854 and 13861) produced average numbers of 41.2 and 28.6 bud clusters/stump respectively. *A. auriculiformis* (13684) showed the lowest coppicing ability by producing 13.1 bud clusters/stump (Fig. 2).

Conclusions

Most of the Australian and local tree species could coppice well in the first month after cutting but *Acacia aulacocarpa* (13866) produced maximum average number of bud clusters the second month after cutting. The tendency was for the average number of bud clusters to decrease with increasing time after cutting.

All Australian and local tree species tested could sprout at every level (from 0 to 100 cm above ground level). The tendency was for average numbers of bud clusters to decrease towards the base of the stump.

Acacia polystachya (13871) produced the highest number of sprouts in the acacias, while *Eucalyptus pellita* (12013) could coppice best of all the eucalypts. *Casuarina cunninghamiana* and *A. auriculiformis* (local 6) produced the maximum average number of bud clusters/stump. Besides, *A. auriculiformis* (local 6) had the best coppicing capability when compared to other seed lots of *A. auriculiformis* from natural stands.

References

Boland, D.J. and Pinyopusarerk, K. 1987. Early growth of some Eucalyptus and other Australian tree species at Tung Kula Ronghai Development Project in northeast Thailand. Thai Journal of Forestry, 6, 3, 250–267.

Chittachumnonk, P. 1988. Progress report for ACIAR Project No. 8320: Australian Hardwoods for Fuelwood and Agroforestry in the Kingdom of Thailand. Division of Silviculture, Royal Forest Department. 20 p.

Pinyopusarerk, K. 1989. Growth and survival of Australian tree species in field trials in Thailand. In: Boland, D.J., ed., Trees for the Tropics. ACIAR Monograph No. 10. Canberra, Australia, 109–127.

Puriyakorn, B., Pinyopusarerk, K. and Luangviriyasaeng, V. 1988. Assessment of early growth of Australian tree species trials in Thailand. Paper presented to the fourth seminar on silviculture, Pattaya, Thailand. 16 p.

Standing Above-ground Yields of Some Tropical Acacias

S. Kiratiprayoon* and E.R. Williams**

Abstract

Above-ground yield was estimated on nine 5-year-old *Acacia* seedlots from an ACIAR species trial in Nakorn Ratchasima Province, Thailand. Estimating equations for each seedlot for stem, branch, leaf and firewood biomass were developed. The equations were used to estimate standing biomass components for the plots in each of the three replicates of the ACIAR trial. Analyses of variance were performed on the estimated plot biomass components.

Most of the nine seedlots studied had a high survival rate and a good rate of growth. The two most prominent seedlots were *Acacia auriculiformis* (seedlot No. 13684) and *Acacia crassicarpa* (seedlot No. 13683), with stem, branch, leaf and firewood production of 82.6, 34.2, 10.4 and 111.1 t/ha and 84.4, 15.3, 7.0 and 87.9 t/ha respectively.

A COMMON method for estimating standing biomass is to sample a number of trees, weigh the components and then derive regression relationships between the components and diameter at breast height (dbh) or a combination of dbh and total height (ht), e.g. $dbh^2.ht$. These regression equations can then be applied to the standing trees to provide estimates of biomass components on a mean tree or plot basis (see Bunyavejchewin and Kiratiprayoon 1989).

This paper reports on a biomass study of 5-year-old *Acacia* seedlots from an ACIAR species trial at Sakaerat in Nakorn Ratchasima Province, Thailand, planted in 1985. The experiment has 34 seedlots in three randomised complete blocks of 25 tree plots with 2 m spacing. Further details of the site and experiment are contained in the ACIAR publication *Trees for the Tropics* (Boland 1989). Nine of the most productive *Acacia* seedlots were chosen for biomass sampling and these are listed in Table 1.

Methods

Diameter at breast height (dbh) and total height of all trees were measured in the three replicates of eight of the selected seedlots. However, only two replicates were available for measuring *Acacia mangium*. Frequency distributions of five dbh classes for each seedlot were established. Ten to 12 trees of each seedlot were selected proportionally according to the frequency in each dbh class and covered the range of dbh values. All of the sample trees were felled and divided into stem, branch, leaf and firewood (woody component 2 cm in diameter and above). After the components were weighed, fresh samples were taken to the laboratory for drying to convert the sample tree fresh weights into dry weights (biomass).

Individual equations estimating biomass for each component and each seedlot were constructed using regression analysis techniques to fit the power model: $y = a.x^b$, where y = individual stem, live branch, leaf and firewood biomass (kg) and x = dbh (cm) or $dbh^2.ht$ ($cm^2.m$). The power equation was transformed to $\log(y) = \log(a) + b \log(x)$, where

Table 1. Species and origins of seedlots.

Seedlot Number	Species	Origin
13689	*A. aulacocarpa*	Oriomo River PNG
13684	*A. auriculiformis*	Balamuk PNG
13854	*A. auriculiformis*	Oenpelli Area NT
13861	*A. auriculiformis*	Springvale Hld QLD
13683	*A. crassicarpa*	Woroi Wipim PNG
13863	*A. crassicarpa*	Shoteel L.A. QLD
13653	*A. leptocarpa*	Starcke Holding QLD
14660	*A. holosericea*	Turkey Creek WA
13846	*A. mangium*	7 km SSE of Mossman QLD

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log is the base 10 logarithm; parameters were estimated using the statistical package GENSTAT 5. The seedlots were analysed to test if a model with a common slope was appropriate. Component biomass (kg/tree) for each seedlot was calculated from the best fit equations and converted to component production (t/ha). Biomass estimates were corrected for bias induced by the logarithmic transformation using a ratio method as recommended by Snowdon (1991).

Results and Discussion

Individual biomass estimating equations

Transformed linear regressions for each component of the nine seedlots showed high coefficients of determination (r^2) for both independent variates, dbh and $dbh^2.ht$ (Table 2). In most cases the regressions using dbh had a higher r^2 value than those using $dbh^2.ht$. For all components the model using a common slope for all seedlots was found to be inadequate; this was

Table 2. Estimated parameters and coefficients of determination of equations of the form log(y) = log(a) + b log(x) for estimating individual biomass.

	x variate					
	dbh			$dbh^2.ht$		
Seedlot Number	log(a)	b	r^2	log(a)	b	r^2
STEM						
13689	−0.9416	2.3410	0.990	−1.2232	0.8530	0.996
13684	−0.7168	2.1060	0.981	−1.4021	0.9067	0.986
13854	−0.4704	1.7686	0.891	−1.0037	0.7549	0.898
13861	−0.9585	2.3310	0.951	−1.4522	0.9158	0.968
13683	−1.1901	2.5225	0.988	−1.7375	0.9966	0.995
13863	−1.0718	2.4437	0.984	−1.5770	0.9623	0.989
13653	−0.5962	1.9665	0.995	−0.9996	0.7829	0.995
14660	−0.8620	2.3146	0.984	−1.2300	0.8647	0.996
13846	−0.0545	2.2786	0.994	−1.4751	0.9036	0.994
BRANCH						
13689	−1.4883	2.0683	0.891	−1.7160	0.7463	0.880
13684	−2.7849	3.5735	0.961	−3.8884	1.5205	0.943
13854	−2.5293	3.5839	0.929	−3.5077	1.4957	0.896
13861	−2.2613	2.9180	0.776	−2.8119	1.1234	0.759
13683	−2.6692	3.1038	0.945	−3.2820	0.9113	0.923
13863	−2.3170	3.0541	0.916	−2.8931	1.1832	0.891
13653	−1.6507	2.5035	0.947	−2.1307	0.9840	0.923
14660	−1.7937	2.8813	0.879	−2.1846	1.0477	0.843
13846	−2.0783	2.8450	0.966	−2.5385	1.1057	0.927
LEAF						
13689	−1.4611	1.8421	0.946	−1.6654	0.6653	0.935
13684	−2.4689	2.8259	0.930	−3.3312	1.1993	0.908
13854	−2.5451	2.7754	0.921	−3.3404	1.1708	0.908
13861	−2.1715	2.2916	0.843	−2.6209	0.8880	0.835
13683	−2.0900	2.3320	0.961	−2.5636	0.9113	0.947
13863	−2.1785	2.5229	0.853	−2.6035	0.9596	0.800
13653	−1.3847	1.8342	0.941	−1.7308	0.7188	0.912
14660	−1.2918	1.6470	0.729	−1.4793	0.5821	0.668
13846	−2.0395	2.4014	0.962	−2.4769	0.9503	0.958
FIREWOOD						
13689	−1.6447	3.0148	0.978	−2.0225	1.1125	0.991
13684	−0.9893	2.4415	0.994	−1.7724	1.0477	0.992
13854	−0.8870	2.3389	0.961	−1.5644	0.9891	0.951
13861	−0.8870	2.3389	0.943	−1.6454	0.9937	0.961
13683	−1.2717	2.6174	0.991	−1.8346	1.0325	0.995
13863	−1.2095	2.6283	0.978	−1.7517	1.0345	0.982
13653	−0.7752	2.2083	0.989	−1.4547	0.9562	0.992
14660	−1.0097	2.5719	0.992	−1.4079	0.9562	0.995
13846	−1.2214	2.5043	0.995	−1.6729	0.9894	0.987

still the case when the seedlots were grouped according to species. The significant differences in slope between the seedlots were due to possible variation in wood density, stem form or growth characteristics.

Growth and above-ground yield

Survival rate and average dbh and ht are given in Table 3. These results are combined over all the trees in the three replicates for eight of the acacia seedlots under study; for *A. mangium* growth data were available from two replicates only. All three seedlots of *A. auriculiformis* had 100% survival with average dbh and ht being 9.7–11.5 cm and 10.84–11.64 m respectively. The other species also had high survival rates (81–95%). The fastest growing species was *A. crassicarpa* (seedlot No. 13683) with average dbh and ht of 12.3 cm and 12.71 m respectively; *A. holosericea* had the poorest growth.

Table 3. Survival rate, average dbh and ht of each seedlot.

Seedlot number	Species	Survival rate (%)	Dbh (cm)	Ht (m)
13689	*A. aulacocarpa*	81.33	10.2	11.19
13684	*A. auriculiformis*	100.00	11.5	11.64
13854	*A. auriculiformis*	100.00	9.8	10.84
13861	*A. auriculiformis*	100.00	9.7	11.85
13683	*A. crassicarpa*	85.33	12.3	12.71
13863	*A. crassicarpa*	84.00	8.3	10.06
13653	*A. leptocarpa*	89.33	8.2	9.20
14660	*A. holosericea*	82.67	5.9	8.45
13846	*A. mangium*	88.00	8.7	9.38

Individual biomass components were calculated for each tree and then the results were averaged over each plot. Analysis of variance of the plot means showed that for each component the differences between replicates were non-significant, but seedlot differences were highly significant ($P<0.001$). The estimated seedlot means for each biomass component are presented in Table 4, with least significant differences (LSD) values at the 5% probability level. The above-ground production of each component is obtained by multiplying the mean tree components in Table 4 by the survival percentage (Table 3) and dividing by 40 to scale to tonnes per hectare. Results are presented in Table 5.

The two most prominent seedlots were *A. auriculiformis* (seedlot No. 13684) and *A. crassicarpa* (seedlot No. 13683); the stem, branch, leaf and firewood yield for these two seedlots was 82.6, 34.2, 10.4 and 111.1 t/ha and 84.4, 15.3, 7.0 and 87.9 t/ha respectively. In terms of branching characteristics and firewood production, *A. auriculiformis* (seedlot No. 13684) has potential for firewood plantations. In addition, its large amount of leaf production is important for soil improvement. This aspect could have been studied in more detail if annual foliar litter yields had been recorded up to five years of age. We can apply this seedlot in agroforestry systems by using a wide spacing between trees to allow for the large and dense crown. *A. crassicarpa* (seedlot No. 13683), showing high stem production and light crown, is reasonable to use in agroforestry systems. The big stem can be used as timber for household construction, the rest of the stem and branches are suitable for firewood. Moreover, since acacias are nitrogen-fixing species, they are beneficial for soil improvement.

Table 4. Average individual biomass (kg/tree) of each seedlot.

Seedlot Number	Species	Individual biomass (kg/tree)			
		Stem	Branch	Leaf	Firewood
13689	*A. aulacocarpa*	25.89	4.83	2.77	25.18
13684	*A. auriculiformis*	33.03	13.69	4.16	44.42
13854	*A. auriculiformis*	20.13	15.96	2.07	30.21
13861	*A. auriculiformis*	22.48	5.73	1.39	25.27
13683	*A. crassicarpa*	38.63	7.15	3.26	41.20
13863	*A. crassicarpa*	17.22	4.15	1.70	18.02
13653	*A. leptocarpa*	18.34	6.92	2.63	20.43
14660	*A. holosericea*	7.68	3.74	1.09	7.48
13846	*A. mangium*	13.86	5.12	1.93	15.76
	Lsd (0.05)	12.4	6.7	1.5	16.5

Table 5. Yield (t/ha) of each component for each seedlot.

Seedlot Number	Species	Dry matter production (t/ha)			
		Stem	Branch	Leaf	Firewood
13689	*A. aulacocarpa*	52.6	9.8	5.6	51.2
13684	*A. auriculiformis*	82.6	34.2	10.4	111.1
13854	*A. auriculiformis*	50.3	39.9	5.2	75.5
13861	*A. auriculiformis*	56.2	14.3	3.5	63.2
13683	*A. crassicarpa*	84.4	15.3	7.0	87.9
13863	*A. crassicarpa*	36.2	8.7	3.6	37.8
13653	*A. leptocarpa*	41.0	15.5	5.9	45.6
14660	*A. holosericea*	15.9	7.7	2.3	15.5
13846	*A. mangium*	30.5	11.3	4.2	34.7

References

Boland, D.J. 1989. Trees for the Tropics: Growing Australian multipurpose trees and shrubs in developing countries. ACIAR Monograph No. 10.

Bunyavejchewin, S. and Kiratiprayoon, S. 1989. Primary production of plots of five young close-spaced fast-growing tree species, I. Biomass equations. Nat. Hist. Bull. Siam. Soc., 37, 47–56.

Snowdon, P. 1991. A ratio estimator for bias correction in logarithmic regressions. Can. J. Forestry (in press).

Identifying Climatic Areas in China Suitable for *Acacia mearnsii* and *A. mangium*

T.H. Booth* and Yan Hong**

Abstract

Previous work to develop descriptions of the climatic requirements of *Acacia mearnsii* and *Acacia mangium* is summarised. New descriptions of requirements are presented and suitable areas in China are mapped. The potential for future work including soil information and simple simulation models is briefly outlined.

COMPUTERS have greatly improved our capability to analyse species' climatic requirements. For example, Booth and Jovanovic (1988) used the BIOCLIM package (Nix 1986) to determine climatic conditions at 287 locations where *Acacia mearnsii* De Wild. grows naturally. They also gathered climatic data from 59 locations where *A. mearnsii* has been grown successfully in plantations outside Australia. These data were used to suggest locations in China which would be climatically suitable for growing the species (Booth 1988). The potential of cooler sites was examined in more detail in a later paper (Booth 1991a). Pan and Yang (1987) had suggested that *A. mearnsii* was only suitable for locations in China where the absolute (i.e. record) minimum temperature was above −5 °C. So, Booth (1991a) produced maps showing locations with generally suitable climates, as well as indicating where frosts might be a problem.

The climatic requirements of *Acacia mangium* Willd. were described by Webb et al. (1984). However, a computer program which can evaluate climatic conditions at 608 locations in southern Asia quickly showed errors in this description (Booth 1991b). An improved description of climatic requirements was produced based on a review of published information from trials (see Fig. 1).

Maps such as Fig. 1 show conditions at actual meteorological stations. A much better idea of climatically suitable areas can be obtained using interpolation relationships. For example, Yan Hong (1989) has described a mapping program for identifying regions in China climatically suitable for particular species. The program evaluates four climatic factors (mean annual temperature, minimum temperature of the coldest month, maximum temperature of the hottest month and mean annual precipitation) at 3911 locations in a regular half-degree grid across China. Each location is placed in one of five classes indicating climatic suitability, and a colour map is produced indicating the most suitable areas. The program was first demonstrated using another Australian species, *Acacia dealbata* Link.

Current Work

In this paper we examine more information on the climatic suitability of *A. mearnsii* and *A. mangium* and use the program described by Yan Hong (1989) to indicate suitable areas in China. For example, a recent Chinese publication (Anon. 1989) has summarised conditions said to be suitable for *A. mearnsii* as follows:

	Suitable	Most Suitable
Mean annual temperature	15–23 °C	16–21 °C
Warmth Index	120–220	125–202
Cold Index	0	0
Koeppen Index	12–28	16–24

The warmth index was calculated as the sum of monthly mean temperatures above 5 °C. The cold index was calculated as the sum of monthly mean

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temperatures below 5 °C. The Koeppen index was calculated as follows:

$$KI = P/(2(T+14))$$

where P is annual mean precipitation and T is annual mean temperature.

Since publication the program described by Yan Hong (1989) has had eight climatic factors added, including the warmth, cold and Koeppen indices used in the above description. So, the program was run to indicate suitable areas for *A. mearnsii* using the description of requirements given above (see Fig. 2). No sample location in Fig. 2 is shown in the most suitable class, because the cold index was given as a single figure not a range. A location would have had to have a cold index of exactly zero, as well as satisfying the other requirements, to be rated as class 1. The most suitable areas that are shown in Fig. 2 (i.e. class 2 locations) include many locations where the absolute minimum temperature falls below −5 °C and therefore frost damage would be a problem (see Booth 1991a for map showing locations with absolute minimum temperatures below −5 °C).

An alternative map (Fig. 3) showing areas suitable for *A. mearnsii* was produced using the following description of requirements:

Mean annual precipitation	700–2300 mm
Mean annual temperature	14–22 °C
Min. temp. coldest month	0–17 °C
Max. temp. hottest month	21–35 °C
Absolute min. temperature	> −5 °C

This description was based on the previous analysis of successful trial sites and recent results from ACIAR trials in China (see Booth 1988 for map showing location of ACIAR *A. mearnsii* trials). The

Dark-shaded locations satisfy following requirements:

· 1. Mean annual rainfall : 1000 - 4000 mm
· 2. Rainfall regime : 3 1 0
1= uniform/biomodal, 2 = winter, 3 = summer
· 3. Dry season : 0.0 - 5.0 mm
· 4. Mn max. hot month : 30.0 - 40.0°C
· 5. Mn min. cold month : 13.0 - 24.0°C
· 6. Mn annual temp. : 18.0 - 28.0°C
· indicates selected factor(s)

Fig. 1. Dark-shaded locations satisfy description of climatic requirements for *A. mangium* shown below map.

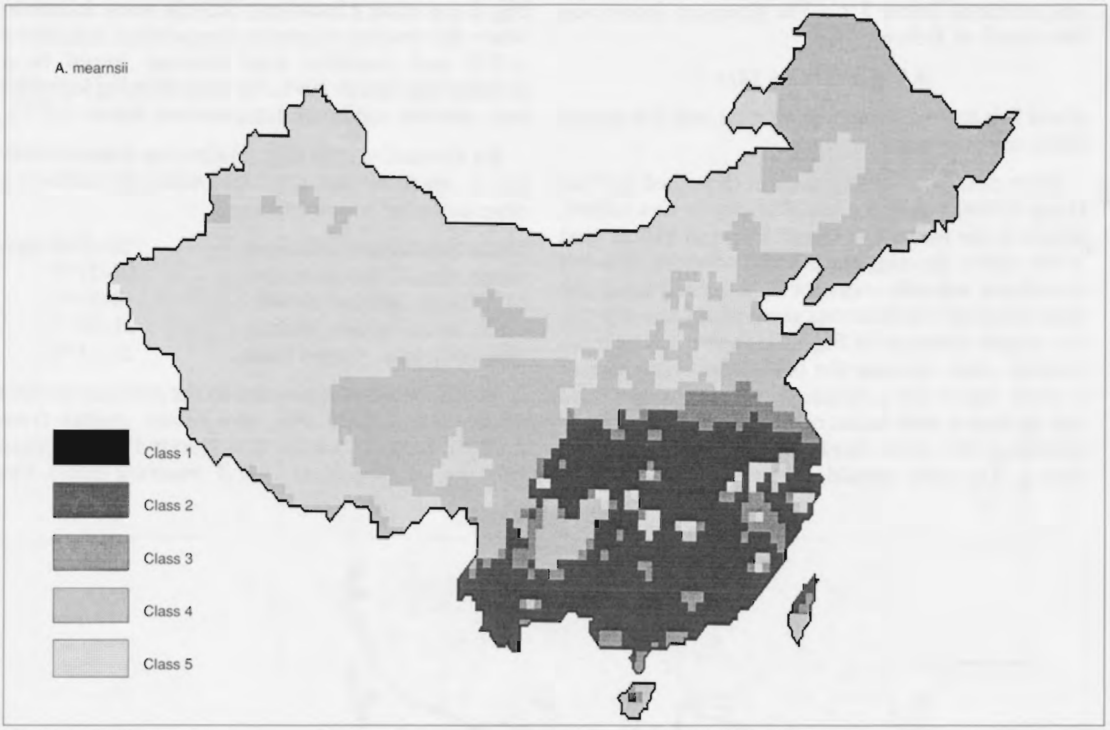

Fig. 2. Dark-shaded locations satisfy description of climatic requirements for *A. mearnsii* (Anon. 1989).

climatically most suitable areas (i.e. class 1 locations) include coastal areas of Zhejiang and Fujian provinces, including ACIAR trials at Wenzhou and Changtai. Other class 1 areas include parts of Yunnan, Guizhou, Hunan and Guangxi. In addition a large class 1 area is shown in Sichuan. Interestingly, the species is not grown in this region at present, but the Chinese Academy of Forestry is currently establishing trials in the region.

The description of the climatic requirements of *A. mangium* used to produce Fig. 1 was also tried using Yan Hong's 1989 program. The most suitable (class 1) areas included parts of Taiwan, Hainan Island and Leizhou Peninsula. The main *A. mangium* plantations in China are indeed in Tun Chang county in the northwest of Hainan Island. However, experience from trials in Guangxi and Guangdong (Pan Zhigang 1989) suggests that *A. mangium* is suitable for coastal areas in these provinces. The requirement for minimum temperature of the coldest month was therefore lowered from 13 to 10 °C. Fig. 4 was produced using Yan Hong's program and the following requirements:

Mean annual temperature	18–28 °C
Min. temp. coldest month	10–24 °C
Max. temp. hottest month	30–40 °C
Mean annual precipitation	1000–4000 mm

Discussion

The results shown here demonstrate how information from trials, including those established as part of the ACIAR program, together with new methods of climatic analysis are helping to improve descriptions of species requirements. Maps produced using interpolated grids of data show suitable areas much more clearly than maps using only data from meteorological stations.

Studies with species such as *A. mearnsii* have indicated the importance of minimum temperatures for defining areas in cool regions where Australian acacias can be grown successfully. Our current work is concerned with improving knowledge about trees' responses to minimum temperature. Interpolation

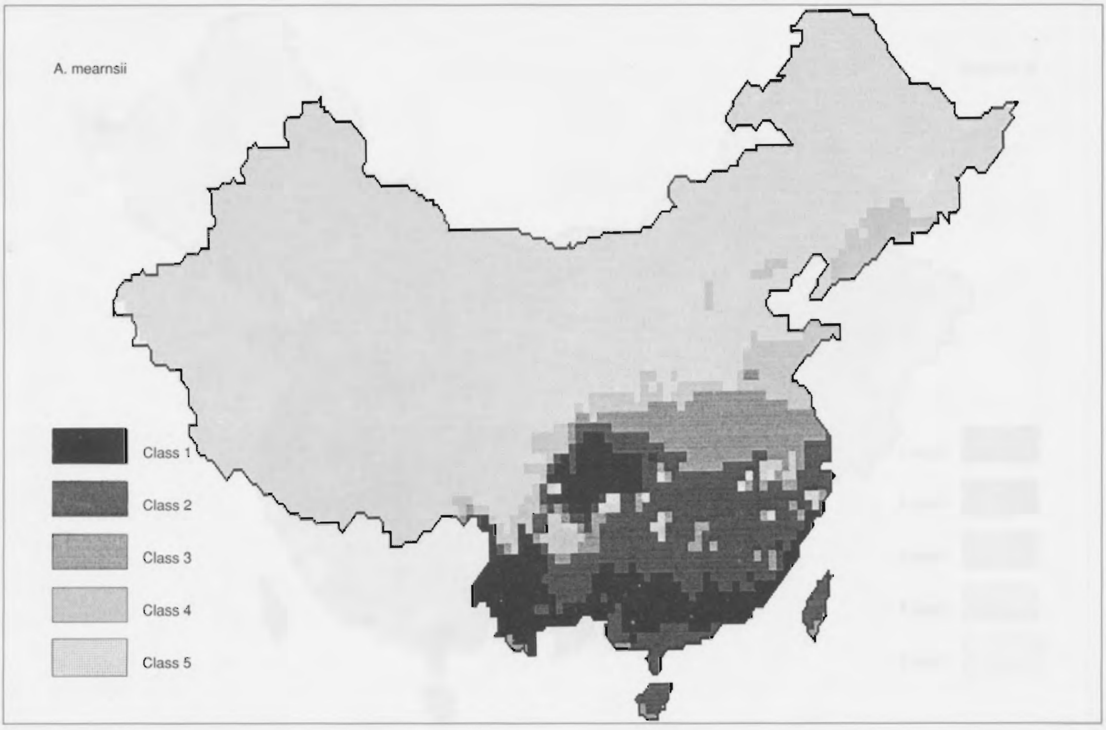

Fig. 3. Dark-shaded locations satisfy description of climatic requirements for *A. mearnsii* described in text.

relationships have been developed for various mean monthly measures of minimum temperature in Australia (i.e. average daily, average monthly and absolute minimum data). Interpolation relationships for these factors are now being developed for China. These relationships will allow us to evaluate trees' responses to minimum temperature in more detail and will assist us to identify suitable areas with more precision.

There is great potential to extend this work to include edaphic factors and simple simulation models. These methods would not only identify regions where particular species will grow, but also suggest how well a species will grow at different locations (see Booth 1991c for description of a prototype of such a system developed for Africa). For example, Yuo Yintian (1989) has reported an interesting comparison of seasonal growth measurements of *A. mangium* at two sites in China, one on Hainan Island and the other near Guangzhou. In the warm conditions of Hainan Island height and diameter growth occur throughout the year. In the cooler conditions at Guangzhou growth is good in summer, but winter temperatures clearly reduce growth to relatively low levels. In the future, analysis methods similar to those described by Booth (1991c) will utilise this type of information, along with knowledge of species' soil requirements, to provide predictions of how well particular species will grow in different environments.

The development of better predictive methods will not replace the need for field experiments. However, they can ensure that the best use is made of trial results by using this information to indicate other locations where species may be successfully grown.

Acknowledgments

We are grateful to ACIAR for their financial support. Climatic data used in Fig. 1 were derived from data supplied by R. Gommes (FAO).

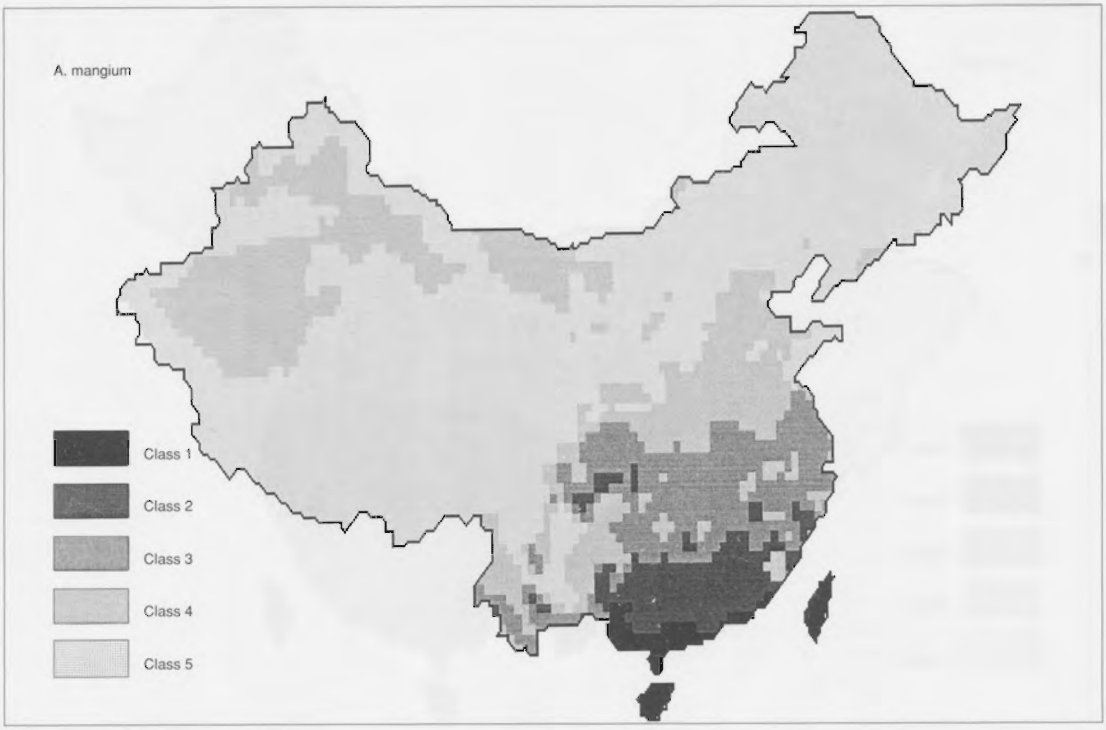

Fig. 4. Dark-shaded locations satisfy description of climatic requirements for *A. mangium* described in text.

References

Anon. 1989. The silviculture of wattles. Subtropical Crop Research Institute Zhejiang Province, Chinese Forestry Press, Beijing, 142 p.

Booth, T.H. 1988. Climatology of *Acacia mearnsii*. 2. Homoclime analysis of potential trial sites in China. New Forests, 2, 31–40.

1991a. Climatic factors. In: Brown, A.G. and Jinko, He, ed., Black Wattle and its Utilisation. ACIAR/CAF joint publication (in press).

1991b. Sharing information and creating knowledge with climatic analysis. Paper presented at FAO/UNDP Regional Planning Workshop on Tree Breeding and Propagation, Bangkok, 10–14 July 1990 (in press).

1991c. A climatic/edaphic database and plant growth modelling system for Africa. Ecological Modelling (in press).

Booth, T.H. and Jovanovic, T. 1988. Climatology of *Acacia mearnsii*. 1. Characteristics of natural sites and exotic plantations. New Forests, 2, 17–30.

Nix, H.A. 1986. A biogeographic analysis of Australian elapid snakes. In: Longmore, R., ed., Atlas of Australian Elapid Snakes. Bureau of Flora and Fauna, Canberra, 4–15.

Pan Zhigang 1989. Preliminary report on introduction of *Acacia mangium* in China. Internal Chinese Academy of Forestry Report, 6 p.

Pan Zhigang and Yang Minquan 1987. Australian acacias in the People's Republic of China. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, Canberra, 136–138.

Webb, D.B., Wood, P.J., Smith, J.P. and Henman, G.S. 1984. A Guide to Species Selection for Tropical and Sub-Tropical Plantations. Trop. For. Paper No. 15 (Revised 2nd Edition) Commonwealth Forestry Institute, Oxford, 256 p.

Yan Hong 1989. A decision support system for introduction of exotics. I. Delineation of suitable zones. Scientia Silvae Sinicae, 25, 395–400.

Yuo Yintian 1989. Introduction and Utilisation of *Acacia mangium* in China. Chinese Academy of Forestry Report, 27 p.

Genetic Resources and Tree Improvement

Exploring and Accessing the Genetic Resources of Four Selected Tropical Acacias

B.V. Gunn and S.J. Midgley*

Abstract

The past 10 years' activities with regard to the seed collection, distribution and field testing of *Acacia aulacocarpa, A. auriculiformis, A. crassicarpa* and *A. mangium* are discussed. The changes in patterns of demand for seed of individual trees reflect an increasing recognition of the potential for tree improvement. Large anticipated demands for seed will make the establishment of seed orchards a commercial necessity. Future directions for seed collections, as opportunities arise for selection for new end-uses, are discussed.

THERE are about 1100 species in the genus *Acacia* of which over 850 occur in Australia and neighbouring Papua New Guinea (PNG) and Indonesia. The remainder are endemic largely to Africa and tropical America (Boland et al. 1984). A number of the Australasian species are native to the lowland wet tropics and are emerging as important species internationally with potential for both industrial and domestic use.

Of these tropical species, *A. mangium* Willd., *A. auriculiformis* Cunn. ex Benth., *A. crassicarpa* Cunn. ex Benth. and *A. aulacocarpa* Cunn. ex Benth. are the most widely planted. They demonstrate an ability to survive and grow rapidly in a wide range of environments with low soil nutrients. Their ability to fix atmospheric nitrogen, compete successfully on grasslands infested with *Imperata cylindrica*, coppice and produce wood for a wide range of uses are notable advantages. In addition to these species, there are a number of other less well-known species with potential for the tropics, including *A. leptocarpa, A. polystachya, A. hylonoma* and *A. cincinnata*. Turnbull (1986) provides information on these and other promising Australian species.

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Progress in Exploration and Field Testing

Since 1979 the Australian Tree Seed Centre (ATSC), part of CSIRO's Division of Forestry, has been the principal organisation involved in research seed collections of *A. mangium, A. auriculiformis, A. crassicarpa* and *A. aulacocarpa* from throughout the species' natural ranges. Figs 1–4 provide maps showing the natural distribution of the four species, collection sites and the names of the better known provenances.

A. mangium

A. mangium was unknown as an exotic until 1966 when it was introduced into Sabah, Malaysia for trials as a firebreak species around plantations on *Imperata* grasslands (Tham 1979). By 1973 it was evident that *A. mangium* had potential as a plantation species for wood production and there are now an estimated 100 000 ha planted with plans for the establishment of at least a further 500 000 ha primarily in Malaysia.

Fig. 1. *Acacia mangium*

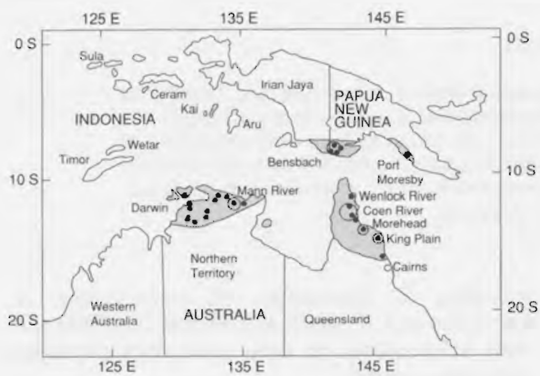

Fig. 2. *Acacia auriculiformis*

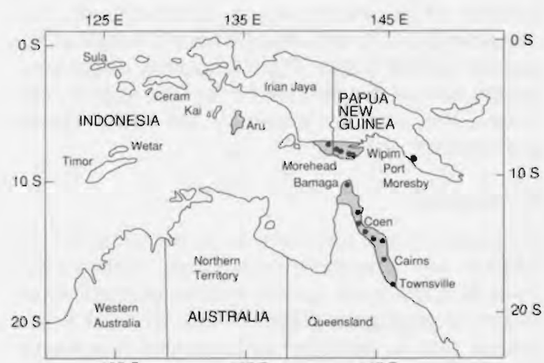

Fig. 3. *Acacia crassicarpa*

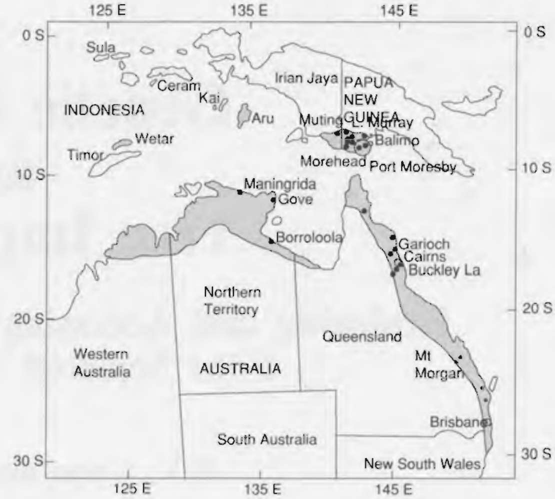

Fig. 4. *Acacia aulacocarpa*

Figs 1–4. Natural distribution of *Acacia mangium*, *A. auriculiformis*, *A. crassicarpa* and *A. aulacocarpa*. Black dots indicate collection sites with better known provenance areas identified.

The species occurs naturally as disjunct populations extending from the northeast coast of Queensland to southern PNG and nearby areas in Indonesia as shown in Fig. 1. The latitudinal range is from about 1–19° south with the altitude of the main occurrence of the species from just above sea level to 100 m with a known upper limit of 720 m (Doran and Skelton 1982; NAS 1983; Turnbull 1986). It is commonly a tree of 20 m in height but can extend to 30 m and occurs in abundance after forest disturbance, along roads and following slash and burn agriculture in PNG and Indonesia. Evidence of 'piping' in the boles of large diameter trees has been observed in natural populations.

In extensive field trials established with seed provided by ATSC, certain provenances have been identified as more successful than others. Of the Queensland sources the material from Claudie River (Iron Range) in the state's far north has shown most promise. Recent additional collections have been made in the region north of the Claudie River (Gunn et al. 1989; Morse et al. 1991), namely in the Olive and Pascoe River systems which flow east between latitude 12 and 13° south. These new seedlots have not been trialed sufficiently to provide meaningful results. However, their form and vigour in natural populations and proximity to Claudie River suggest that they will be good performers.

Provenances from the Western Province of PNG have given superior growth rates in some trials with sources from the Oriomo region showing greatest promise. *A. mangium* occurs throughout the Oriomo Plateau to the south of the Fly River with no distinct natural breaks throughout its range in PNG. Provenance names mainly refer to the closest village, so provenances may only be 10 km apart and therefore could be regarded as sub-provenances as suggested by Skelton (1981). The plateau is a slightly undulating featureless plain rising to a maximum of 70 m elevation. Skelton (1987) describes the distribution and ecology of PNG acacias. During the 1990 collections two new sites were sampled; one near Lake Murray in the Western Province of PNG and the other near Muting in Irian Jaya, Indonesia (Morse et al. 1991).

Assessment of genetic variation and groupings of related populations using isozyme markers demonstrated low levels of genetic variability within and between all populations of *A. mangium* (Moran et al. 1989) despite the evidence of substantial variation in the field trials. This lack of variation has restricted laboratory assessment of population patterns and development of collection strategies.

A. auriculiformis

This species is well known as a cultivated tree in Asia, Africa and South America where it normally grows as a poorly formed tree for a range of uses including fuelwood, windbreak, erosion control, construction wood and as a street tree. Whilst widely planted outside its natural range, until recently little was known of the pattern of variation.

A map of the natural distribution of *A. auriculiformis* as it is currently known is shown in Fig. 1. In Australia, the species occurs on Cape York Peninsula, Queensland and in the north of the Northern Territory. In PNG the species occurs in the Western Province and Central Province. The distribution in Indonesia is restricted to the southeastern region of Irian Jaya and the Kai group of islands. In most locations the species occurs on the banks of rivers and streams including areas immediately behind mangroves along saline estuaries. It is also found away from these systems on the edge of monsoon vine forests and seasonally inundated sites in PNG. The latitudinal range is from 8–16 °S, with altitudinal range from sea level to 400 m with the main occurrence below 100 m. The species shows considerable variation in the wild from single stemmed trees over 36 m with excellent form to 10 m stunted trees with less than 1 m bole length.

There have been reports from a number of countries of superior growth and tree form of newly introduced provenances — especially those from PNG — compared with the performance of local seed sources (Bulgannawar and Math, these proceedings; Harwood et al., these proceedings, Pinyopusarerk 1990). Other seed sources, for example the Springvale provenance from Queensland, have the ability to produce light branching and single stemmed form. A number of other references have broadened the knowledge on *A. auriculiformis* including the glasshouse studies of morphological variation (Pinyopusarerk et al. 1991), the review by Boland et al. (1990) and the annotated bibliography of Pinyopusarerk (1990).

A. crassicarpa

A. crassicarpa is a fast growing tropical tree with wide adaptability. Under natural conditions it tolerates more adverse conditions than the other three species, ranging from areas of impeded drainage in PNG to dry woodland sites in northern Queensland. *A. crassicarpa* has been found the most vigorous coloniser on the degraded soils following slash-and-burn cultivation in PNG.

The species occurs north of latitude 20 °S in Queensland and extends to the tip of Cape York Peninsula. It is widespread in the Western Province of PNG and in the adjacent area of Irian Jaya, Indonesia (Fig. 3). Latitude range is 8–20 °S with main altitudinal occurrence from sea level to 200 m. Most trees are 10–20 m tall but occasionally reach 30 m. The stem is frequently straight with large open crown and heavily branched.

As yet there are no recognised superior provenances within *A. crassicarpa* as the trials are too young. Collections from PNG have been favoured for distribution in preference to Australian sources. This is understandable when one considers the natural environment in which the species grows and its subsequent form. In Queensland the species is a stunted tree growing to 10 m in leached soils under dry conditions. In contrast, *A. crassicarpa* in PNG is found growing under more favourable conditions including the edges of monsoon vine-forest, where it is known to attain heights of 30 m with a diameter of 60 cm.

A. aulacocarpa

One of the largest acacias, *A. aulacocarpa* is commonly found in monsoon vine-forest, on the margin of rainforest, along watercourses and extending into open eucalypt forest. This species can reach over 35 m with a diameter in excess of 100 cm where it occurs on moist sites associated with tropical rainforest. Under these conditions the trunk is clear, with a straight bole but often subject to fluting. However, on drier sites and sites at the southerly end of its natural range it becomes an erect, rather open, shrub or small tree 4–10 m. This great morphological variation is the focus for some taxonomic attention.

A. aulacocarpa has the widest distribution of the four species with a latitude range from 6–30 °S and an altitudinal range from near sea level to 1000 m. In Australia it has two disjunct occurrences. The main population runs along the east coast from northern New South Wales to the top of Cape York Peninsula in Queensland. The second area is in the northern area of the Northern Territory with extensions into Queensland and Western Australia. Further north it occurs in the Western Province of PNG and adjoining area of south-eastern Irian Jaya (Fig. 4). On a recent visit by staff of the ATSC to the Indonesian island of Wetar, *A. aulacocarpa* was tentatively identified as endemic on the island. If this identification is confirmed it will further extend the distribution of the species.

A. aulacocarpa is relatively untried at this stage with no provenances reported as being superior. Considering its ecological niche it has the potential to grow well under conditions of high rainfall in better soil types than *A. mangium*. From wood samples examined in the field there appears to be potential for future selection as a highly decorative timber.

Collections and Accessions

In 1980 the first range-wide seed collections of tropical acacias were conducted. This followed an FAO recommendation that special attention be given to *A. mangium* with the view to establishing international provenance trials. FAO made arrangements for the collection through the then CSIRO Division of Forest Research, Australia, the then Office of Forests, PNG (Doran and Skelton 1982) and the Indonesian Ministry of Forestry (Turnbull et al. 1983). Since then there have been numerous collections especially in Australia and PNG and these are a regular feature of the ATSC's early summer collection program (Gunn et al. 1988, 1989, 1990; Morse et al. 1991). Priorities have been set in relation to research results, access to new populations and regular discussions with colleagues.

Funding and support have been provided by CSIRO and the PNG Forest Department. International donor organisations and private companies have contributed under collaborative arrangements where all parties share the risk and the benefits of uncertain collections in remote areas. Collaborators have included the Australian International Development Assistance Bureau (AIDAB), ACIAR, FAO, Sabah Foundation of Malaysia, Centre Technique Forestier Tropical (CTFT), USAID through the Forestry/Fuelwood Research and Development (F/FRED) Project, Swedish International Development Authority (SIDA), PT.Indah Kiat of Indonesia and Shell International. A feature of the collections has been the detailed tree and site descriptions gathered and provided to collaborators as reports.

Throughout these collections the PNG Forest Department, Queensland Forest Service, Queensland National Parks and Wildlife Service and the Conservation Commission of the Northern Territory who control the major regions where these species grow, gave their full cooperation and allowed free exchange of seed. The Indonesian Government also authorised and assisted with collections in Irian Jaya and Ceram. Without this support the development that has taken place with these species would not have been possible.

Since 1980 the ATSC has made a total of 262 provenance collections comprising over 4400 trees. A number of these provenance collections have been repeat collections from sites sampled previously. Within each species the population numbers comprise: *A. mangium* — 107 (>2100 trees) including 39 populations from PNG and Indonesia; *A. auriculiformis* — 70 (>700 trees) including 24 populations from PNG; *A. crassicarpa* — 38 (>650 trees) including 26 populations from PNG; *A. aulacocarpa* — 47 (>950 trees) including 31 populations from PNG. This represents probably the most comprehensive early sampling ever for tropical tree species and reflects the acceptance of the potential for tree improvement.

The main method of collection is from standing trees either by climbing or use of a .308 calibre rifle. Other methods include felling trees and collection from vehicular mounted cherry pickers. Pods are stripped from branches and spread on sheets of hessian or calico to dry before the seed is cleaned. Methods for collecting and processing acacias are described in Doran et al. (1983). From each provenance collection, a portion of the seed is kept separate as individual tree samples whilst the balance is bulked to represent the genetic composition of the population.

After cleaning, all seed is routinely fumigated in carbon dioxide for two weeks as a phytosanitary precaution. Seed crops vary considerably from year to year and early predictions have proved unreliable. A high percentage of the crop is often lost prior to maturation. This can be attributed largely to abortion through poor pollination and insect attack of the green legumes prior to maturation.

Where possible collections of root nodules have been made in conjunction with the seed collection and these have been used in ACIAR-supported research on rhizobial nitrogen fixation.

Seed Distribution

During the period between 1980 and 1990 seed of the four tropical acacias was sent to over 90 countries. Table 1 gives the 20 countries receiving most seed and the number of seedlots sent by species. In the case of France, the entries mainly relate to requests from CTFT for use in their client countries. Over 50% of seedlots dispatched were sent to tropical Asia and in particular the south-east region.

There has been a dramatic increase in dispatches, particularly of individual tree lots, since 1987–88. This is shown in Fig. 5 and reflects the increased number of tree improvement programs. During the 10-year period a total of 10 996 dispatches of the four tropical acacias was sent from the ATSC. *A. mangium* dispatches rose from 90 to 1343 per year with a total of 4612. *A. auriculiformis* (3349 dispatches), *A. crassicarpa* (1463 dispatches) and *A. aulacocarpa* (1572 dispatches) have only gained prominence in the last three years. Demand for research seedlots is greatest where these species have been shown to outperform *A. mangium*. There has been a dramatic increase in dispatches of *A. aulacocarpa* since 1989 (Fig. 5). This is largely attributed to the availability of seed. This species tends to be a sporadic seeder and until the PNG collections of 1989, very limited amounts of seed were available from limited sources.

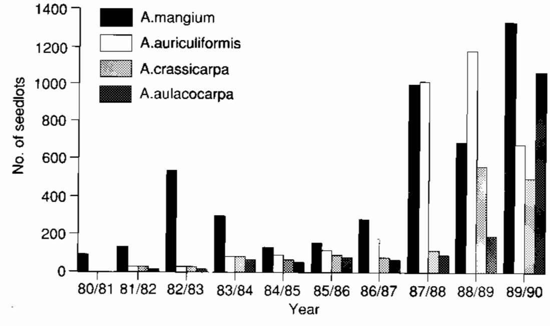

Fig. 5. Seedlot dispatches (bulk and individual trees) for four tropical acacias from 1980/81 to 1989/90.

Table 1. Number of bulk seedlots dispatched to recipient countries 1980–1990. Figures in parentheses indicate individual treelots sent since 1987.

	mangium	*auriculiformis*	*crassicarpa*	*aulacocarpa*
Australia	100 (530)	140 (1180)	62 (683)	123 (567)
Bangladesh	86	10	9	4
Brazil	53	27	9	11
China	83 (393)	79 (84)	67 (134)	50
Costa Rica	62	5	0	0
Fiji	86 (21)	191 (11)	31	54 (265)
France	50 (88)	26 (97)	22 (65)	15 (4)
India	110	125	67	41
Indonesia	122 (460)	76 (56)	63 (113)	44 (294)
Kenya	32	39	23	18
Laos	27	25	20	17
Malaysia	184 (88)	119 (334)	33 (65)	25 (4)
Pakistan	25	39	2	4
Papua New Guinea	39 (351)	15 (70)	21 (96)	41 290)
Philippines	219	116	42	32
Sri Lanka	34	31	21	22
Taiwan	37	25 (5)	7	7
Tanzania	48	13	6	3
Thailand	138 (88)	133 (133)	47 (65)	46 (183)
Vietnam	69	79	0	30

Future Directions

As resources allow, seed of the lesser known acacias will be collected and made available — particularly *A. hylonoma* and *A. bakeri*, two large rainforest acacias so far untried. Plans are also in place to sample more thoroughly the natural populations of *A. cincinnata, A. leptocarpa* and *A. polystachya.*

The uncertainty of seed availability from the natural forests and remoteness of some natural populations, will make the establishment of seed orchards a commercial necessity. The precocious flowering habit and early seed set of the more important species should make this an attractive proposition.

Tree improvement work thus far has clearly demonstrated the potential for improved wood yields through selection (Harwood et al., these proceedings). For these reasons it is anticipated that there will be a strong ongoing demand for seed of individual trees and future ATSC collections will aim to cater for this demand. In addition to this basic genetic material, ATSC is now in a position to provide technical advice on seed orchard design and establishment based on experience with its own orchards.

Most field selections so far have been based upon growth rates and form. Given, for instance, the natural occurrence of *A. auriculiformis* close to saline estuaries (Gunn et al. 1990), records of its browsing by cattle (Gunn et al. 1989), its use as an antiseptic (Barr 1988) and reports of use of the seed for seed meal and the extraction of oils from the seed in West Bengal (Mandal et al. 1987), there appear to be great possibilities for selection for other traits which will increase the usefulness of this species and others more useful for farm forestry and community plantings. Reports of the human consumption of *A. holosericea* seed in Niger are exciting (Rinaudo, pers. comm.).

Development and selection for human food value of seed would extend the use of a number of species, particularly in dryland farming systems. Such a development, which will require, in addition to the availability of research seed, input by nutritionists, sociologists and agronomists, is the subject of a major funding proposal by the ATSC.

Most Australian seed collectors and dealers can specify the origin of the seed they supply and can provide collection data. There is, however, no tree seed certification scheme operating and it is recommended that the purchaser ascertain details of the seed origins before entering into any purchase agreement. It must not be assumed that seed obtained from Australian seed suppliers will necessarily come from trees growing in Australia.

As more is discovered about the potential of these valuable species the demand for seed for research and development will increase. The Australian Tree Seed Centre looks forward to maintaining its established service and efficiently meeting this demand.

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References

Barr, A. 1988. Traditional bush medicines: an Aboriginal pharmacopoeia/Aboriginal communities of the Northern Territory of Australia. Greenhouse.

Boland, D.J., Brooker, M.I.H., Chippendale, G.M., Hall, N., Hyland, B.P.M., Johnston, R.D., Kleinig, D.A. and Turner, J.D. 1984. Forest trees of Australia. Australia, Nelson/CSIRO.

Boland, D.J., Pinyopusarerk, K., McDonald, M.W., Jovanovic, T. and Booth, T.H. 1990. The natural habitat of *Acacia auriculiformis* and probable factors associated with its distribution. Journal of Tropical Forest Science, 3(2), 159–180.

Doran, J.C. and Skelton, D.J. 1982. *Acacia mangium* seed collections for international provenance trials. Forest Genetic Resources Information No. 11, 47–53. Rome, FAO.

Doran, J.C., Turnbull, J.W., Boland, D.J. and Gunn, B.V. 1983. Handbook on Seeds of Dry-zone Acacias. Rome, FAO.

Gunn, B.V., McDonald, M.W. and Moriarty, J. 1988. 1987 seed collections of *Acacia auriculiformis* from natural populations in Papua New Guinea and northern Australia. Report No. 4, Winrock International, Bangkok.

Gunn, B.V., McDonald, M.W. and Gardiner, C. 1989. 1988 seed collections of tropical acacias in Papua New Guinea and north Queensland. ATSC, CSIRO, Canberra.

Gunn, B.V., Morse, J. and Thomson, L.A.J. 1990. 1989 seed collections of tropical acacias in Papua New Guinea and north Queensland. ATSC, CSIRO, Canberra.

Mandal, B., Majmumdar, S.G. and Maity, C.R. 1987. Processing and toxicological evaluation of akashmoni and eucalyptus seed meals. Food Sciences and Nutrition 41F:2, 135–143.

Moran, G.F., Muona, O. and Bell, J.C. 1989. *Acacia mangium*: A tropical forest tree of the coastal lowlands with low genetic diversity. Evolution, 43, 231–235.

Morse, J., McDonald, M.W. and Vercoe, T.K. 1991. 1990 seed collections of tropical acacias in north Queensland and Papua New Guinea. ATSC, CSIRO, Canberra. (In press).

NAS (National Academy of Sciences) 1983. Mangium and other acacias of the humid tropics. Washington, D.C., National Academy Press.
Pinyopusarerk, K. 1990. *Acacia auriculiformis*: an annotated bibliography. Winrock International/ACIAR.
Pinyopusarerk, K., Williams, E.R. and Boland, D.J. 1991. Geographical variation in seedling morphology of *Acacia auriculiformis* A. Cunn. ex Benth. Aust. Journal of Botany. (In press).
Skelton, D.J. 1981. Provenance seed collections of *Acacia mangium* Willd. in Western Province, Papua New Guinea, October, 1980. Working Paper No. 10 FAO/UNDP-MAL/78/009.
1987. Distribution and ecology of Papua New Guinea acacias. In: Turnbull, J.W., ed. Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, 38–44.
Tham, C.K. 1979. Trials of *Acacia mangium* as a plantation species in Sabah. Forest Genetic Resources Information 9, 32–35. Rome, FAO.
Turnbull, J.W. ed., 1986. Multipurpose Australian Trees and Shrubs: lesser-known species for fuelwood and agroforestry. ACIAR Monograph No. 1, 316 p.
Turnbull, J.W., Skelton, D.J., Subagyono, M. and Eko Bhakti Hardiyanto 1983. Seed collections of tropical acacias in Indonesia, Papua New Guinea and Australia. Forest Genetic Resources Information. No. 12, 2–15. Rome, FAO.

The History of Acacia Introductions to China

Wang Huoran* and Fang Yulin**

Abstract

There are five species and one variety of *Acacia* native to China. Almost all acacias grown in commercial plantations in China were introduced from Australia. Of about 100 acacias grown in China, *A. mearnsii, A. auriculiformis, A. mangium, A. dealbata* and *A. crassicarpa* have been of great importance in plantation forestry and agroforestry. Total planting area of acacias is estimated to be about 60 000 ha in China. There has been a boom in planting acacias in south China since the commencement of collaborative forestry projects between ACIAR and the Chinese Academy of Forestry in 1985.

THE common name for acacia in Chinese is 'xiangsi', which means lovesickness tree. In Silva Sinica (Zheng 1985) five species and one variety of *Acacia* were documented as indigenous to China:

- *A. richii* A. Gray (*A. confusa* Merr.), commonly known as Taiwan xiangsi, reaching 16 m in height and 60 cm in diameter at breast height (dbh), is native to Taiwan, but widely planted in other provinces on the Chinese mainland for fuelwood and soil conservation.
- *A. yunnanensis* Franch., called Yunnan xiangsi, up to 10 m tall, is naturally distributed in southwestern Sichuan and northwestern Yunnan Province, usually seen above 1700–3000 m altitude.
- *A. catechu* (L.) Willd. var. *wallichiana* (DC.) P.C. Wang, known as thornless catechu, occurs in Xishuangbanna area in southern Yunnan Province and also in India. Its heartwood is often used in Chinese herbal medicine to cure skin cancer.
- *A. intsia* (L.) Willd., *A. pennata* (L.) Willd. and *A. sinuata* (Lour.) Merr. are all twining shrubs with thorns on branchlets, widely distributed in southern China, India, Vietnam and Burma.

These species are not economically important, and all acacias grown in plantations are exotics introduced from Australia. In recent years, there has been greatly increased interest in growing acacias in southern China, in particular since the commencement of the collaborative forestry projects between ACIAR and the Chinese Academy of Forestry (CAF) in 1985. Now throughout China the total area of acacia plantations is estimated at 60 000 ha. In addition, roadside plantings extend for 3000 km. Main species are *A. mearnsii, A. dealbata, A. mangium, A. auriculiformis* and *A. crassicarpa*. There is great potential for growing acacias in plantation forestry, agroforestry and community forestry in China.

Early Introduction

A. mearnsii was probably the first species introduced to China in the early 1950s (Gao et al. 1989; Gao and Ren 1989). Among all acacias grown in China, this species has become the most important in commercial plantations for the tannin industry. The plantation area is 10 000 ha, of which around half is located in southern Fujian (Lu 1987).

A. dealbata and *A. decurrens* were introduced together shortly after *A. mearnsii. A. dealbata* was planted in Kunming as a street tree in the 1950s. Thirty years later, about 300 ha of plantations have been established in Yunnan, Zhejiang, Sichuan, Fujian and other provinces in subtropical China. *A. dealbata* has adapted well to poor sites, resists cold and is able to colonise bare land. Biomass studies have indicated that this species can yield 15–21 t/ha of dry matter at 5 years (Zhang Maoqin 1989, pers. comm.). Some experimental plantings have been

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established in Zhejiang Province with the third generation of this species.

In the years that followed, *A. farnesiana, A. melanoxylon, A. arabica, A. senegal, A. elata, A. delavayi* and *A. glauca* were introduced to China. These species were described by How (1958), Wu (1983) and Zheng (1985). However, they have not been planted on a large scale.

Introduction of Tropical Acacias

Australia is rich in genetic resources of tropical acacias with characteristics suitable for plantation forestry in tropical China (Boland and Turnbull 1989). Many species of *Acacia* from northern Australia and adjacent Papua New Guinea have been tested widely in south China since the 1960s.

A. auriculiformis has been grown in Guangdong Province since 1961 (Xu and Huo 1982) and then expanded rapidly to Guangxi, Hainan and Fujian provinces. It is by far the most widely planted acacia (Table 1). This species has adapted to a range of environments, and is used as a multipurpose tree (Xu and Huo 1982; He 1988; Huang 1989) and as an associate species in mixed plantations with eucalypts and tropical pines.

Table 1. Plantation areas of more important acacias in China (1990).

Species	Plantation area (ha)
Acacia auriculiformis	50000 (plus 3000 km roadside plantings)
A. dealbata	300
A. holosericea	1500
A. mangium	3300
A. mearnsii	10000
Others	1000

Three other important tropical acacias — *A. mangium, A. holosericea* and *A. cunninghamii* — were introduced to China in 1979. *A. mangium* was first introduced to Guangdong and Hainan provinces where it has started producing seed. However, in Guangxi it was killed by low temperatures caused by cold air currents from Mongolia in 1984 (Yang 1990). In a species trial in Hainan *A. mangium* produced 1.6 times more biomass than *A. auriculiformis.*

A. holosericea and *A. cunninghamii* are more capable of adapting to poor and dry soils. It was found that *A. cunninghamii* had two forms — one a small tree with a single stem, the other a multi-stemmed bush. Both were good for soil conservation and amenity planting (Yang 1990).

It was evident from the results of species trials established in Leizhou Peninsula and Hainan Island in 1984 that *A. crassicarpa* had a faster growth rate than *A. auriculiformis, A. cincinnata, A. aulacocarpa* or *A. leptocarpa* (Pan et al. 1988). *A. crassicarpa* has been used in local plantation programs.

More genetic resources of *Acacia* have been transferred to China since 1985 when the collaborative forestry projects between ACIAR and CAF were launched. Introductions of Australian acacias have been greatly accelerated.

Introduction of *Acacia* is presently characterised by species trials in combination with provenance trials at many establishments in different locations. Because genetic materials are available in large quantities directly from Australia, there are more opportunities for China to choose more suitable genotypes. Many results of species and provenance trials have been reported (Gao et al. 1989; Pan et al. 1988; Wei 1984; Yang et al. 1989) and about 100 species have so far been tested.

Also academic exchanges have been made frequently between Chinese and Australian scientists, studying environmental matching, species biology in natural habitat and performance in the new environments. These have enabled genotype selection to become scientifically precise, where earlier introductions were haphazard.

Current Research

Many research projects are being carried out, especially species and provenance tests — for instance, provenance trials of *A. mearnsii, A. dealbata, A. mangium* and *A. auriculiformis.* Most of these are part of Sino-Australian collaborative projects.

A. mearnsii has now reached the phase of breeding and improvement. A comprehensive plan was drawn up by Raymond (1987) and a breeding population established with 144 entries in Fujian in 1988. Early trial plots of *A. dealbata, A. mangium, A. auriculiformis* and *A. crassicarpa* have been converted to seed production areas.

Research in silviculture has been undertaken with *A. mearnsii* (Chen 1984; Gao and Ren 1989; Zhang 1990), *A. mangium* (He 1988; Huang 1990), *A. auriculiformis* (Xu and Huo 1982; Huang 1989). It was reported that *A. holosericea*, interplanted with *Melinis minutiflora* (Gramineae) to control soil erosion, produced 18.6 t/ha of fuelwood at age 2 years (Wang and Bu 1990).

A disease caused by *Oidium* sp. has been reported (Gong 1985). It mainly occurs on seedlings of several tropical acacias, for example, *A. auriculiformis, A. mangium, A. cincinnata* and *A. cunninghamii*, but the indigenous *A. confusa* is not susceptible.

Micropropagation has been attempted with more than 20 acacias (Zai et al. 1984).

Future Directions

With the introduction of *Acacia* species to China there are some technical problems for which more research is needed. It was found difficult to raise seedlings in the nursery and some trials failed at this stage (perhaps due to incorrect seed treatment, disease, or insect attack). Termites, for instance, can be a serious problem.

Modern concepts of the biology of *Acacia* are limited in China, as little information is available in Chinese. An introduction to taxonomy, biogeography and genetics of *Acacia* is badly needed.

References

Boland, D.J. and Turnbull, J.W. 1989. Australian tree species for fuelwood and agroforestry in China, Kenya, Thailand and Zimbabwe. In: Boland, D.J., ed., Trees for the Tropics: Growing Australian Multipurpose Trees and Shrubs in Developing Countries. ACIAR Monograph No. 10, 13–21.

Chen, Xiangxin 1984. Seedling nutrition of *Acacia mearnsii*. Forestry Science and Technology, CAF, No. 12, 5–6.

Gao, C., Zhang, F., Ren, H. and Liu, S. 1989. A preliminary report on provenance trials of black wattle. Forestry Research, 2(2), 488–493.

Gao, C. and Ren, H. 1989. Division of suitable areas for growing black wattle, *Acacia mearnsii*, and key points of planting techniques in each area. Forestry Research, 2(5), 489–494.

Gong Mingqin 1985. A preliminary study on the incidence of disease of powdery mildew of *Acacia auriculiformis* and its control. Tropical Forestry, No. 1, 8–13.

He, K. 1988. A preliminary report on a comparative experiment on planting with *Acacia mangium* and *A. auriculiformis*. Forestry Science and Technology, CAF, No. 2, 17–19.

How, F.C. 1958. A Dictionary of the Families and Genera of Chinese Seed Plants. Academic Press, Beijing, 2.

Huang, L. 1989. Researches on the introduction and cultural technique of *Acacia auriculiformis*. Forestry and Science Technology, CAF, No. 5, 10–11.

Huang Shineng 1990. Study on the effect of stump diameter and height on sprout regeneration on mangium (*A. mangium*). Forestry Research, CAF, 3(3), 242–249.

Lu, Y. 1987. Introduction and cultivation of *Acacia mearnsii* in Fujian Province. Tropical Forestry, No. 3, 62–65.

Pan, Z., Yang, M. et al. 1988. Preliminary report on the 3-year-old provenance tests of tropical acacias in China. Forestry Research, CAF, 553–558.

Raymond, C.A. 1987. *Acacia mearnsii*, a breeding plan for China. ACIAR Project 8848 (working report), 53 p.

Wang, S. and Bu, J. 1990. *Acacia holosericea* interplanted with molasses grass for soil conservation. Forestry Science and Technology, CAF, No. 4, 32.

Wei, Z. 1984. Preliminary report on the introduction of *Acacia mangium*. Forestry Science and Technology, CAF, No. 10, 4–6.

Wu, Zonglun 1983. Introduction to the Exotics. Academic Press, Beijing, 253–261.

Xu, Y. and Huo, Y. 1982. A study on the silviculture and utilisation of *Acacia auriculiformis*. Tropical Forestry, No. 1, 21–30.

Yang, M. 1990. A study on the adaptability and growth of some tropical acacias in south China. Forestry Research, 3(2), 155–161.

Yang, M., Bai, J. and Zheng, Y. 1989. Tropical Australian acacia trials on Hainan Island, People's Republic of China. In: Boland, D.J., ed., Trees for the Tropics: Growing Australian Multipurpose Trees and Shrubs in Developing Countries. ACIAR Monograph No. 10, 89–96.

Yang, M. and Zheng, Y. 1989. The provenance trial of *Acacia mangium*. Forestry Research, CAF, 2(2), 113–115.

Zai, Y., Zhou, Z. and Li, T. 1984. Tissue culture of *Acacia* species. Tropical Forestry, No. 4, 20–25.

Zheng, W. 1985. Silva Sinica, Vol. 2. Forestry Press, Beijing, 1248–1263.

Zheng, F., Gao, C. et al. 1990. Preliminary study on fertilisation for *Acacia mearnsii*. Forestry Research, CAF, 3(2), 172–177.

Variation in Seedling Morphology of *Acacia auriculiformis*

K. Pinyopusarerk, E.R. Williams and D.J. Boland*

Abstract

Seedlings of *Acacia auriculiformis* from 30 provenances from Papua New Guinea, Queensland and Northern Territory, Australia, (and two Thai sources), were raised under uniform glasshouse conditions, and 17 attributes were measured for each seedling. Provenance differences were evident; variation amongst families within provenances was generally small. The main finding was the distinctiveness of the Papua New Guinea, Queensland and Northern Territory material as data from provenances for these areas clustered into three distinct groups. The Thai material possibly originated as seed from Queensland.

Acacia auriculiformis A. Cunn. ex Benth. is a leguminous, nitrogen-fixing tree which occurs naturally in Australia, Papua New Guinea and Indonesia (see Fig. 1). In Australia, it occurs in the northern area of Northern Territory, Cape York Peninsula, Queensland and on islands in Torres Strait. In Papua New Guinea it is found mainly in the Western Province extending from the Irian Jaya border to Oriomo. The occurrence in Indonesia is not well documented, but it is known in Irian Jaya and on the Kai Islands. Its natural occurrence and factors probably affecting its distribution have been outlined by Boland et al. (1990). In nature the species typically occurs along the levees of rivers and streams but can also occur away from river systems on seasonally inundated soils in Papua New Guinea.

In its natural range *A. auriculiformis* is of limited use to local people. However it has been widely planted and utilised in China, India and Southeast Asia. More recently it is being considered for large-scale plantations in Zaire, Africa. Its main attributes are rapid early growth, good wood quality for pulp, sawn timber, charcoal and fuelwood, and tolerance to a wide range of soil conditions.

A. auriculiformis was selected as one of five priority species by the International Union of Forestry Research Organisations for intensive research development in the humid tropical lowlands (Shea and Carlson 1984). Current international research on this species involves growth and management trials, and studies of geographic variation in replicated field provenance trials. The interpretation of results from these trials would benefit from a detailed examination of geographic variation in seedling morphology from a range of provenances grown under uniform environmental conditions.

Glasshouse experiments in which a range of seed sources from natural populations is grown under uniform environmental conditions are a common method used in forestry research for determining intraspecific variation. In the present study, intraspecific variation in seedling morphology of

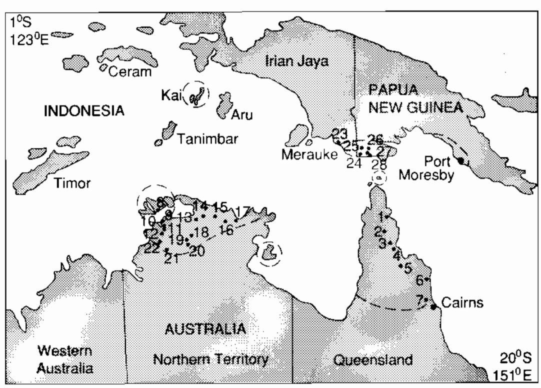

Fig. 1. Natural distribution of *Acacia auriculiformis* in Australia, Papua New Guinea and Indonesia. Small black dots indicate location of provenances in the study.

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A. auriculiformis was examined in a glasshouse using seed collected from the three major distribution centres of the species covering Papua New Guinea, and Queensland and the Northern Territory, Australia. In addition seed from two exotic sources from cultivated stands in Thailand was included in order to determine whether the original sources of seeds which were introduced to Thailand can be traced from the comparison of seedling morphology. Some of the results obtained from the study are reported here.

Materials and Methods

Establishment

The experiment was conducted in a glasshouse in which temperature was controlled to about 30/25 °C day/night.

Thirty provenances were used in the study: from Queensland (7) and Northern Territory (15) in Australia, Papua New Guinea (6) and Thailand (2) (Table 1). Of the 30 provenances, 21 were family-identified (seeds kept separate for each tree), and nine were bulked. Bulked seeds of these provenances have also been used for the Forestry/Fuelwood Research and Development (F/FRED) and ACIAR collaborative international provenance trials.

For each of the family-identified seedlots, seedlings from five trees were used to compare variation between trees within provenances. This made up 105 seedlots (treatments). Similarly for the nine bulked provenances, each was repeated five times to make up another 45 seedlots. Therefore there were 150 seedlots in total.

The experimental design was a generalised lattice design for 150 seedlots, four replicates and incomplete blocks of five. The seedlots were arranged

Table 1. Details of origin of the 30 provenances of seed of *A. auriculiformis.*

Code No.	CSIRO seedlot No.	Locality	Latitude (S)	Longitude (E)	Altitude (m)
1	15483	Archer River, Qld	12 26	142 57	100
2	16145	Wenlock River, Qld	13 06	142 56	130
3	16142	Coen River, Qld	13 53	143 03	170
4	15697	South Coen, Cape York, Qld	14 07	143 16	160
5	16484	Morehead River, Qld	15 03	143 40	50
6	16485	Kings Plain, Qld	15 42	145 06	150
7	15985*	Mt Molloy, Rifle Creek, Qld	16 41	145 17	380
8	16187*	Melville Island, NT	11 55	130 50	1
9	16147	Noogoo Swamp, NT	12 23	131 00	28
10	16161*	Howard Springs, NT	12 27	131 03	70
11	16163	Elizabeth River, NT	12 36	131 04	40
12	16148	Manton River, NT	12 50	131 07	100
13	16152	East Alligator River, NT	12 17	132 55	10
14	16153*	Cooper Creek, NT	12 06	133 11	40
15	16154	Goomadeer River, NT	12 08	133 41	50
16	16155*	Mann River, NT	12 22	134 08	60
17	16156*	Yarunga Creek, NT	12 18	134 48	50
18	16160	South Alligator River, NT	13 16	132 19	100
19	16158	Gerowie Creek, NT	13 19	132 15	100
20	16151	Mary River, NT	13 36	132 08	120
21	16149	Douglas River, NT	13 51	131 09	70
22	16162	Reynolds River, NT	13 32	130 52	150
23	16101*	North Bensbach to Weam, PNG	8 50	141 15	10
24	16103*	South Balamuk, PNG	9 00	141 15	10
25	16105	Balamuk on Bensbach River, PNG	8 55	141 17	20
26	16106	North Mibini, PNG	8 49	141 38	40
27	16107	Old Tonda Village, PNG	8 55	141 33	40
28	16108*	Mari Village, PNG	9 11	141 42	5
29	16297	Nong Sanom, Rayong, Thailand	12 35†	101 15	10
30	16397	Sai Thong, Thailand	11 25†	99 27	50

N.B. * indicates bulked seedlot
† 'N' latitude

so that comparisons between 1) the bulked and family-identified seedlots and 2) the 30 provenances could be made efficiently.

The seeds were pretreated with boiling water and allowed to soak overnight in the gradually cooling water. Four seeds were sown in a 15 cm diameter pot containing a 70:30 mixture of river sand and vermiculite, but germinated seedlings were thinned out to only one per pot. Seedlings received the same amount of one quarter strength Hoagland nutrient solution which was flushed through drippers. Supplementary watering was provided through overhead sprinklers.

Seeds started to germinate in the first week after sowing but most seeds germinated within 4 weeks. Once the cotyledons had fully expanded a pinnate leaf emerged, and it was counted as leaf No. 3. This was followed by a bipinnate leaf of which a few exhibited a flattened but small petiole. Another bipinnate leaf soon developed and usually it was at this leaf position that the flat petiole modified to a phyllode first appeared, but with a bipinnate leaf still intact at the tip. The seedling then developed to the full phyllode stage i.e. phyllode without intact bipinnate leaf (mostly at leaf No. 6). However, there were variations among seedlings between families and between provenances in the leaf number which developed to full phyllode stage, i.e. some developed sooner and some later than others.

Assessments

Assessments were made on each seedling from week 6 to 13 after sowing the seed. Pinnule counts were carried out after week 6 at which time all seedlings had already developed to the full phyllode stage. Assessments of phyllode characters were made from week 12 on the phyllode at leaf No. 11 (including cotyledons). At this stage most seedlings had developed to about the 15–20 leaf (phyllode) stage, and the size and shape of the phyllode No. 11 was quite similar to those at higher nodes. The following characters were assessed:

1. Number of pinnules per pinna
2. Length of pinnule
3. Width of pinnule
4. Pinnule length/width
5. Pinnule tip
6. Angle between pinnae
7. Onset of first phyllode without intact bipinnate leaves
8. Length of phyllode
9. Width of phyllode
10. Phyllode length/width
11. Phyllode asymmetry (curvature)
12. Phyllode tip angle
13. Gland (extrafloral nectary) colour
14. Pulvinus colour
15. Distance from gland to pulvinus
16. Branching
17. Stem colour

Statistical analyses

Analyses of variance were carried out, using the GENSTAT statistical package (Payne et al. 1987), for each of the variates to assess differences (1) between trees within provenances, (2) between provenances within country (country is defined as Queensland, Northern Territory, Papua New Guinea and Thailand), and (3) between countries. For the qualitative variates, such as pulvinus colour, the colour classes were converted to ordered scores before analysis. For the quantitative variates, such as phyllode length and width, the variation between the trees for each family-identified provenance was calculated and then pooled. This was then compared with the same quantity for the bulked seedlots.

Estimated provenance means for the 17 varieties were subjected to a canonical variate analysis using GENSTAT. This multivariate technique attempts to summarise differences between the countries using a small number of canonical variates which are linear combinations of the original 17. Seedlots from Thailand were not included in this analysis since it is of interest to see how these seedlots of known origin align in relation to the other countries.

Results

Analyses

There were country differences for all 17 variates. Similarly there was a residual provenance effect (after removing country) for all variates. Variation between trees after taking out provenances was small and thus only estimated provenance means were carried forward for multivariate analysis. There was no evidence of greater variation in the family-identified provenances over the bulked seedlots for all variates except phyllode length/width where the variance between single trees was 2.2 times that for the bulked seedlots. The differences between countries are summarised in Table 2.

The results of the multivariate analysis are shown in Fig. 2 where the first canonical variate is plotted against the second. The first is more important, accounting for 80% whereas the second only accounts for 20% of the variance. It is clear that the provenances can be divided into three groups according to their geographical origins. These are Queensland, Northern Territory and Papua New

Guinea. A least significant difference between Papua New Guinea and Queensland at the 0.1% probability level is 9.2, and for comparisons involving Northern Territory, the value is 7.6.

In regard to the Thailand seedlots, the coordinates obtained for the two seedlots were:

Seedlot	1st coordinate	2nd coordinate
16297	−8.34	−5.31
16397	+4.27	−4.98

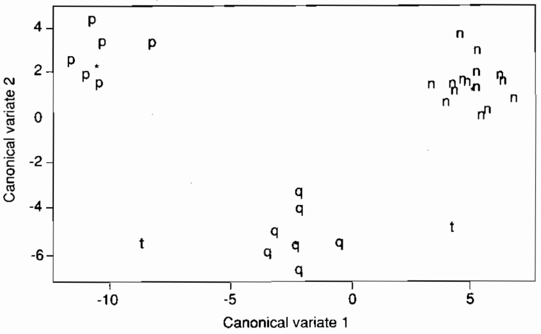

Fig. 2. Plots of first two canonical variates from canonical variate analysis of 17 variates to compare Papua New Guinea (p), and Queensland (q) and Northern Territory (n). Superimposed are scores for the means (*) for each geographic region and for the two Thai seedlots (t).

These coordinates can be superimposed in Fig. 2 where it is shown that both Thailand seedlots are within the least significant distance from the centre of the Queensland group with seedlot 16397 also being reasonably close to the Northern Territory group. However the implication is that both Thailand seedlots were originally introduced from Queensland.

Principal discriminating seedling characters

Phyllodes Phyllode quantitative variates (length, width, and length/width) appear to be good provenance discriminators between countries. The ratio length/width of phyllode is an indicator of shape; the smaller the ratio the broader the phyllode. Queensland material consisted of narrow phyllodes whilst the Papua New Guinea material had broad phyllodes. The Northern Territory provenances were variable in phyllode width and phyllode length/width but there was a tendency for the inland group (provenance code No. 18–22) to have narrower phyllodes compared with the coastal group (No. 8–17) resulting in a greater ratio of phyllode length/width. The two seedlots from Thailand had broad phyllodes similar to those of Papua New Guinea. Comparing length of phyllode, provenances from Northern Territory produced longer phyllodes than those from Queensland, Papua New Guinea and Thailand.

Table 2. Summary of results of glasshouse study on seedling morphology of *Acacia auriculiformis* showing mean values for Queensland, Northern Territory, Papua New Guinea and Thailand.

Variate	Qld	NT	PNG	Thai
1. No. pinnules/pinna (mm)	9.9	10.6	9.5	10.8
2. Length of pinnule (mm)	8.4	9.1	9.0	9.1
3. Width of pinnule (mm)	2.5	2.9	3.0	3.0
4. Pinnule length/width	3.4	3.2	3.2	3.2
5. Pinnule tip	obtuse	obtuse	pronounced obtuse	pronounced obtuse
6. Angle between pinnae	90–120°	120–150°	90–120°	90–120°
7. Leaf No. of onset of first phyllode	6.4	6.1	6.4	6.4
8. Length of phyllode (mm)	182.0	200.5	178.1	173.1
9. Width of phyllode (mm)	18.5	22.8	26.5	27.6
10. Phyllode length/width	10.2	9.3	6.9	6.4
11. Phyllode asymmetry*	1.3	1.2	1.1	1.0
12. Phyllode tip#	1.4	1.8	2.2	2.4
13. Gland colour	brown	green-brown	red	brown
14. Pulvinus colour	green-brown	green-brown	brown-red	brown
15. Gland to pulvinus (mm)	0.5	0.4	0.6	0.4
16. Branching	light-moderate	light-moderate	moderate	light-moderate
17. Stem colour	green-light brown	green-light brown	brown	light brown

N.B. * 0.5 is perfectly symmetrical; the higher the value the more the curvature of the phyllode
1 = <15°, 2 = >15° but <30°, thus the higher the value the more obtuse the tip of phyllode

With regard to leaf position for the onset of first full phyllode, it was noted that seedlots from Northern Territory reached the full phyllode stage earlier than those from Queensland, Papua New Guinea and Thailand.

Pinnules Pinnules were shorter and narrower for Queensland. The number of pinnules per pinna was lower for Papua New Guinea and Queensland, and somewhat higher for Northern Territory. Provenances from Northern Territory had a wider angle between pinnae.

Pinnule tip was more acute for Queensland provenances than for Papua New Guinea provenances and this is generally related to the narrower phyllodes. The Northern Territory provenances were variable but mostly had an obtuse tip. Material from Thailand had a pronounced obtuse tip.

Colour characters Results obtained for colour of gland, pulvinus and stem all indicated that most Papua New Guinea seedlings were brown to red colour whilst Queensland and Northern Territory seedlings were green to light brown. Material from Thailand had light brown colour for stem but brown for gland and pulvinus.

Discussion

The present study has demonstrated provenance variation in seedling morphology in many pinnule and phyllode characters of *A. auriculiformis* and, to a lesser extent, variation amongst families within provenances.

Multivariate analysis showed three distinct groups of provenances which are in accord with the three major natural occurrences of the species, i.e. Papua New Guinea, Queensland and Northern Territory. There is a suggestion that the Northern Territory material is closer to Queensland.

A. auriculiformis belongs to the flora of seasonally dry tropics. Barlow and Hyland (1988) postulated the existence of a seasonally dry climatic corridor for a long period to the north of Australia through western New Guinea to eastern Indonesia. Within this climatic zone the species would have been able to disperse as sea levels fell. Such links for the less mobile species were severed with rising sea levels and minor climatic changes (e.g. a dry zone developing between eastern Queensland and the northern part of Northern Territory) resulting in subsequent fragmentation of distributions of many species. It is most likely that the original distribution of *A. auriculiformis* became fragmented by rising sea levels in recent times as overall differences amongst the three main groupings are not large, e.g. they do not warrant subspecific taxonomic status. The wider separation of Papua New Guinea from both Queensland and Northern Territory material could be interpreted as implying a more recent separation of the two main Australian groups, viz. Queensland and Northern Territory. Quite clearly the physical separation of the three current main centres has led to a significant divergence in seedling morphology.

The study was diminished somewhat by the lack of seed for experiment from the Kai Islands, Indonesia and from sources from near Port Moresby, Papua New Guinea; these sources would reveal the degree of uniformity within Papua New Guinea and Indonesia. Material from western Cape York was another notable omission. Despite this, the general trends were clear and all future provenance trials and domestication work would greatly benefit by the inclusion of material from all three main geographic regions viz. Papua New Guinea, Queensland and Northern Territory.

The material from Thailand did not fit neatly into the three main groupings but nevertheless was somewhat similar to material from Queensland. This could imply that a better fit could have been achieved if more natural material from the species range was included in the study or else it could mean that under cultivation the original material of *A. auriculiformis* introduced to Thailand has 'moved' morphologically over subsequent generations in cultivation. It is possible that a distinct land race has developed in Thailand. The Thai material was first introduced in 1935 from Australia but there was no record of the seed origin (Corvanich 1982). From an historical perspective a Queensland origin is likely.

Acknowledgments

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References

Barlow, B.A. and Hyland, B.M.P. 1988. The origins of the flora of Australia's wet tropics. In: Kitching, R.L., ed., The ecology of Australia's wet tropics. Proceedings of the Ecological Society of Australia, Vol. 15, 1–17.

Boland, D.J., Pinyopusarerk, K., McDonald, M.W., Jovanovic, T. and Booth, T.H. 1990. The habitat of *Acacia auriculiformis* and probable factors associated with its distribution. Journal of Tropical Forest Science, 3(2), 159-180.

Corvanich, A. 1982. Fast-growing tree and plantation forestry in Thailand. Forestry Association of Thailand, Bangkok, 228 p.

Payne, R.W., Lane, P.W., Ainsley, A.E., Bicknell, K.E., Digby, P.G.N., Harding, S.A., Leech, P.K., Simpson, H.R., Todd, A.D., Verrier, P.J., White, R.P., Gower, J.C. and Tunnicliffe Wilson, G. 1987. Genstat 5 reference manual. New York, Oxford University Press.

Shea, K.R. and Carlson, L.W. 1984. Increasing productivity of multipurpose tree species: a blueprint for action. IUFRO planning workshop for Asia held in Kandy, Sri Lanka, 16–28 July 1984, 100 p.

Growth and Survival at 18 Months of an *Acacia auriculiformis* Trial in Southern China

Yang Minquan and Zeng Yutian*

Abstract

Growth results from an 18-month-old international provenance trial of *Acacia auriculiformis* established near Guangzhou, Guangdong province, China are presented. At this early stage Queensland provenances are superior to those from Papua New Guinea, Northern Territory (Australia) and China in terms of stem form, height and diameter growth.

ACACIA *auriculiformis* was first introduced to southern China in the early 1960s, but the origin of the seed is not known. Approximately 50 000 ha have been established in plantations and 3000 km along roadsides with locally collected seed. Trees of *A. auriculiformis* are generally heavily branched with short crooked stems. This poor stem form is a major drawback, limiting the utilisation of the species. The species also lacks wind resistance, possibly due to its branching characteristics. There is a pressing need for genetic improvement.

Provenance testing of *A. auriculiformis* in China began with the 1985 planting of five provenances in an *Acacia* species/provenance trial on Hainan Island (reported by Yang and Zeng elsewhere in these proceedings). Twenty-five seed sources were introduced in 1989 for a wide-ranging provenance trial in Guangdong province and this paper reports the 18-month survival and growth results. This 1989 trial is part of an international series of *A. auriculiformis* trials that has been coordinated by the USAID Forestry/Fuelwood Research and Development (F/FRED) project.

Materials and Methods

Trial site

The trial was planted in June 1989 at Long Dong Forest Farm (23° 14 'N, 113° 14 'E, 150–180 m asl) northeast of Guangzhou, Guangdong in hilly topography on 20–25° slope. The soil is a yellow-red latosol derived from granite, acid (pH 4.5) and infertile. The site formerly carried a poor plantation of *Pinus massoniana*.

The climate in this area is subtropical with monsoonal influences. The mean annual temperature is 21.8 °C, and mean annual rainfall is 1694 mm. Temperature extremes are 0 °C and 38 °C.

Provenances in trial

The trial consisted of 26 *A. auriculiformis* seedlots. Twenty-five of these were provided by the CSIRO Australian Tree Seed Centre and covered the natural range of the species: in Australia, Queensland (9 provenances) and Northern Territory (13 provenances); in Papua New Guinea (3 provenances) (Gunn et al. 1987). One *A. auriculiformis* provenance was collected from local plantings in Guangzhou and *Acacia confusa* (Lufeng County) was included as a control. Seed origin details are given in Table 1.

Site preparation, planting and trial design

After clearing and burning the vegetation on site, planting holes (40 × 40 × 40 cm) were dug at 3 × 3 m spacings. Phosphorus fertiliser (100 g per hole) was applied prior to planting. The seed was sown in March and the seedlings planted three months later in June 1989. Nursery establishment was based on the guidelines given in the field operation manual (Boland and Pinyopusarerk 1988). The trial design was a completely randomised block for 27 treatments with six replicates and 16 (4 × 4) tree plots. Two rows of *A. auriculiformis* were planted around the trial to minimise edge effects.

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Measurement and analysis

Height, diameter (dbh), crown width and number of stems/tree and survival were measured and assessed at 18 months. These six characters were analysed at the provenance level using Duncan's multiple range tests. An analysis of variance using plot means for these six characters was also conducted using GENSTAT statistical software. Crown width was assessed to give an indication of how quickly the provenances could occupy a site and control competing weeds.

Results

The Queensland provenances were the best in trial in terms of height and diameter growth. These were from Coen River (S16142), Wenlock River (S16145), Rifle Creek, Mt Molloy (S15985), Kings Plain (S16485) and Coen (S15697). They grew 3.9–4.3 m in height and 3.2–3.7 cm in diameter (dbh) after 18 months, and all had good stem form. There were no significant differences between them (see Table 2) and they had grown significantly larger than the local *A. auriculiformis* (3.7 m, 2.9 cm dbh) and *A. confusa* (1.8 m, 0.6 cm dbh). The Somerset, Qld (S16129) and Coomarlie Creek, NT (S16150) provenances were the poorest of the trial introductions, growing 2.7 m and 3.2 m respectively. Coomarlie Creek had the lowest survival (62%) in trial and particularly poor form with many stems. In general the NT provenances had the poorest form in the trial.

Provenance means for height, diameter, crown width, stem form, number of stems per tree and survival analysed using Duncan's multiple range tests are presented in Table 2. The analysis of variance used in Table 3 demonstrates that variation between the provenances was highly significant for height, diameter, number of stems per tree and survival.

Table 1. Selections for international provenance trials of *Acacia auriculiformis*.

CSIRO Seedlot No.	Location	Lat (S)	Long (E)	Alt. (m)	No. parents
15483	Archer River, QLD	12°26′	142°57′	100	5
15697	Coen, QLD	14°07′	143°16′	160	10
15985	Mt Molloy, Rifle Ck, QLD	16°41′	145°17′	380	10
16142	Coen River, QLD	13°53′	143°03′	170	7
16145	Wenlock River, QLD	13°06′	142°56′	130	20
16484	Morehead River, QLD	15°03′	143°40′	50	6
16485	Kings Plain, QLD	15°42′	145°06′	150	7
16129	Somerset, QLD	10°45′	142°36′	15	1
16137	Piccaninny Creek, QLD	13°09′	142°48′	40	3
16147	Noogoo Swamp, King Ck, NT	12°23′	131°00′	28	5
16148	Manton River, NT	12°50′	131°07′	100	10
16150	Coomarlie Creek, NT	13°07′	131°17′	100	1
16151	Mary River, NT	13°36′	132°08′	120	8
16152	E Alligator River, NT	12°17′	132°55′	10	10
16153	Cooper Creek, NT	12°06′	133°11′	40	5
16154	Goodmadeer River, NT	12°08′	133°41′	50	9
16156	Yarunga Creek, NT	12°18′	134°48′	50	6
16158	Gerowie Creek, NT	13°19′	132°15′	100	12
16161	Howard Springs, NT	12°27′	131°03′	70	12
16162	Reynolds River, NT	13°32′	130°52′	150	10
16160	S Alligator River, NT	13°16′	132°19′	40	10
16163	Elizabeth River, NT	12°36′	131°04′	40	9
15648	Bensbach-Balamuk, PNG	8°52′	141°15′	20	9
16106	Mibini, PNG	8°49′	141°38′	40	35
16107	Old Tonda, PNG	8°55′	141°33′	40	19
89002	Guangzhou, CHN	23°06′(N)	113°14′	100	—
A. confusa					
89003	Lufeng County, CHN	23°00′(N)	115°40′	150	—

Table 2. Duncan's multiple range tests for height, diameter at breast height (dbh), crown width, stem form index, number of stems per tree at 18 months in a provenance trial.

Height (m)			Dbh (cm)			Crown width (m)			No. of stems per tree			Survival (%)		
16142	QLD	4.3	16142	QLD	3.7	16162	NT	1.68	16142	QLD	1.00	16132	NT	99.5
16145	QLD	4.1	16145	QLD	3.5	16161	NT	1.57	15985	QLD	1.02	16107	PNG	99.3
15985	QLD	4.1	15985	QLD	3.5	15648	PNG	1.56	16129	QLD	1.02	16106	PNG	99.3
16485	QLD	4.1	16485	QLD	3.4	16106	PNG	1.55	16485	QLD	1.02	16161	NT	99.3
16484	QLD	4.1	15483	QLD	3.4	16163	NT	1.54	16484	QLD	1.03	15985	QLD	98.6
15697	QLD	3.9	16107	PNG	3.4	16142	QLD	1.54	15483	QLD	1.05	16147	NT	98.4
16163	NT	3.9	16484	QLD	3.3	15985	QLD	1.53	16145	QLD	1.07	16154	NT	96.6
15483	QLD	3.8	15648	PNG	3.3	16151	NT	1.52	15648	PNG	1.07	16153	NT	96.2
16107	PNG	3.8	16106	PNG	3.3	16107	PNG	1.50	16154	NT	1.07	16160	NT	96.0
15648	PNG	3.8	16161	NT	3.3	16153	NT	1.46	16106	PNG	1.10	89002	CHN	95.0
16106	PNG	3.7	15697	QLD	3.2	16145	QLD	1.46	15697	QLD	1.10	15697	QLD	94.9
16161	NT	3.7	16163	NT	3.1	16154	NT	1.45	16160	NT	1.10	16162	NT	94.7
16147	NT	3.7	16147	NT	3.1	16148	NT	1.45	16107	PNG	1.12	16151	NT	94.7
16154	NT	3.7	16154	NT	3.1	16152	NT	1.45	16153	NT	1.12	16137	QLD	94.7
16151	NT	3.7	16156	NT	3.0	15697	QLD	1.44	16161	NT	1.13	16148	NT	94.5
16137	QLD	3.7	16162	NT	2.9	16160	NT	1.44	16156	NT	1.13	15483	QLD	94.5
89002	CHN	3.7	89002	CHN	2.9	16147	NT	1.42	16158	NT	1.13	16484	QLD	94.5
16156	NT	3.6	16151	NT	2.9	16485	QLD	1.40	16163	NT	1.17	16142	QLD	94.2
16153	NT	3.6	16153	NT	2.8	89002	CHN	1.39	89002	CHN	1.20	16145	QLD	93.8
16160	NT	3.6	16148	NT	2.8	16150	NT	1.38	16137	QLD	1.22	16485	QLD	93.2
16158	NT	3.6	16152	NT	2.8	16158	NT	1.38	16148	NT	1.25	16158	NT	91.7
16162	NT	3.5	16160	NT	2.8	16156	NT	1.37	16152	NT	1.30	15648	PNG	87.4
16148	NT	3.4	16137	QLD	2.7	16484	QLD	1.35	16150	NT	1.38	16156	NT	86.9
16152	NT	3.4	16158	NT	2.7	16137	QLD	1.30	16151	NT	1.40	16150	NT	83.4
16150	NT	3.2	16150	NT	2.4	16129	QLD	1.29	16162	NT	1.43	16163	NT	81.5
16129	QLD	2.7	16129	QLD	2.1	15483	QLD	1.27	16147	NT	1.45	89003	CHN	81.9
89003	CHN	1.8	89003	CHN	0.6	89003	CHN	0.97	89003	CHN	1.45	16129	QLD	61.9
						(A. confusa)								

Table 3. Analyses of variance, based on plot means, for height, dbh, crown width, number of stems per tree and survival rate for an *Acacia auriculiformis* provenance trial.

Source of variation	DF	MS	F-ratio
Height			
Provenance	26	1.4189	10.77**
Replication	5	1.6310	12.38**
Error	130	0.1317	
Dbh			
Provenance	26	2.1128	8.69**
Replication	5	1.6310	10.08**
Error	130	0.2432	
Crown width			
Provenance	26	0.1036	2.36**
Replication	5	0.1560	3.55**
Error	130	0.0439	
No. of Stems per tree			
Provenance	26	0.1235	2.91**
Replication	5	0.0686	1.61
Error	130	0.0425	
Survival rate ($Sin^{-1}P$ value)			
Provenance	26	335.5040	3.01**
Replication	5	183.9994	1.65
Error	130	111.5308	

Note: ** indicate significant differences at 1% level

Discussion

Differences between the provenances for all growth parameters measured were highly significant. These results differ from those obtained for five provenances in trial on Hainan Island where variation was significant (0.05 level) between provenances for diameter only after four years (reported by Yang and Zeng elsewhere in these proceedings). At this early stage the Queensland provenances of *A. auriculiformis* have the overall best growth and stem form, followed by the PNG provenances. The Northern Territory provenances are generally the poorest.

In terms of volume growth, estimated using a simple formula (⅓ diameter^2 × height), the best Queensland provenance (16142 Coen River) showed 199% volume increase over the *A. auriculiformis* control from Guangzhou. By comparison the best PNG provenance (S16107 Old Tonda) produced a 123% volume increase and the best NT provenance (S16161 Howard Springs) a 105% volume increase in wood production over the Chinese control.

Papua New Guinea was only represented by three provenances in this trial and thus it is recognised that the potential of *A. auriculiformis* from this region has not yet been fully assessed. A more extensive trial of PNG provenances with the best of the Queensland provenances is strongly recommended.

These trial results indicate the considerable potential for new provenances of *A. auriculiformis* to improve the productivity and utilisation of the species in southern China.

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References

Boland, D.J. and Pinyopusarerk, K. 1988. *Acacia auriculiformis* international provenance trials — guide for research cooperators. CSIRO Division of Forestry and Forest Products, Canberra, Australia, 13 p. (unpublished).

Gunn, B.V., McDonald, M.W. and Moriarty, J. 1987. 1987 seed collections of *Acacia auriculiformis* from natural populations in Papua New Guinea and northern Australia. CSIRO Australian Tree Seed Centre, Canberra, Australia.

Results at 12 Months of *Acacia auriculiformis* Trials in Thailand

V. Luangviriyasaeng*, K. Pinyopusarerk** and E.R. Williams**

Abstract

Three provenance trials of *Acacia auriculiformis* at Sai Thong, Kanchanaburi and Sakaerat in Thailand were analysed for growth and survival at age 12 months. Twenty-seven provenance samples from three major natural occurrences of the species, viz. Papua New Guinea and Queensland and Northern Territory, Australia were included. Provenance means were significantly different for two trials at Sai Thong and Sakaerat. There are no clear superior provenances at this stage as the effect of provenance by site interaction was quite substantial. The results suggest the genetic diversity of the species and support the need for genetic improvement.

ACACIA *auriculiformis* occurs naturally in Australia, Papua New Guinea and Indonesia. The species was first introduced to Thailand as an ornamental tree from Australia in 1935 (Corvanich 1982). There is no record of the seed origin. The species is easy to establish and grows well in most parts of the country. It has been used in reforestation programs since the 1960s, with seed from local sources supplying most of the plantings.

It was not until after 1984, when new seed sources from Australia and Papua New Guinea were imported, that field trials were established to investigate provenance variation in the species. These early provenance trials, although somewhat limited in the range of provenance material included, demonstrated marked differences in growth rate and tree form (Pinyopusarerk 1989). A wider range of provenances of *A. auriculiformis* was planted in 1989. Seed for these plantings was made available when CSIRO Australian Tree Seed Centre and the Forestry/Fuelwood Research and Development (F/FRED) Project jointly funded the first extensive provenance seed collection of this acacia in northern Australia and Papua New Guinea (Gunn et al. 1987). The F/FRED Project collaborated further with ACIAR in a range-wide provenance evaluation of replicated trials in eight countries in Africa and Asia including Thailand. This paper reports growth and survival recorded at 12 months of three trials planted in Thailand by the Royal Forest Department (RFD).

Materials and Methods

Seedling establishment

Twenty-seven provenances in all were used but only 25 were planted at each of three sites. These provenances cover a major part of the species' natural distribution. Details of the seed origins are given in Table 1.

Nursery establishment followed the guidelines provided in the manual for field operation (Boland and Pinyopusarerk 1988). In summary, seed was pretreated by pouring boiling water on to the seed and soaking the seed overnight in the gradually cooling water. The treated seed was sown directly into polythene bags. No special inoculation with a microorganism (*Rhizobium*) was made in the nursery. Seedlings were about 6 months old at the time of planting.

Field establishment

Field trials were established in 1989 at three sites with differing conditions as follows:

(1) Sai Thong, Prachuap Khirikhan (latitude 11°25′N, longitude 99°27′E, altitude 50 m)

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representing humid site type. Mean annual rainfall is 1500 mm and mean annual temperature 27.2 °C. Soil is loamy sand to sandy clay loam, pH 4.9.

(2) Lampao-Lamsai, Kanchanaburi (13 °58 'N, 99 °18 'E, 45 m) representing dry site type. The area normally receives a mean annual rainfall around 900–1000 mm and has a mean annual temperature of 29.9 °C. Soil is sandy and silty loam, pH 6–7.

(3) Sakaerat, Nakhon Ratchasima (14 °13 'N, 101 °55 'E, 420 m) is heavily infested with *Imperata cylindrica* as a result of shifting cultivation. Mean annual rainfall and temperature are 1300 mm and 25.9 °C respectively. Soil is red yellow podzolic, pH 5–6.

A randomised complete block design with six replicates was used. Each replicated plot consisted of 16 trees (4 × 4) spaced at 3 m × 3 m. Two buffer rows were planted to surround the experimental area.

The trial sites were fully cultivated prior to planting and 50 g of complete fertiliser (NPK 12:24:12) was applied to each plant within one month of planting. Fertiliser was dug in.

Assessments

Height, diameter at 10 cm above ground (dgl) and survival were recorded for each plant at 6 and 12 months after planting at all sites. Diameter at breast height (dbh) was measured at 12 months for the trials at Sai Thong and Sakaerat. Geometric mean dbh (square root of the sum of the squares of each individual stem diameter) was used for multistemmed trees at Sakaerat whereas at Sai Thong only dbh of the largest stem was measured. The trial at Kanchanaburi was not measured for dbh because most trees were less than 1.3 m in height. Only the 12-month data were subjected to statistical analyses.

Data analyses

Analyses of variance were carried out to investigate differences between provenances at each site as well as interactions between provenance and site, and between geographic region and site (geographic region refers to Queensland, Northern Territory and Papua New Guinea). The 'GENSTAT' statistical package was used for all analyses.

Table 1. Details of the origin of the 27 provenances of *Acacia auriculiformis*.

CSIRO seedlot No.	Provenance	Latitude (S)	Longitude (E)	Altitude (m)	Number parents
15483	Archer River, Qld	12 °26 '	142 °57 '	100	5
15697	South Coen, Qld	14 °07 '	143 °16 '	160	10
15985	Mt Molloy, Rifle Creek, Qld	16 °41 '	145 °17 '	380	10
16142	Coen River, Qld	13 °53 '	143 °03 '	170	7
16145	Wenlock River, Qld	13 °06 '	142 °56 '	130	20
16484	Morehead River, Qld	15 °03 '	143 °40 '	50	6
16485	Kings Plain, Qld	15 °42 '	145 °06 '	150	7
16147	Noogoo Swamp, NT	12 °23 '	131 °00 '	28	5
16148	Manton River, NT	12 °50 '	131 °07 '	100	10
16149	Douglas River, NT	13 °51 '	131 °09 '	70	10
16151	Mary River, NT	13 °36 '	132 °08 '	120	8
16152	East Alligator River, NT	12 °17 '	132 °55 '	10	10
16153	Cooper Creek, NT	12 °06 '	133 °11 '	40	5
16154	Goomadeer River, NT	12 °08 '	133 °41 '	50	9
16155	Mann River, NT	12 °22 '	134 °08 '	60	4
16156	Yarunga Creek, NT	12 °18 '	134 °48 '	50	6
16158	Gerowie Creek, NT	13 °19 '	132 °15 '	100	12
16160	South Alligator River, NT	13 °16 '	132 °19 '	100	10
16162	Reynolds River, NT	13 °32 '	130 °52 '	150	10
16163	Elizabeth River, NT	12 °36 '	131 °04 '	40	9
16187	Melville Island, NT	11 °55 '	130 °50 '	1	7
16101	North Bensbach to Weam, PNG	8 °50 '	141 °15 '	10	16
16103	South Balamuk, PNG	9 °00 '	141 °15 '	10	7
16105	Balamuk on Bensbach River, PNG	8 °55 '	141 °17 '	20	12
16106	North Mibini, PNG	8 °49 '	141 °38 '	40	35
16107	Old Tonda Village, PNG	8 °55 '	141 °33 '	40	19
16108	Mari Village, PNG	9 °11 '	141 °42 '	5	8

Results

Provenance differences

Separate analyses for each site showed significant differences between provenances for height and diameter at Sai Thong and Sakaerat whilst provenance survival was only significantly different at Sai Thong (Table 2). For Kanchanaburi, there were no significant differences between provenances for all traits, probably due to the poor overall growth at this site.

At Sai Thong, a group of provenances from Queensland (i.e. Wenlock, South Coen, Kings Plain and Morehead) and one provenance from Northern Territory (Mann) were growing faster while Papua New Guinea provenances were poorer in overall performance, specially a seedlot from Mari Village. The results for Sakaerat were however different; most Papua New Guinea seedlots were outstanding particularly in diameter growth. The Mari Village provenance from Papua New Guinea was the poorest in height and diameter at all sites.

It should be noted here that mean dbh for Sai Thong was determined from the largest stem only, and thus it may not reflect the actual size of multi-stemmed trees. Nevertheless, the results are consistent with the general trend for height and dgl.

Combined analyses across sites

Because of the poor overall growth at Kanchanaburi, the data for this site were not included in the combined analyses.

Height There were marked differences in height between sites ($P < .001$), trees at Sakaerat being taller than those at Sai Thong. Differences between

Table 2. Provenance means for height (m), dbh (cm), dgl (cm) and survival (%) at 12 months after planting of *A. auriculiformis* provenance trials in Thailand.

CSIRO Seedlot No.	Sai Thong				Kanchanaburi			Sakaerat			
	Ht	Dbh	Dgl	Sur	Ht	Dgl	Sur	Ht	Dbh	Dgl	Sur
15483	2.6	1.8	4.3	96.1	—	—	—	3.3	3.4	6.1	100.0
15697	2.9	2.2	4.3	94.0	1.2	1.8	90.3	3.5	4.1	6.4	99.9
15985	2.6	1.8	3.7	99.0	1.2	1.9	80.2	2.9	3.0	5.6	99.9
16142	2.7	1.9	4.3	97.9	1.2	2.0	88.5	3.4	3.6	6.3	99.9
16145	3.0	2.2	4.5	98.5	1.3	2.0	85.3	3.4	4.0	6.2	100.0
16484	2.8	1.9	4.1	94.9	1.2	1.8	92.1	3.1	3.3	5.5	99.5
16485	2.8	2.1	4.3	96.4	1.2	2.0	88.5	3.3	3.6	6.0	99.9
16147	2.4	1.2	4.0	96.2	1.2	2.2	79.3	3.0	3.1	5.7	100.0
16148	2.6	1.5	4.1	97.1	1.0	1.7	83.9	3.0	3.4	6.0	99.6
16149	2.7	1.7	4.3	99.5	1.1	1.9	89.7	3.2	3.8	6.3	99.9
16151	2.6	1.6	4.1	91.8	1.3	2.2	82.4	3.1	3.9	6.7	99.9
16152	2.4	1.4	4.8	99.5	1.3	2.5	92.2	2.4	2.6	5.3	100.0
16153	2.5	1.4	3.7	97.2	1.2	2.0	84.3	3.1	3.3	5.7	99.5
16154	2.8	1.8	4.7	99.2	1.0	1.7	71.5	3.1	3.6	6.4	100.0
16155	3.2	2.1	4.6	99.9	1.1	1.9	82.8	3.3	3.5	5.6	100.0
16156	2.5	1.6	4.5	94.8	1.2	1.9	73.2	3.4	4.0	7.0	99.9
16158	—	—	—	—	1.2	2.2	82.2	—	—	—	—
16160	2.5	1.4	4.0	95.9	1.1	1.8	90.3	3.1	3.1	5.8	100.0
16162	—	—	—	—	1.2	1.9	86.9	—	—	—	—
16163	2.8	1.7	4.3	99.2	1.1	2.0	77.2	3.4	3.7	6.3	100.0
16187	2.4	1.3	4.0	97.9	1.1	1.7	84.0	2.8	3.2	5.7	99.9
16101	2.5	1.6	3.9	93.5	1.1	1.6	80.4	3.6	4.5	6.9	99.9
16103	2.6	1.6	3.9	98.2	—	—	—	3.3	4.1	6.2	100.0
16105	2.4	1.4	3.7	95.5	1.4	2.4	82.4	3.4	4.2	6.6	99.9
16106	2.4	1.5	3.9	99.2	1.3	2.1	84.7	3.3	4.1	6.7	99.6
16107	2.4	1.3	3.9	92.6	1.2	2.0	89.7	3.4	4.3	7.0	99.9
16108	2.1	1.1	3.5	81.7	1.0	1.6	82.0	2.3	2.6	5.0	99.6
Significant difference	**	**	**	**	ns	ns	ns	**	**	**	ns

(** significant at $P < .01$, ns = not significant) geographic regions were significant (P < .01), and there was also a significant provenance within geographic region effect (P < .01), possibly due to the values for seedlots 16152 (East Alligator River, NT) and 16108 (Mari Village, PNG) being low. The geographic region by site interaction was barely significant (P < .05) and resulted from the inconsistent behaviour of the PNG provenances, i.e. they grew slowly at Sai Thong and faster at Sakaerat. Estimated height means for the geographic region by site are included in Table 3.

Diameter at breast height The pattern of results for dbh was the same as that for height, but the differences were more pronounced. The effects for site, geographic region, provenances within geographic region and the geographic region by site interaction were all highly significant (P < .001). Estimated dbh means for the geographic region by site interaction (Table 3) again demonstrate the inconsistent performance of the PNG provenances for the Sakaerat site.

Diameter at ground level The results obtained for dgl were somewhat different. There were no significant differences between geographic regions and for provenances within geographic region. However, there were still strong site effects and geographic region by site interactions (P < .001), again due to the behaviour of PNG material (Table 3).

Survival There was a significant difference (P < .001 in survival between sites, with Sai Thong (96.2%) having poorer survival than Sakaerat (99.9%). The site difference was accentuated by the inclusion of Kanchanaburi (84.2%) in the analysis. All other effects were non-significant.

Discussion

The three RFD-planted provenance trials in Thailand, though only 12 months old, have shown variation in height and diameter growth of *A. auriculiformis* amongst the three main geographic regions, viz. Queensland, Northern Territory and Papua New Guinea. Provenance variation within each geographic region was also observed. There are no distinct superior provenances as the effect of provenance by site interaction was quite substantial. Nevertheless the variation found at this early stage indicates the genetic diversity of the species within its natural distributional range. This variation offers an opportunity for further improvement of the species following provenance selection.

Material from Papua New Guinea had previously been found to grow more vigorously than that from Australia (Pinyopusarerk 1989) or when compared to local seed sources (Turnbull 1987; Bulgannawar and Math, these proceedings). However, in the present study which included a wider range of provenance samples, the results indicate that provenances from Queensland and/or Northern Territory can grow as well as or faster than provenances from Papua New Guinea at particular sites. In fact one provenance from Papua New Guinea, i.e. Mari Village, was the slowest growing at all three sites.

There were marked differences in growth and survival between sites. Sai Thong is generally a favourable site for many *Acacia* species including *A. auriculiformis* (Pinyopusarerk 1989). In these provenance trials, however, growth was less at this site compared to Sakaerat. Sai Thong was hit by a typhoon in November 1989, and growth could have been checked by the gusty wind, resulting in a slower development.

The poor overall growth at Kanchanaburi, although not totally surprising, was worse than expected. The planting area normally receives less rainfall than other sites but suffered from a severe drought in 1989 (total rainfall being less than 600 mm) shortly after planting, which further deteriorated growth and survival of the trees.

The present early results are for growth and survival only. Other traits, especially tree form, are equally important and must be included in future assessments. Furthermore, provenance performance may change with time.

Table 3. Estimated means for height (m), dbh (cm) and dgl (cm) for the country by site interaction in *A. auriculiformis* provenance trials in Thailand.

	Height		Dbh		Dgl	
	Sai Thong	Sakaerat	Sai Thong	Sakaerat	Sai Thong	Sakaerat
Qld	2.78	3.25	1.96	3.57	4.22	6.00
NT	2.60	3.08	1.56	3.42	4.25	6.04
PNG	2.40	3.21	1.42	3.95	3.79	6.39

Acknowledgments

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References

Boland, D.J. and Pinyopusarerk, K. 1988. *Acacia auriculiformis* international provenance trials — a guide for research cooperators. CSIRO Division of Forestry and Forest Products, Canberra, Australia, 13 p. (unpubl.).

Corvanich, A. 1982. Fast-growing trees and plantation forestry in Thailand. The Forestry Association of Thailand, Bangkok. 228 p.

Gunn, B.V., McDonald, M.W. and Moriarty, J. 1987. 1987 seed collections of *Acacia auriculiformis* from natural populations in Papua New Guinea and Northern Australia. CSIRO Australian Tree Seed Centre, Canberra, Australia (unpubl.).

Pinyopusarerk, K. 1989. Growth and survival of Australian tree species in field trials in Thailand. In: Boland, D.J., ed., Trees for the Tropics. ACIAR Monograph No. 10, 109–127.

Turnbull, J.W. 1987. Recent results of Australian nitrogen fixing trees in the tropics. Report on regional training course in nitrogen fixing trees. Regional Wood Energy Development Program in Asia. GCP/RAS/111/NET, Bangkok, October 1987, 108–118.

Genetic Variation for Salt and Waterlogging Tolerance of *Acacia auriculiformis*

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Abstract

A. auriculiformis, an economically important tropical and subtropical nitrogen-fixing tree species, has been shown in salt screening trials to be moderately salt tolerant. This study has demonstrated considerable provenance variation for salt and waterlogging tolerance. Provenances for further field evaluation and individual plant selection have been identified.

ACACIA *auriculiformis* is now widely planted as an exotic in many developing countries, particularly tropical lowlands. The advantages of this tree include good growth rates, excellent fuelwood and pulping properties and an ability to fix atmospheric nitrogen. Recent glasshouse studies also indicate that this species is moderately salt-tolerant (Aswathappa et al. 1986). Therefore the potential also exists for the use of *A. auriculiformis* in the utilisation and reclamation of saline land.

Within its wide natural distribution, *A. auriculiformis* is exposed to a broad range of edaphic and climatic conditions. It is found on saline, alkaline and waterlogged soils (Turnbull et al. 1986). It is possible that populations on saline sites may have become adapted to their environment and therefore become altered genetically from other populations.

This paper reports on a glasshouse study of intraspecific variation for salt and waterlogging tolerance in *A. auriculiformis*. The provenances tested were from natural populations in Australia (Queensland (Qld) and Northern Territory (NT)) and Papua New Guinea (PNG) as well as naturalised populations in Thailand.

Materials and Methods

Seedlings used in the two experiments outlined below were obtained from a study on morphological variation within *A. auriculiformis* (Pinyopusarerk et al. 1991). Seedlings had been grown in 150 mm diameter plastic pots containing a mixture of 70% perlite and 30% washed coarse river sand in a glasshouse at the CSIRO Division of Forestry maintained at day/night temperatures of 30/25 °C. The relative humidity was high, reaching up to 80% towards the end of the experimental period. Plants were supplied with daily additions of one-quarter strength Hoagland's No. 2 nutrient solution via an automated drip irrigation system. Seedlings were approximately 3 months old (average heights of 60–65 cm) when salt and waterlogging treatments began.

Experiment 1

This experiment was designed as a randomised complete block, with 30 provenances (Table 1) treated with either sodium chloride (NaCl) or no salt (control) in two blocks. Twenty-one provenances were represented by three individual tree seed collections ('families') and nine provenances consisted of bulked seed. Each provenance was represented by six seedlings in each block.

Pots were watered three times per day by an automated recirculating drip irrigation system, so that each plant received 900–1200 ml per day. Control plants were given nutrient solution only whereas the salt-treated plants were challenged with increasing concentrations of NaCl made up in nutrient background. NaCl concentrations were increased by 25 mol m^{-3} per day and held at constant salinities for varying periods (Table 2). Salt concentrations in the large holding tanks were monitored daily for electrical conductivity (EC) and pH and adjusted where necessary.

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Table 1. Details of *A. auriculiformis* provenances used in salt and waterlogging screening experiments (seed obtained from ATSC, CSIRO Division of Forestry, Canberra, Australia).

Provenance (CSIRO seedlot)	Location	Latitude (S)	Longitude (E)
# 15483	Archer River, Qld	12°26′	142°57′
15697	S. Coen, Cape York, Qld	14° 7′	143°16′
# 15985 *	Mt. Molloy, Rifle Ck, Qld	16°41′	145°17′
# 16142	Coen River, Qld	13°53′	143°03′
16145	Wenlock River, Qld	13° 6′	142°56′
# 16484	Morehead River, Qld	15° 3′	143°40′
16485	Kings Plain, Qld	15°42′	145°06′
# 16147	Noogoo Swamp, King Ck, NT	12°23′	131°00′
16148	Manton River, NT	12°50′	131°07′
16149	Douglas River, NT	13°51′	131°09′
16151	Mary River, NT	13°36′	132°08′
16152	E. Alligator River, NT	12°17′	132°55′
# 16153 *	Cooper Ck, NT	12° 6′	133°11′
16154 *	Goomander River, NT	12° 8′	133°41′
# 16155 *	Mann River, NT	12°22′	134°08′
# 16156 *	Yuranga Ck, NT	12°18′	134°48′
16158	Gerowie Ck, NT	13°19′	132°15′
16160	S. Alligator River, NT	13°16′	132°19′
# 16161 *	Howard Springs, NT	12°27′	131°03′
16162	Reynolds River, NT	13°32′	130°52′
16163	Elizabeth River, NT	12°36′	131°04′
# 16187 *	Melville Island, NT	11°55′	130°50′
# 16101 *	N. Bensbach to Weam, PNG	8°50′	141°15′
# 16103 *	1 hr. S. Balamuk, PNG	9°00′	141°15′
# 16105	Balamuk on Bensbach R, PNG	8°55′	141°17′
# 16106	3 km N. Mimbini, PNG	8°49′	141°38′
# 16107	Old Tonda Village, PNG	8°55′	141°33′
# 16108 *	Mari Village WP, PNG	9°11′	141°42′
16297	Nong Sanom, Rayong, Thailand	12°35′(N)	101°15′
16397	Sai Thong, Prachuap, Khirikhan, Thailand	11°25′(N)	99°27′

* indicates provenances with bulked families
# indicates provenances used in waterlogging screening experiment (expt. 2)

Table 2. Chronology of salt application (experiment 2). Measurement periods are the same for experiments 1 and 2.

Day no.	NaCl concentration (mol m^{-3})	Measurements
1	0	height, diameter
7	0	
14	100	height
21	200	height
28	300	height, diameter
35	400	height
43	650	height
50	750	height, diameter
51	750	final harvest

Experiment 2

This experiment was also set up as a randomised complete block but with only 16 provenances (see Table 1) and only a waterlogging treatment. In the case of provenances with families, two families per provenance were used. Each provenance was represented by six plants. This experiment ran concurrently with experiment 1, but it was not possible to include data in the same statistical analysis as for experiment 1, since control plants were only included in experiment 1. Nevertheless, it was possible to compare results 'non-statistically' for waterlogged plants with control plants.

Waterlogging was achieved by filling large plastic tanks with nutrient solution and submerging pots to just above the surface of the medium. Solutions were changed approximately every 10 days.

Plant measurements

Plant height was measured weekly. Basal stem diameter (2 cm from the surface of the sand in the pot) was measured three times (exp. 1) and twice (exp. 2) with digital calipers. Symptoms of salt or waterlogging damage were recorded. All plants were destructively harvested on day 51 (after salt treatment began) and day 71 (after waterlogging began). Shoot dry weight (SDW) was determined after oven drying at 80 °C for 48 h. For experiment 1, chloride (Cl^-) concentration of the youngest expanded phyllode was determined spectrophotometrically using mercuric thiocynate after extraction of samples in hot water.

Calculations were made of:

(i) relative growth rates (RGR) based on height (RGRh) as follows:

$$RGR = (\ln X_f - \ln X_i)/n$$

where, f = end of period n
i = initial period
X = height (cm)
n = length of period (days)

(ii) salt damage index (SDI) based on number of phyllodes shed per unit plant size, as follows:

$$SDI = P_s/H_f$$

where, P_s = number of phyllodes shed per plant, determined from the number of abscission points
H_f = plant height at final harvest (height used because total phyllode number not recorded)

Analysis of variance (ANOVA) and regression analysis were carried out using the statistical package GENSTAT V, Release 4.40 B. Shoot dry weight, final height, final stem diameter and phyllode Cl^- concentrations were transformed logarithmically before analysis.

Results

There was considerable browning and yellowing of phyllodes of salt-treated plants, and, with increasing NaCl concentrations, necrosis and premature shedding of older phyllodes. The average SDI for salt-treated plants was 0.26 compared with only 0.03 for control plants. SDI values for individual salt-treated provenances were 0.15–0.51, however, this variation was not statistically significant, due to considerable within-provenance variation.

Phyllodes of most waterlogged plants were also chlorotic, with little apparent provenance variation. There was no salt or waterlogging-induced salt damage.

There was a highly significant ($p<0.001$) effect of NaCl on average RGRh, for all measurement periods (as described in Table 2). RGRh decreased considerably more over time for both NaCl and waterlogging treated plants than for control plants (Fig. 1). Even a relatively low NaCl concentration of 100 mM had a highly significant effect on RGRh (Fig. 1). The impact of NaCl was considerably greater than waterlogging after day 35. The continued decrease in RGRh for control plants during the course of the experiment indicates that all plants were in a post-exponential growth phase.

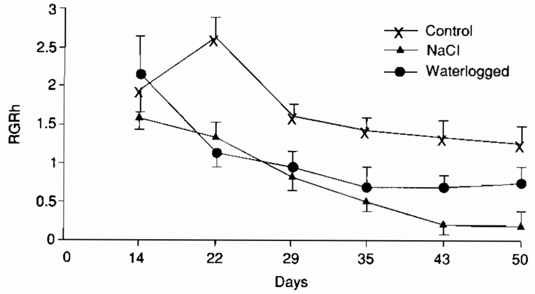

Fig. 1. Effect of salt and waterlogging on mean relative growth rates, based on shoot heights of 30 (salt) and 16 (waterlogging) provenances of *A. auriculiformis*.

There was no statistically significant variation between provenances or families within provenances in RGRh or relative salt tolerance, as assessed by [RGRh (salt)/RGRh (control)], even though the range of responses was large (Table 2). However, a poor correlation (r^2 = 0.41–0.43) was found between shoot dry weight and plant height at the final harvest. Considerably better correlations (r^2 = 0.66–0.75) were found between basal stem diameter and shoot dry weight, however only a few measurements of stem diameter were made during experimentation. There was significant ($p<0.05$) intraspecific variation in waterlogging in the ratio of [RGRh (waterlogged)/RGRh (control)] shown in Table 3.

Table 3. Intraspecific variation for salt and waterlogging tolerance in *A. auriculiformis*, based on the ratio of relative growth rate (RGRh) for salt- and waterlogging-treated plants compared with controls for 3 measurement periods (experiment 1 and 2; experiments were commenced on same day).

Measurement period	Days from expt. commencement	[$RGRh_{salt}$/ $RGRh_{control}$]	[$RGRh_{waterl}$/ $RGRh_{control}$]
2	14–21	0.44–0.62	0.32–0.62
4	29–35	0.27–0.47	0.30–0.79
6	43–50	0.02–0.22	0.22–1.21

The relative salt and waterlogging tolerance of provenances was also determined by the ratio for SDW under saline or waterlogging and control conditions. Ranking of provenances for SDW under control conditions and relative SDW under salinity and waterlogging at harvest is shown in Table 4.

Table 4. Intraspecific variation for salt and waterlogging tolerance in *A. auriculiformis* based on the ratio of final shoot dry weight of salt- and waterlogging-treated plants compared with controls for experiment 1 and 2. Shoot dry weights of control plants are also included, and ranked in decreasing order (letters next to each value indicate significance based on Duncan's multiple range test, $p<0.05$).

Provenance no.	Shoot dry wt controls (g per plant)		$SDW_{(salt)}/SDW_{(control)}$	$SDW_{(waterl)}/SDW_{(control)}$
16107	74.8	a	0.70	0.53
16106	69.0	ab	0.69	0.63
16108	66.2	ab	0.44	0.66
16161	65.3	ab	0.53	0.92
16160	64.5	abc	0.45	—
16151	63.9	abcd	0.60	—
15483	63.6	abcd	0.49	0.39
16105	62.6	abcd	0.64	0.79
16147	62.4	abcd	0.42	0.78
16152	58.1	abcd	0.72	—
16101	56.1	abcd	0.77	1.09
16103	55.9	abcd	0.67	1.08
15985	55.0	abcd	0.45	0.47
16142	53.0	abcd	0.70	0.71
15697	52.6	abcd	0.71	—
16187	52.0	abcd	0.76	0.89
16163	51.1	abcd	0.41	—
16155	50.6	abcd	0.61	0.65
16156	50.5	abcd	0.60	0.99
16145	48.2	abcd	0.57	—
16297	47.5	abcd	0.41	—
16153	44.8	bcd	0.46	0.82
16158	42.6	bcd	0.51	—
16484	42.1	bcd	0.98	0.80
16162	40.2	cd	0.51	—
16149	38.5	cd	0.56	—
16154	38.5	cd	0.63	—
16397	36.1	d	0.56	—
16148	35.5	d	0.90	—

Average phyllode Cl^- concentrations increased significantly ($p<0.001$) from 0.31 mmol g^{-1} (control) to 0.44 mmol g^{-1} (NaCl treated). There was no significant provenance or family variation in Cl^- concentration.

Discussion

The seed sources used in this study covered an extensive geographic and edaphic range in Australia and Papua New Guinea (PNG). Seed of some provenances (e.g. S16147, S16152) was collected from saline sites near the coast. Many provenances occur naturally on seasonally waterlogged and/or flooded land, often in association with *Melaleuca* species.

Considerable intraspecific variation was found for salt tolerance (for different NaCl concentration ranges, 'moderate', 'high' and 'very high'), based on relative RGRh reduction (Table 3) or relative SDW (Table 4). For example, the relative tolerance based on SDW reduction ranged from 41 to 98%. However, it must be remembered that plants were only challenged with different NaCl concentrations for short periods (Table 2); therefore it is not possible to determine growth reductions for exposure to NaCl for extended periods. The system employed here was a convenient way of screening a large number of seedlots.

It was possible to identify the better performing provenances as those with a relative tolerance greater than one standard deviation from the average. However, since there was a poor correlation between height and SDW (probably partly due to differential phyllode shed), different provenances were selected depending on which index was used. Provenances 16156 (NT), 16154 (NT) and 16105 (PNG) were consistently the best performers based on RGRh across a range of salinites. Provenances 16148 (NT), 16484 (Qld) and 16103 (NT) were the best performers based on SDW.

However, there appeared to be little correlation between the degree of salinity at the collection site and measured salt tolerance in this experiment. For example, seed of provenance S16147 (NT) was collected from a tidal salt-pan, yet its salt tolerance was relatively poor (Table 4). Seed of provenance S16148 (NT) was collected from a non-saline riparian forest community, yet its salt tolerance was found to be high (Table 3). These results are in agreement with other workers (Aswathappa et al. 1987; Thomson 1988) and indicate that salt tolerance characteristics extend to populations that a priori may be expected not to be especially adapted to saline conditions.

Based on RGRh, provenances 16108 (PNG), 16105 (PNG) and 16161 (NT) were the most waterlogging tolerant, particularly after long exposure. Based on SDW, the best provenances were 16156 (NT), 16101 (PNG) and 16103 (PNG).

It is possible, therefore, from this study to select provenances with varying levels of tolerance to both salt and waterlogging. Since all provenances were grown under identical conditions, it is also possible to select provenances for superior growth rate and size under control conditions. High growth rate will obviously be a very important factor affecting productivity in the field. Provenances from PNG, in particular 16106 and 16107, had best growth under control conditions. This result is consistent with field observations. The most impressive stands are found in the swamp forests of western PNG; trees grow up to 35 m tall with long boles and small crowns (D.J. Boland, pers. comm.).

Results of this study support the findings of earlier work in which *A. auriculiformis* was found to be highly salt-tolerant compared with several other tropical acacias (Aswathappa et al. 1986). The ability of *A. auriculiformis* to minimise the accumulation of Cl^- in expanding tissues (i.e. young phyllodes) is also highlighted in this study and is in agreement with other findings (Marcar et al. 1991).

Although this study was performed in a glasshouse environment, with conditions (e.g. high humidity, adequate nutrient supply) favourable to plant growth and minimisation of salt impact, the results obtained have highlighted the high salt and waterlogging tolerance of *A. auriculiformis*. This study has also demonstrated considerable intraspecific variation and suggested the most promising provenances for further field evaluation.

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References

Aswathappa, N., Marcar, N.E. and Thomson, L.A.J. 1986. Salt tolerance of Australian tropical and subtropical acacias. In: Turnbull, J.W., ed., ACIAR Proceedings No. 16, 70–73.

1987. Screening of Australian tropical and subtropical tree species for salt tolerance. In: Rana, R.S., ed., Aforestation of Salt Affected Soils. Volume 2. CSSRI, Karnal, India. 1–17.

Marcar, N.E., Dart, P. and Sweeney, C. 1991. Effects of salinity and nitrogen application on growth, nitrogen fixation and chemical composition of three *Acacia* species. Plant and Soil (submitted).

Pinyopusarerk, K., Williams, E.R. and Boland, D.J. 1991. Geographic variation in seedling morphology of *Acacia auriculiformis* A. Cunn. ex Benth. Australian Journal of Botany (submitted).

Thomson, L.A.J. 1988. Salt tolerance in the genus *Eucalyptus*. University of Melbourne, Melbourne, Australia. PhD Thesis. 345 p.

Turnbull, J.W., Martensz, P.N. and Hall, N. 1986. Notes on lesser-known Australian trees and shrubs with potential for fuelwood and agroforestry. In: Turnbull, J.W., ed., Multipurpose Australian Trees and Shrubs. ACIAR Monograph No. 1, 108–111.

Seed Orchards of *Acacia auriculiformis* at Melville Island, Northern Territory, Australia

C.E. Harwood*, A.C. Matheson*, N. Gororo and M.W. Haines*****

Abstract

Seed orchards of *Acacia auriculiformis* were established at Melville Island, Northern Territory, Australia, in December 1988. Measurements at age 18 months of height, basal area at breast height and bole length are presented for the largest orchard, which contains 191 seedlots of individual families from across the natural range of the species and 9 from Thai selection programs. There were highly significant differences among geographic regions of origin for all variates. Papua New Guinea (PNG) and Queensland seedlots were substantially taller (around 4.5 m mean height) than those from the Northern Territory and Thailand (around 3.9 m). PNG seedlots had the largest basal area and those from Thailand the smallest, with Queensland and Northern Territory intermediate. Bole length was greatest for Queensland seedlots (mean bole length 2.27 m) and smallest for Northern Territory (0.74 m). The orchards have been selectively thinned and will be managed for seed production. A small number of individuals have clear straight boles and are candidates for genetic improvement programs.

Acacia auriculiformis is one of the most promising tree species for plantation forestry and reforestation in tropical environments (Pinyopusarerk 1990). Operational plantings in many countries use seed from local 'land races' which yield trees of poor form, with a bushy, multi-stemmed habit. However, some natural populations have much better form, with a straight single trunk and adult tree heights of over 30 metres in favourable environments. These traits would greatly improve the usefulness of the species for timber and pulp production. There is now great interest in many countries in identifying provenances and families (individual parent seed trees) that are superior in growth rate and form, and in commencing programs of genetic improvement and dissemination of improved seed for utilisation on a large scale.

Natural provenances occur in remote areas of Papua New Guinea (PNG), Irian Jaya and tropical Australia and thus require considerable financial and technical resources for seed collection, the results of which are highly unpredictable (Gunn et al. 1987). Seed orchards of *A. auriculiformis* have been established on Melville Island, Northern Territory, Australia in a collaborative venture involving the CSIRO Australian Tree Seed Centre, the Conservation Commission of the Northern Territory, and Melville Forest Products Pty Ltd. The aim is to provide a reliable source of high-quality seed of *A. auriculiformis* and lay the foundations for programs of genetic improvement for the species.

This paper reports on the performance of the largest of the orchards, as indicated by measurements of growth and form traits 18 months after planting. The emphasis is on differences between the three major geographic areas represented in the plantings, namely PNG, the Northern Territory and Queensland. A later publication will deal with variation between and within local provenances and heritability of economically important traits.

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Materials and Methods

Site description

Plantings are located in the Yapilika area, Melville Island, at approximately 11°34′S latitude and 130°34′E longitude, some 20 m above sea level.

Planting sites are separated at least 1 km from one another and from natural stands of *A. auriculiformis* to minimise external pollen inputs to individual stands.

The mean annual rainfall at Yapilika is approximately 1750 mm. The climate is monsoonal with about 90% of the annual rainfall occurring in the six months October to March, and a marked dry season of four months in which monthly rainfall remains below 40 mm. Mean annual temperature is about 25 °C, and the soil is predominantly a sandy earth over laterite. Sites were cleared and ploughed prior to establishment.

Establishment

Seedlings were raised in the Pickertaramoor Nursery, Melville Island. Seed was sown in seed trays and the germinants pricked out into plastic, book-type nursery containers with multiple seed cavities each of around 200 cm^3. Seedling stem height at the end of the nursery phase (around 3–4 months) was variable, but averaged 20–25 cm at field establishment in December 1988. Deficiencies with the watering system led to some nursery stock mortality, and a dry spell at planting provided less than optimal conditions for part of the field establishment phase.

Fertiliser was applied after planting at the rate of 229 g per tree (approximately 0.5 tonnes per hectare). The specially formulated NPK mix, with added zinc and copper, was developed for routine forestry operations on Melville Island. Weed control between rows was carried out mechanically with a tractor-mounted slasher, 3 and 15 months after field establishment.

Planting design

The material planted came from individual family collections of seed from across most of the natural range of the species, together with a small number of plus-tree families from genetic improvement programs in Thailand. Two types of planting were made:

1) Genetic conservation stands for the PNG material. There were separate stands for the Bensbach River catchment and the Morehead River catchment. In the individual stands, each family was initially represented by six replicates of five-tree row plots, with 3 m spacing between rows and 1.5 m spacing between trees within rows. Incomplete block designs were used.
2) Two seedling seed orchards, the larger with 200 PNG, Australian and Thai seedlots. An incomplete lattice design was used, again with six replicates of five-tree row plots for each family, and at the same spacing.

The genetic conservation and seed orchard plantings were duplicated to provide some security against environmental hazards such as fire, drought and attack by pests or pathogens. Only results from Seed Orchard 1 are reported here. Seed Orchard 1 incorporated 14 individual families from the Bensbach River catchment and 24 from the Morehead River catchment in PNG, 108 families from the Northern Territory and 45 from Queensland. Nine families from selection programs in Thailand were included. Details of the seedlots used are given in Table 1.

Assessment

The first measurement in July 1989 assessed survival and height, and the second measurement in July 1990 recorded height, diameter and form. Height was measured with height poles to an accuracy of 0.1 m. Diameter of all stems at breast height was measured by templates in 1 cm classes at half cm centres (0.5 cm, 1.5 cm, 2.5 cm, etc.). The length of the bole through to the first major fork was measured. For trees with bole length in excess of 2.0 m, the straightness of the bole was estimated as a score from 1 through 4 as follows:

1 not utilisable for applications requiring straightness
2 some utilisation potential but form poor
3 good but not completely straight
4 straight.

Statistical analysis

Data were entered initially into dBase III data files. The range of values for each variate was checked, and the within-plot variances were examined to identify data entry errors. Fill trees and the few trees judged to be hybrids with *A. mangium* were excluded from the subsequent analysis. The data sets were analysed using the REML computer program (Robinson 1987) to produce unbiased estimates of overall family means, adjusted for non-orthogonality. The unbiased family means were then analysed with GENSTAT (GENSTAT 5 1987) using the model:

$$Y(i,j,k) = \text{overall mean} + \text{area}_i + \text{provenance}_{ij} + \text{family}_{ijk}$$

Only the area and provenance terms of the GENSTAT analyses are presented in this paper.

Table 1. Provenances of *Acacia auriculiformis* used in Melville Island plantings.

CSIRO No.	Area and provenance	Latitude °S	Longitude °E	Altitude (m)	No. of families*
Papua New Guinea Bensbach					14
16101	Bensbach	8°50′	141°15′	20	2
16102	Dog Track	8°48′	141°13′	20	5
16103	S. Balamuk	9°00′	141°15′	10	3
16104	Karmuben	8°59′	141°16′	15	1
16105	Birrbant	8°55′	141°17′	20	3
Papua New Guinea Morehead					24
16106	Mibini	8°49′	141°38′	40	18
16107	Old Tonda	8°55′	141°33′	40	6
Northern Territory					108
16147	Noogoo Swamp	12°23′	131°00′	28	4
16148	Manton River	12°50′	131°07′	100	10
16149	Douglas River	13°51′	131°09′	70	10
16150	Coomarlie Creek	13°01′	131°07′	100	1
16151	Mary River	13°36′	132°08′	120	8
16152	E. Alligator River	12°17′	132°55′	10	10
16153	Cooper Creek	12°06′	133°11′	40	1
16154	Goomander River	12°08′	133°41′	50	8
16155	Mann River	12°22′	134°08′	60	4
16157	Ramingining	12°28′	134°54′	80	1
16158	Gerowie Creek	13°29′	132°15′	100	12
16159	Gerowie Creek	13°29′	132°15′	100	1
16160	S. Alligator River	13°03′	132°19′	40	9
16161	Howard Springs	12°27′	131°03′	70	1
16162	Reynolds River	13°32′	130°52′	150	10
16163	Elizabeth River	12°36′	131°04′	40	10
16187	Melville Island	11°55′	130°50′	1	8
Queensland					45
16129	Fly Point	10°45′	142°36′	15	1
16137	Piccaninny Creek	13°09′	142°48′	40	3
16141	Coen River	13°57′	143°11′	170	1
16142	Coen River	13°53′	143°03′	170	4
16144	S. Coen	14°03′	143°12′	250	2
16145	Wenlock River	13°06′	142°56′	130	21
16484	Morehead River	15°03′	143°40′	50	6
16485	Kings Plains	15°42′	145°06′	100	7
Thailand					9
16297	Nong Sanom	12°35′N	101°15′	10	4
16397	Sai Thong	11°25′N	99°27′	50	5

* Number of families included in seed orchard planting

Results and Discussion

Survival

Despite suboptimal establishment conditions, survival at age 6 months was high, averaging 93% across all regions, with no significant differences between regions. The number of additional deaths between 6 and 18 months was negligible.

Eighteen-month results for growth and form

The relevant terms of the analysis of variance tables for height, basal area at breast height (of the two largest stems, for multi-stemmed individuals), and bole length to first fork are shown in Table 2. The significance of differences among areas is indicated. Overall mean value of the three traits for the four areas are shown in Table 3.

Table 2. Analysis of variance for height, basal area at breast height and bole length to first fork of *Acacia auriculiformis* at 18 months after planting. Only the area and area.provenance terms are presented.

Stratum	Degrees of freedom	Mean square	Significance of difference between areas
a) Height			
area	4	4.774	*** (P<.001)
area.provenance	29	0.712	
b) Basal area at breast height			
area	4	540.7	***
area.provenance	29	32.6	
c) Bole length			
area	4	18.53	***
area.provenance	29	0.46	

Table 3. Mean height, basal area at breast height, and bole length to first fork of *Acacia auriculiformis* from five geographic areas, at 18 months after planting.

Area	Height (m)	Basal area* (cm^2)	Bole length (m)
PNG Bensbach	4.58	19.4	1.06
PNG Morehead	4.48	19.9	1.15
Northern Territory	3.90	11.3	0.74
Queensland	4.53	14.3	2.27
Thailand	3.85	9.8	1.17

* Of two largest stems, for multistemmed individuals

In the environment of Melville Island, there are clear trends in the performance of the three main geographic areas of the natural range and the selections from Thailand, with highly significant differences among areas for all three traits. Queensland and the two PNG regions are approximately equal in their height growth, mean height being around 4.5 m at 18 months after planting, while Northern Territory provenances and Thailand selections are substantially shorter. The trend in basal area is different. The two PNG regions have the greatest mean basal area, and Queensland is only slightly ahead of Northern Territory and the Thai material. This is a consequence of differences in form.

The majority of Queensland trees were single-stemmed at breast height, mean bole length to the first fork being 2.27 m for Queensland trees. This figure is in fact conservative, since it includes some trees which were single-stemmed to their full height and thus had not yet expressed their full bole length potential. The PNG and Thailand trees tended to fork below breast height (mean bole length around 1.1 m), and Northern Territory trees mostly forked at a lower height (mean bole length 0.74 m). PNG provenances were noted during assessment to have broader, denser crowns than those from Queensland. Many individuals, particularly those from the Northern Territory, had three or more stems but the elimination of smaller stems for basal area calculation is considered to have had negligible impact on relative performance for this trait.

Data on stem form for individuals with bole length over 2 m are not presented here, but it may be noted that there are a small number of individuals from PNG and Queensland which are fast-growing, single-stemmed and straight (i.e. scoring 4 on form assessment). These individuals have been identified as candidates for inclusion in genetic improvement programs, through vegetative propagation and seed collection.

Considerable insect activity was noted in the stands, with a wide range of insect species causing damage to leaves and young growing tips and in a few cases girdling or borer attack on larger stems. It was noted that the Thai families appeared to be more badly damaged by insects than the natural provenances, and it appears that this susceptibility is a major factor responsible for their poor performance on Melville Island.

Future management and seed production

In November 1990 the seed orchards were selectively thinned, removing four of the five trees in each row plot and retaining the best-formed individual of acceptable size. Inferior families, including the majority of Northern Territory families, will be removed altogether in 1991. A number of trees flowered and produced very small quantities of seed in September 1990, and substantial quantities of seed are expected in 1991. A gain trial is planned with the 1991 seed, to compare its performance against the original seedlots that were used to establish the best-performing families in the plantings.

Acknowledgments

Melville Forest Products Pty Ltd, representing the Tiwi land owners on Melville Island, is thanked for permission to establish the seed orchards and support of the project. Beau Robertson and Steve Taylor carried out much of the field management and measurement. The project has been made possible by funding from the Australian International Development Assistance Bureau, through the Seeds of Australian Trees project managed by the Australian Tree Seed Centre, which supplied the seedlots for the orchards.

References

GENSTAT 5 1987. GENSTAT 5 Reference Manual. Clarendon, Oxford.

Gunn, B., McDonald, M. and Moriarty, J. 1987. 1987 Collections of *Acacia auriculiformis* from natural populations in Papua New Guinea and Northern Australia. Australian Tree Seed Centre (unpublished).

Pinyopusarerk, K. 1990. *Acacia auriculiformis*: an annotated bibliography. Winrock International/ Australian Centre for International Agricultural Research.

Robinson, D.L. 1987. REML Users Manual. University of Edinburgh.

Short Communications

These papers present preliminary results which will be published at length at a later date.

Genetic Variation of *Acacia melanoxylon*

J. Playford*, C. Bell and G.F. Moran****

Acacia melanoxylon (blackwood) is an Australian native tree used for furniture timber. It is distributed along the east coast of Australia from southern Tasmania to Atherton in Queensland.

In order to gain greater understanding of the clustering of genetic variation within this wide geographic range, 27 populations throughout its distribution (Table 1) were analysed using isozymes — a technique that quickly and cheaply enables the division of samples into distinct groups.

An electrophoretic comparison of variation at 30 presumptive isozyme gene loci provided data to enable relationships between the populations to be deduced using phenetic procedures.

The isozyme analysis (Nei 1978) showed two distinctly different groups dividing the species into north/south at the Hunter River in New South Wales. Mean heterozygosity levels were high and averaged 0.177 but northern populations were much less heterozygous (0.124) than the southern populations (0.207). Similarly the percentage of polymorphic loci was also high (54.1) and was lower in the north (40.8) than in the south (59.6). Southern populations were further divided in northern Victoria (see Figs 1 and 2).

These results compare favourably with morphological data from field trials conducted by the Tasmanian Forestry Commission (Allen pers. comm.).

This example illustrates that isozymes may be used to determine different areas of genetic variation, which should be represented in preliminary field trials of a species.

Table 1. Collection sites of *Acacia melanoxylon*.

Number	Locality	State
1	Strathblane	Tasmania
2	Beaufont	Tasmania
3	Oatlands	Tasmania
4	Pt Dalrymple	Tasmania
5	Warners Sugar Loaf	Tasmania
6	Kanunnah	Tasmania
7	Adelaide Hills	South Australia
8	Mt Gambier	South Australia
9	Gellibrand	Victoria
10	Mt Alexander	Victoria
11	Mt Bogong	Victoria
12	Bonang	Victoria
13	Tallaganda	New South Wales
14	Brindabellas	New South Wales
15	Tumbarumba	New South Wales
16	Kangaroo Valley	New South Wales
17	Katoomba	New South Wales
18	Orange	New South Wales
19	Gloucester	New South Wales
20	Barrington Tops	New South Wales
21	Ebor	New South Wales
22	Springbrook	Queensland
23	Mt Mee	Queensland
24	Bli Bli	Queensland
25	Townsville	Queensland
26	Ravenshoe	Queensland
27	Atherton	Queensland

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Fig. 1. Distribution of collections of *Acacia melanoxylon* throughout Australia. Population numbers refer to localities listed in Table 1. The lines on the map indicate the clustering of populations from the dendrogram (Fig. 2).

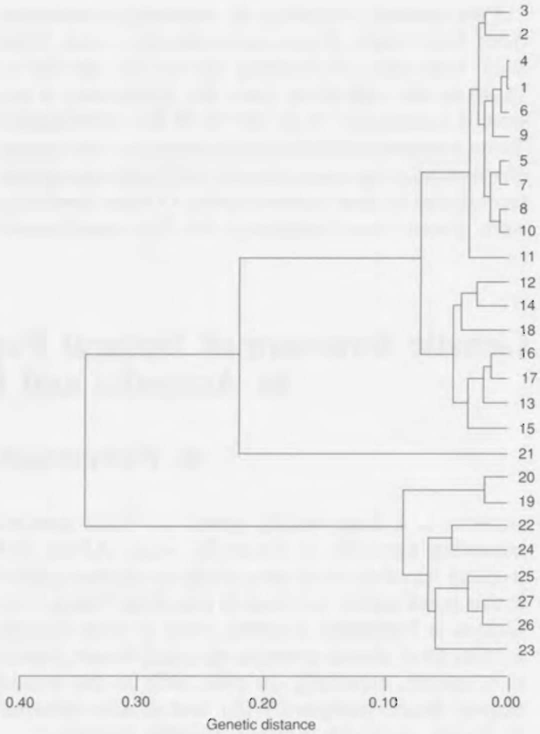

Fig. 2. A dendrogram based on UPGMA clustering of *Acacia melanoxylon* populations using the genetic distance measure of Nei (1978).

Reference

Nei, M. 1978. Estimation of average heterozygosity and genetic distance from a small number of individuals. Genetics, 89, 583-590.

Genetic Variation in Frost Tolerance of *Acacia mearnsii*

S.D. Searle, J.V. Owen, E.R. Williams and C.A. Raymond*

EXPERIMENTAL plantings of *Acacia mearnsii* De Wild. have failed due to death or damage by frost in many countries, including Australia, Brazil, China, South Africa and Zimbabwe. However, only limited research has been conducted to examine the genetic variation in frost tolerance within the natural distribution of the species.

Genetic variation in frost tolerance within two provenances of *A. mearnsii* was examined in detail in a study using a non-destructive electrical conductivity screening technique. The principal objective of this trial was to test the hypothesis that within-provenance variation in frost tolerance is highly significant.

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Two naturally occurring *A. mearnsii* provenances from New South Wales were selected — one from 8-23 km west of Bodalla (36°11'S; 149°58'E; 15-40 m asl), the other from Mt. Gladstone, 4 km west of Cooma (36°15'S; 149°15'E; 925-1070 m asl). These represented altitudinal extremes of the species distribution at the same latitude. Each provenance was represented by seed collected from 15 trees. Seedlings were grown in a shadehouse for five months and hardened over a Canberra winter prior to screening for frost tolerance.

Between-family variation for frost tolerance in *A. mearnsii* was highly significant ($p < .01$). Significant variation ($p < .01$) also exists between the two provenances, with the higher altitude (Mt. Gladstone) provenance being more frost tolerant than the coastal (Bodalla) provenance.

Genetic Structure of Natural Populations of *Acacia auriculiformis* in Australia and Papua New Guinea

R. Wickneswari and M. Norwati*

ACACIA is a large woody genus (> 1000 species) occurring naturally in Australia, Asia, Africa and tropical America. Only nine of the Australian species in this genus extend northwards into either Papua New Guinea or Indonesia. Recently some of these tropical acacias have shown promise as multiple-use plantation species, especially on poor soils in the humid tropics. *Acacia mangium* Willd. and *A. auriculiformis* A. Cunn. ex Benth. are two notable examples.

Seeds from 18 populations of *A. auriculiformis* from Queensland (QLD) and Northern Territory (NT), Australia and Papua New Guinea (PNG) (Fig. 1) were electrophoretically analysed at 22 isozyme loci representing 17 enzyme systems. Genetic variability measures were determined using 12 isozyme loci. On average, 39.8% of the loci were polymorphic (0.99 criterion). Average and effective numbers of alleles per locus were 1.5 and 1.1 respectively. Mean observed (H_o) and expected (H_e) heterozygosity across populations were 0.071 and 0.081 respectively. H_e was highest in *A. auriculiformis* populations from PNG (mean = 0.133) and lowest in *A. auriculiformis* populations from NT (mean = 0.040). The genetic differentiation between populations was high (G_{ST} = 0.270), indicating that about 73% of the isozyme variation was among progenies within populations. Hence, both intra- and inter-population genetic variations are important in initial selections in *A. auriculiformis* domestication programs.

Nei's unbiased genetic distance between populations (Nei 1978) ranged from 0.000 to 0.120, with populations from NT generally being closely related to each other. UPGMA cluster analysis using Nei's unbiased genetic distance revealed three distinct clusters of

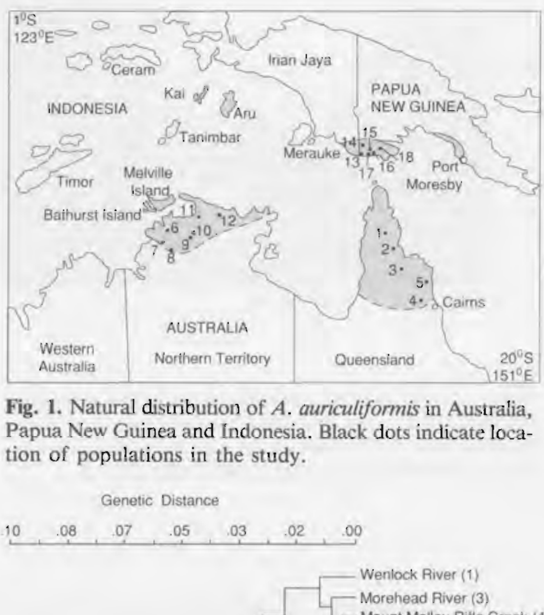

Fig. 1. Natural distribution of *A. auriculiformis* in Australia, Papua New Guinea and Indonesia. Black dots indicate location of populations in the study.

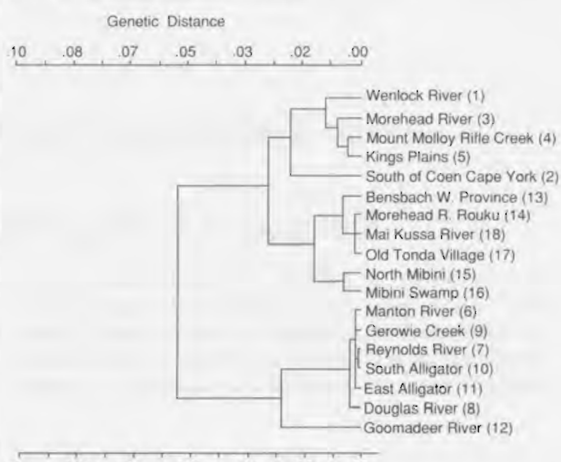

Fig. 2. A dendrogram based on UPGMA clustering of *A. auriculiformis* populations using the genetic distances of Nei.

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populations corresponding to the geographic distribution of the species in QLD, NT and PNG (Fig. 2). Populations from QLD were more closely related to populations from PNG than to populations from NT on the same land mass.

Reference

Nei, M. 1978. Estimation of average heterozygosity and genetic distance from a small number of individuals. Genetics, 89, 583–590.

Silviculture and Utilisation

Use of Acacias in Wastelands Reforestation

Ram Prasad*

Abstract

More than half of the total land mass of India (326 million ha) is estimated to be at various stages of degradation. These lands need to be brought back to productive use, and lands which, due to one or more limitations are unsuitable for cultivation, can be used for raising firewood plantations and for developing pasture lands. Land husbandry and short-term forestry schemes using multipurpose fast growing tree species have already established their credibility.

Eucalyptus spp., on account of their fast growth and tremendous adaptability, have been very popular in almost all reforestation programs. Different types of wastelands have already been planted to various *Eucalyptus* species. However, with growing socioeconomic awareness in the rural areas, more and more objections are being raised to planting this species. Acacias appear a better alternative to eucalypts for reforestation of wastelands. Growth, phytomass productivity and soil improvement of many wastelands by acacias compared with other nitrogen-fixing and other non-leguminous indigenous and exotic species are reported in this paper.

CURRENT understanding equates wastelands with ecologically degraded land — land which under a given set of climatic and edaphic conditions is not in a state of optimum productivity, owing to neglect, overuse or misuse.

Many of our developmental activities are the opposite of the dictum 'development without destruction'. On the other hand, some of them may even be categorised as destructive development, as not only the ecology of the area is disturbed but the whole support system becomes very fragile. Large areas laid bare by extensive open-cast mining provide an eloquent testimony to this. Again large areas become water-logged and in due course turn into saline and alkaline lands on account of unplanned irrigation systems. These developmental wastelands are of recent origin but need to be tackled urgently before they become permanently unproductive.

Although estimates of the extent of wastelands available from different sources differ considerably, there is no doubt that the total extent of wastelands is huge. It is estimated that two-thirds of the total available agricultural area in India is suffering from serious degradation of one kind or another, and that the remaining third is lying almost unproductive. It is also estimated that at least 60% of arable lands and 70% of nonagricultural lands are degraded to a greater or lesser degree, and are therefore producing at levels much below their full potential.

Adequate supply of fuel and fodder to the people can ensure protection to the natural forests. In the absence of alternatives, regulatory measures to contain biotic factors may not succeed. It is in this context that all available degraded lands should be brought under protective tree cover.

Most of India's wastelands are too degraded to allow the successful establishment of more than a few species. Wastelands such as water-logged areas, saline-alkaline soils and mined-out areas are quite adverse to plant growth. In many cases, such as mined-out overburdens where the top fertile layer is buried deep down, exposing inert and rocky material devoid of organic matter and microbial activity, only native primary colonisers and some exotic trees will grow.

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Species recommended for restoration of site productivity of wastelands should be fast growing to form an effective canopy quickly to protect the soil surface from wind and water erosion. They should also be good fuel and fodder species. Most common tree species planted on different types of wastelands in India have been *Eucalyptus* hybrid, *E. camaldulensis, E. tereticornis* (Prasad 1987). However, *Eucalyptus* species do not yield any fodder and there is little or no evidence of their capacity to improve impoverished soils. Acacias on the other hand are regarded as more desirable for reforestation of wastelands. The acacias have tremendous ecological adaptability as they can thrive well on most types of wasteland, from deep ravines to hard laterites, waterlogged and saline-alkaline areas to mined-out overburdens and other similar denuded lands. These nitrogen-fixing trees have a proven capacity to build up the fertility of impoverished sites. Other desirable traits like fast growth, good fuel, fodder and other minor forest produce available from acacia plantations make it more acceptable to foresters and forest farmers. All these traits which make acacias the most important species for wastelands, have been summarised in this paper.

One of the major attributes of acacias is their ability to thrive on infertile soils. Indigenous *A. catechu* regenerates as a component of riverain succession. Extremely impoverished sites such as mined areas and their overburden dumps are also easily rehabilitated by acacias. Some other difficult wastelands such as waterlogged areas and saline-alkaline soils support only a few species, among which acacias figure prominently.

Indigenous acacias such as *A. nilotica, A. catechu, A. leucophloea, A. suman, A. sundra, A. caesia, A. pinnata* and *A. conica*, are well distributed through the country. They are prominent as valuable species in the reafforestation of wastelands, being associated with *Albizia lebbek, Balanites aegyptiaca, Parkinsonia aculeata*, the tamarind, margosa and wood-apple. As early as 1889, George Watt in the *Dictionary of the Economic Products of India* described the utility of gum-yielding acacias as an agent to improve sterile tracts of the country, or to arrest the destructive development of efflorescence known as reh (saline soil). Special mention has been made of *A. arabica* (now *A. nilotica*), which grows rapidly, requires little water and flourishes in dry arid plains (especially in black cotton soil) where other trees rarely grow.

Some of the acacias introduced under different plantation programs in India have done remarkably well. Their growth and productivity under Indian conditions have been outstanding among exotics. Some most prominent acacias now acclimatised to the Indian subcontinent are *A. mearnsii* and *A. decurrens* (black wattles) in Nilgiris, *A. campalycantha* and *A. mellifera* on mine overburden dumps, *A. tortilis, A. senegal* and *A. aneura* in dry sandy plains, *A. albida* on farm bunds and *A. auriculiformis* on denuded sites, mined-out areas, drier sites, lateritic soils and a number of other inhospitable sites under varying soil and climatic conditions.

Mined-out Areas and their Overburden Dumps

The conditions prevailing in mined-out areas are so unfavourable for plant establishment that there is little or no possibility of the original vegetation recovering on its own (Prasad and Pandey 1985). Apart from the scientific and material inputs required to revegetate these difficult sites, careful selection of species assumes great importance. Experimental evidences indicate that nitrogen fixing trees (NFTs) and selected exotics are able to green the area quickly, while restoring the original vegetation requires far more exacting measures. In the areas where original vegetation consisted of near-climax species like sal (*Shorea robusta*) it is difficult to grow the principal species or its associates. The site appears to be suitable to support the flora of primary succession. Amongst the species tried and found most successful are many acacias and eucalypts and some indigenous NFTs (Prasad and Shukla 1985a, b). Pradip and Srivastava (1982) reported successful reforestation of a small area of overburden using *A. auriculiformis* and *Adina cordifolia*.

Dolomite mined-out areas and overburdens

Prasad and Chadhar (1987) reported on the most successful tree species on dolomite mined-out areas at Hirri in Bilaspur district of Madhya Pradesh. Reforestation trials were carried out in 1984 using two acacias (*A. auriculiformis* and *A. campylacantha*), two other indigenous NFTs (*Albizia procera* and *Pongamia pinnata*) and two other species, *Gmelina arborea* and *Eucalyptus* hybrid. The growth of plants at 5 years is shown in Table 1.

Critical study of the data also reveals that although *Eucalyptus* hybrid has given maximum biomass per tree (8.3 kg), in terms of total biomass it is only in second place. The reason for this is lower survival in *Eucalyptus* hybrid than *Acacia campylacantha*. The latter species has proved very hardy and can withstand harsh environmental conditions of dolomite mined-out areas.

Table 1. Growth of plants 5 years after planting on a dolomite mine overburden dump (planted July 1984, recorded June 1989).

Species	Max. ht. (cm)	Min. ht. (cm)	Av. ht. (cm)	Av. girth (cm) at breast height
A. auriculiformis	860	382	660	21
A. campylacantha	1083	365	785	26
Pongamia pinnata	395	64	225	13
Albizia procera	95	30	53	22
Eucalyptus hybrid	1240	232	773	28
Gmelina arborea	860	363	555	25

In yet another set of experiments, apart from *Eucalyptus* (*E. camaldulensis* and *Eucalyptus* hybrid), *Gmelina arborea, Dalbergia sissoo, Albizia lebbek, Dendrocalamus strictus* (common bamboo) and four important acacias (*A. campylacantha, A. nilotica, A. tortilis* and *A. catechu*) were also tried. Average height of acacias (excepting *A. catechu*) compared quite favourably with those of ther fast-growing species such as *Eucalyptus* hybrid and *E. camaldulensis*, bamboo *Dalbergia sissoo* and *Gmelina arborea*. Three-year-old plants of *A. auriculiformis, A. tortilis* and *A. campylacantha* gave an average biomass mean annual increment (MAI) of 3.75 tonnes per hectare per year, compared with 3.80 for *D. sissoo*, 4.05 for *G. arborea* and 5.52 for *Eucalyptus camaldulensis*. In terms of leaf litter production, *A. campylacantha* was found to be better than *D. sissoo, A. lebbek, Eucalyptus* hybrid, *D. strictus* and very close to *G. arborea*. From these accounts it is clear that most of the introduced acacias (especially *A. auriculiformis* and *A. campylacantha*) are well suited to such harsh sites.

Iron-ore mined-out sites

A large number of species were tried on sites which were mined-out for the extraction of iron ore. The area consisted of tropical dry deciduous forests predominated by teak with associates such as *Terminalia tomentosa, Pterocarpus marsupium, Anogeissus latifolia, Cleistanthus collinus, Diospyros melanoxylon* with understorey bamboo (*Dendrocalamus strictus*). Mining caused the soil to become pulverised and other attributes such as nutrient status and microbial activity were very poor. The site is excessively dry due to undulating topography and compacted soil. There is very little infiltration and moisture retention. Although rain water falling upon the mined-out area has better infiltration, the absence of any vegetation on such sites means evaporation is exceedingly high.

A large number of leguminous and non-leguminous tree species were planted on this site. Although the experimental plantation was very young (4 years old) biomass assessment is already highlighting the most successful species. Results show that nitrogen fixing trees have not only survived well but have contributed to enrich the site. Among acacias, although only one species (*A. auriculiformis*) was tried, it produced 7.9 t/ha (dry weight) (Prasad and Dhuria 1989).

Bauxite mined-out areas

Experimental plantations using exotics and indigenous species have been underway since 1979 by Madhya Pradesh State Forest Research Institute, Jabalpur. The area before mining consisted of moist sal (*Shorea robusta*) forests. These natural forests are floristically very rich with a large number of species of medicinal and aromatic values. The mining is done after clearing the layered, near-climax vegetation predominated by sal. Here the general elevation is about 1000 m with mean annual rainfall of about 1500 mm. Here again the soil after mining becomes pulverised but the soil brought out from 10–15 m below consists of bouldery earth devoid of organic matter and microbial activity. On these sites some tropical pines (*P. caribaea, P. roxburghii, P. kesiya, P. oocarpa* and *P. elliottii*), *Eucalyptus* (*Eucalyptus* hybrid, *E. camaldulensis, E. grandis*), silky oak (*Grevillea robusta*) and an Australian introduction (*G. pteridifolia*) and *Acacia auriculiformis* (Prasad and Shukla 1985a) have been planted. Tree species of original forest stands were also tried (*Shorea robusta, Emblica officinalis, Cedrela toona, Sterculia urens, Cleistanthus collinus, Albizia procera* etc. Studies on comparative growth performance and biomass productivity indicated that *Acacia auriculiformis* ranks with the other tree species viz., pines, *Eucalyptus* spp. and *Grevillea pteridifolia*. Although in terms of growth and productivity *A. auriculiformis* is placed fourth, in terms of soil enrichment it is better than all other exotics and indigenous NFTs and non-NFTs (Prasad and Mohammad 1990).

Coal mine overburdens

Original vegetation before mining was layered sal forest. NFTs and non-NFTs (indigenous and exotics) have been planted since 1982 by the State Forest Research Institute, Jabalpur on coal mine spoils in central India. Experimental plantations have also been raised on similar sites by concerned collieries. Apart from *Eucalyptus* hybrid and other species, a number of NFTs like *Dalbergia sissoo, Pongamia pinnata, Prosopis juliflora, Albizia lebbek* and *A.*

procera, Gliricidia sepium and some acacias (*A. nilotica, A. catechu, A. auriculiformis, A. mellifera, A. campylacantha* etc.) were also planted. After *Eucalyptus* the other most successful species were *Acacia, Dalbergia sissoo, Albizia, Casuarina* and *Prosopis juliflora*. Growth statistics in respect of some important trees species are summarised in Table 2.

Table 2. Growth performance of selected species on coal mine overburden dumps (planted July 1982, observed December 1987).

Species	Average height (cm)	Average breast height girth (cm)
Emblica officinalis	246	8.5
Eucalyptus hybrid	877	31.2
E. camaldulensis	764	26.0
Pongamia pinnata	348	10.3
Acacia auriculiformis	529	17.2
A. nilotica	478	15.5
A. catechu	365	15.2
Dalbergia sissoo	425	17.5

Biomass productivity studies have shown that a 3-year-old plantation (Prasad 1986) of *Eucalyptus camaldulensis* gave above-ground biomass of about 104.5 t/ha. The other most important species was *Acacia auriculiformis* with a plant biomass of 76.0 t/ha and *A. mellifera* yielding 69.0 t/ha. The two acacias tried here provide excellent foliage, which is of paramount importance on such a site. Effective canopy cover up to 92% by *A. mellifera* and 82% by *A. auriculiformis* is far better than those recorded by fast-growing *Eucalyptus* spp. (67–69%). Another most important attribute in *A. auriculiformis* has been its capacity to regenerate naturally on such an impoverished site.

Lignite mined-out areas and overburden dumps

The activities of the existing mines at Neyveli are currently converting about 120 hectares of productive land into wastelands. The mining activity, with an estimated reserve of 32 million tonnes, is likely to render 6250 hectares unproductive. Another 4000 hectares are likely to be disturbed due to associated activities (road, township, dumping yard, overburden dumps etc.).

The prevailing climate in the mining area is typically tropical, characterised by moderately cold winters, windy springs and hot summers with very high relative humidity and moderate precipitation. In short the climatic conditions are not extreme. The mean monthly temperature ranges from 40 °C in summer to 20 °C in winter. Mean annual precipitation is about 1250 mm (750–2100 mm).

A number of species valuable for fruits, fuel, fodder, shade and ornamental purposes have been planted by Neyveli Lignite Corporation (Tamil Nadu). Among the most successful genera and species are *Acacia auriculiformis, A. nilotica, A. leucophloea, Albizia, Cassia fistula, Casuarina, Dendrocalamus strictus, Sesbania grandiflora, Eucalyptus, Tectona grandis* (Sengupta 1990). Among different acacias tried on this site *A. auriculiformis* has been found to be most promising in terms of survival, height growth and dry matter production. Assessment of soil properties in the plantation blocks also showed improvement.

Soil Improvement on Mined-out Areas and their Overburden Dumps

Soils under plantations planted on a bauxite mined-out area in 1979, 1982 and 1983 were analysed in 1988 (after 9 years, 6 years and 5 years, respectively). The data show that on nutrient-deficient soils *A. auriculiformis* has enriched the soil more than any other species. In terms of leaf litter productivity, although *Eucalyptus camaldulensis* and *G. pteridifolia* contributed more (10.5 and 16.6 t/ha, respectively) than *A. auriculiformis* (4.2 t/ha) the nutrient status of soil under *A. auriculiformis* was better (Prasad and Mohammad 1986; Prasad 1988a). The leaf litter of *Eucalyptus camaldulensis* and *G. pteridifolia* (needle type) present difficulties in decomposition. This probably explains the low nutrient status of soil under these plantations as compared to *A. auriculiformis* in which decomposition is not difficult.

Data pertaining to the soil enrichment by *Acacia* planted on coal mine overburden dumps show that soil under the *A. auriculiformis* plantation has been enriched, as reflected by higher organic carbon and available N and P values. Another species (*A. catechu*) has also done remarkably well. The soil under successful tree species like *Eucalyptus camaldulensis* has not improved to the same extent as has been witnessed under *A. auriculiformis*. The comparatively slow-growing species *A. catechu* 6 years after planting has also made its mark in respect of organic carbon and available N and P, presumably because of easy decomposition of leaf litter and capacity to fix atmospheric nitrogen. Its performance in terms of soil improvement has been better than the eucalypt, even in a stand less than 2 years old.

Remarkable improvements in the soil under *A. auriculiformis* have been observed on overburden dumps of lignite. As compared to less than 1 kg nitrogen per ha on the unreclaimed site, there was found to be 85.3 kg/ha available N under *A. auriculiformis*. Similar trends of enrichment through available P and K were also observed (Sengupta 1990).

Prasad and Mohammad (1990) reported the microbial improvement of soil brought about by some nitrogen fixing trees planted on bauxite and coal mined-out areas. It was observed that 9-year-old plantations of *A. auriculiformis* have more root nodules in comparison to 5-year-old plantations of *Pongamia pinnata*.

Saline and Alkaline Soils

Although no scientific study has been carried out to determine the exact extent of saline and alkaline soils, recent estimates made by the Society for Promotion of Wastelands Development (Bhumbla and Khare 1984) place the total area affected by this problem at 71 650 km^2. This vast area is lying unutilised, as in its present form it may be difficult to use it for any profitable agriculture. By contrast, such areas could easily be brought under tree cover for producing much needed fuel, fodder and agricultural timber.

Great care is required in selecting only those species for afforestation which are inherently capable of producing a prolific root system, are able to resist salt content and thrive well under conditions of arid climate with low moisture supply. The high salt concentration in soil solution also causes physiological drought, and thus chosen species should also be drought resistant.

A large number of species have been tried on such sites in different parts of this country. The most successful species have been *Dalbergia sissoo, Prosopis juliflora, Acacia nilotica, A. farnesiana, A. catechu* (all are NFTs), *Salvadora oleoides, Tamarindus indica, Cassia auriculata, Tamarix articulata, Parkinsonia* spp. and *Eucalyptus* spp. Among these species *A. nilotica, P. juliflora* and *D. sissoo* have been found most promising (Prasad 1988b). Other acacias recommended for such sites are *A. catechu, A. eburnia, A. modesta* and *A. senegal.*

Arid and Semi-arid Areas

The area under arid and semi-arid climates in the world totals 49.10 million km^2, of which 1.14 million km^2 is in India, consisting of 932 400 km^2 of semi-arid and 207 200 km^2 of arid land.

Out of the total area of 3.26 million km^2 of India, 30% has less than 750 mm rainfall, 42% receives between 750–1250 mm and 28% receives more than 1250 mm rainfall. In view of the fast disappearance of vegetation on slopes and hillsides and the general trend of ecological degradation, all areas with less than 1250 mm rainfall should be considered suitable for restoration through reforestation. The afforestation of these denuded tracts has a direct bearing on the improvement of the fertility of agricultural fields, on the improvement of fodder and grazing for the large cattle population of the country, on the production of fuel and agricultural timber for the local population and on checking the damage caused by floods and soil erosion.

Since it is not possible to specify any set of species for all arid and semi-arid soils, it may be desirable to consider species which have inherent plasticity. The species under this category may survive and extend their habitat if protection against biotic pressure is ensured and desired material and scientific inputs are given. Acacias in particular are most suited to dry and semi-arid conditions as these have long root systems and modified leaves to minimise moisture requirements.

Different acacias found suitable for arid and semi-arid soils in different regions of India are as follows:

- Northern Region (plains of the Punjab, Uttar Pradesh, Delhi and northern Madhya Pradesh): *Acacia nilotica, A. jacquemontii, A. senegal, A. tortilis, A. catechu.*
- Rajasthan Desert Area: *A. nilotica, A. leucophloea, A. senegal, A. tortilis.*
- Central Region (Madhya Pradesh, Andhra Pradesh): *A. nilotica* (var. *cupressiformis*), *A. auriculiformis, A. catechu, A. mellifera, A. campylacantha.*
- Southern Region (Tamil Nadu, Andhra Pradesh, Kerala): *A. nilotica, A. mollissima, A. monoliformis.*
- Eastern Region (Bengal, Assam, Orissa, Bihar): *A. auriculiformis.*
- Sea Coast Region: *A. auriculiformis.*
- Western Region (black cotton soil of Maharastra, Gujarat, Goa): *A. nilotica, A. leucophloea.*

Lateritic Soils

Laterite and lateritic soils cover an area of about 0.12 million km^2 in the states of eastern and southern India and occupy flat plateaux, high ridges and plains in both high and low rainfall zones. The low fertility status coupled with hard vesicular structure and deficient moisture supply renders many of these soils unsuitable for the growth of tree species (although the topographical features modify their fertility status to some extent). The annual rainfall of the region varies from 750 to over 3000 mm, with mean temperature being around 27 °C. Many of these soils are devoid of tree growth and are generally deficient in nutrients. These soils being hard and compact, infiltration is very poor, allowing maximum water run-off.

Soil and moisture conservation, application of manures and fertilisers, and correct choice of plant species are three strategies to reclaim this type of wasteland. A large number of acacias have been tried, and the most successful and universally planted species has been *A. auriculiformis*. Among other acacias tried on such sites are *A. catechu, A. tortilis, A. planiformis* and *A. nilotica*. The last species has been very successful on deep soils with black-soil mix.

In terms of growth, biomass productivity and leaf litter addition *A. auriculiformis* has been superior to many other nitrogen fixing trees (Suri 1977; Prasad 1988b). Growth parameters and aboveground dry matter production by various trees planted on hard lateritic soils of Madhya Pradesh are summarised in Table 3.

From the figures given in Table 3 it can be seen that *Eucalyptus* spp., *D. sissoo, Tectona grandis* and *G. arborea* are the only species having better growth performance than *A. auriculiformis*. Although only some species have been given in Table 3, Prasad (1988b) reported the growth attributes of 25 species, among which *A. auriculiformis* was found superior to all the species tried, except the four species given above.

Eighteen species, aged between 4 and 16 years, were compared for their dry matter production (above ground). It was found that a 9-year-old *A. auriculiformis* plantation gave total dry matter production of 25.60 t/ha, which was better than many known fast-growing indigenous tree species (Prasad 1988b).

In another set of studies pertaining to annual leaf litter accumulation, 8–10-year-old *Eucalyptus* contributed slightly less than one tonne of organic matter to the forest floor, while the same-aged plantation of *A. auriculiformis* added 3.2 t/ha/year.

Soil under acacias and other plantations was also analysed for nutrient status, and soil under acacias showed signs of improvement (Suri 1977; Prasad 1988b).

Other Wastelands

Waterlogged areas resulting from seepage of canal water, periodically inundated areas in river valley projects, littoral swamps, salty marshes and mud flats, skeletal soils, rocky sites, denuded hill slopes, shallow heavy black soils, etc. are other categories of wastelands. Locally occurring *A. nilotica* is suitable for reforestation of wastelands such as waterlogged and periodically inundated areas, black cotton soils, salt-affected soils, etc.

For highly eroded and disturbed sites, *A. nilotica, A. catechu* and *A. tortilis* have been found to be suitable. *A. auriculiformis* has been found successful on drier sites, denuded hills, eroded spots and as a species for quick cover on wastelands.

Table 3. Growth performance of tree species used for reforestation of 'Bhata' (hard lateritic soils) wastelands of Madhya Pradesh.

Species	Age (years)	Av. Ht. (m)	Dbh (cm)	Mean annual increment Height (m)	Mean annual increment Dbh (cm)
Tectona grandis	10	9.7	12.5	0.97	1.25
Gmelina arborea	9	8.3	9.8	0.92	1.10
Eucalyptus tereticornis	16	16.5	10.6	1.03	0.65
E. camaldulensis	10	9.2	7.4	0.92	0.74
Cleistanthus collinus	10	5.2	4.6	0.51	0.46
Hardwickia binata	9	4.4	5.7	0.49	0.81
Lagerstroemia parviflora	9	3.6	4.6	0.40	0.51
Bridelia retusa	9	2.8	3.8	0.31	0.42
Shorea robusta	10	2.5	2.7	0.25	0.27
A. auriculiformis	10	8.3	7.0	0.83	0.70
A. planiformis	10	1.9	—	0.19	—
A. catechu	10	4.5	5.1	0.45	0.51
A. tortilis	10	4.1	4.2	0.41	0.42
Dalbergia sissoo	9	9.3	8.7	1.04	0.97

Although *Eucalyptus* has been found to be one of the most prominent genera for a variety of wastelands, acacias have advantages over all other species. Rapid revegetation of denuded sites, improvement of soil nutrient status, higher biomass return, ease of plantations (seeding and planting), acceptability as a fuel, fodder, agricultural timber are some of the important criteria which always give weight to nitrogen fixing trees in general and acacias in particular. With growing discontent about the ecological undesirability of *Eucalyptus*, emphasis is being placed on adopting multipurpose trees which may be acceptable to people and at the same time which do not cause any deleterious effects on soil and water table.

References

Bhumbla, D.R. and Khare, A. 1984. Estimates of wastelands in India. Society for Promotion of Wastelands Development, SPWD, New Delhi.

Pradip, P.N.S. and Srivastava, O.S. 1982. The land, its degradation due to mining and reclamation; an analysis with respect to a coal company. National Seminar on Minerals and Ecology, ISM, Dhanbad.

Prasad, R. 1987. Performance of *Eucalyptus* on the wastelands of Madhya Pradesh. Journal of Trop. Forestry, 3 (IV), 311-317.

1988a. Rehabilitation and revegetation of mined-out areas in Madhya Pradesh: some critical issues. Journal of Trop. Forestry, 4 (II & IIII), 139-157.

1988b. Technology of Wastelands Development. Associated Publishing Co., 8798/7, Shidipura, Karolbagh, New Delhi, 356 p.

Prasad, R. and Chadhar, S.K. 1987. Afforestation of dolomite mine overburdens in Madhya Pradesh. Journal of Trop. Forestry, 3 (II), 124-131.

Prasad, R. and Dhuria, S.S. 1989. Reclamation of iron-ore mined out areas: biomass production efficiency. Journal of Trop. Forestry, 5 (I), 52-56.

Prasad, R. and Mohammad, G. 1986. Role of biofertilisers in wastelands development and forest production: a review. Journal of Trop. Forestry, 2 (IV), 179-220.

1990. Effectiveness of nitrogen fixing trees (NFTs) in improving microbial status of bauxite and coal mined out areas. Journal of Trop. Forestry, 6 (I), 86-94.

Prasad, R. and Pandey, R.K. 1985. Natural plant succession in the rehabilitated bauxite and coal mine overburdens of Madhya Pradesh. Journal of Trop. Forestry, 1 (IV), 309-320.

Prasad, R. and Shukla, P.K. 1985a. Reclamation and revegetation of coal mined overburdens in Madhya Pradesh. Journal of Trop. Forestry, 1 (I), 79-84.

1985b. Restoration of ecological balance to the bauxite mined areas of Madhya Pradesh. Journal of Trop. Forestry, 1(III), 236-245.

Sengupta, S.R. 1990. Reclamation practice at Neyveli Lignite Corporation Mines — a case study. Proc. Indo-U.S. workshop on environmental management planning for Singrauli Coalfield. Jan 29-Feb. 2, 1990, Singrauli, N.C.L., Distt. Sidhi, Madhya Pradesh, India.

Suri, S.K. 1977. 'Bhata' land afforestation in Madhya Pradesh. SFRI, Bull. No. 19, Jabalpur, India.

Watt, George 1899. Dictionary of the Economic Products of India. Govt. of India Press, Calcutta.

Use of *Acacia* Species in Agroforestry

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Abstract

A study has been conducted since 1985 in the marginal dryland areas characterised by infertile sandy loam soils at Si Sa Ket Province, northeast Thailand. It involved an investigation of *Acacia* species that could provide in addition to wood production some direct benefits from their nitrogen fixing nodules to other non-legume trees in mixtures. They would also have the potential to improve soil fertility through litterfall decomposition.

The results of this preliminary assessment showed that *Acacia auriculiformis* recorded the best growth at 3 years and also provided the best mixed system in conjunction with two adjacent non-legume species, *Eucalyptus camaldulensis* and *Dipterocarpus alatus*. The poor performance of *A. aulacocarpa* and *A. cincinnata* enabled better growth of the other two mixing species, due to less competition for moisture and nutrients in the soil.

WITH the increasing focus on agroforestry in recent years, attention has been given to its potential as a major land management alternative for maintenance of soil fertility and productivity in a variety of situations in the tropics. An appropriate agroforestry system might improve soil physical properties, maintain soil organic matter and promote nutrient cycling.

One of the advantages commonly attributed to agroforestry technologies is the potential for soil fertility improvement by more efficient cycling of nutrients, and it is often recommended that nitrogen fixing trees and shrubs be included in such technologies (Roskoski 1981; Dommergues 1987). Realising the limited potential to improve the production of food crop annuals in areas with soil of low fertility without high capital inputs, and greater awareness of the ecological fragility of such areas, increased attention has been paid primarily to fast-growing leguminous trees such as acacias (Benge 1989).

The ability of many acacias to increase the nitrogen content of soil through their interaction with symbiotic bacteria augments their value for planting for soil stabilisation and for other purposes. In particular, some species may have application in land restoration after mining, where they may be particularly suitable for growing on the nutrient-depleted soils frequently used for backfilling, and help re-establish a nutrient bank in such soil. *Acacia holosericea*, for instance, is useful after mining activities in the Northern Territory of Australia (Langkamp et al. 1979, 1982). Biological complexities and interaction in multiple-tree-species mixing through agroforestry systems present an interesting challenge to improve system productivity. A number of efficiencies in resources use become operative when two or more tree species are present in the same field with annual crops during the same years; these can be most complex when these trees/crops are grown simultaneously. The multipurpose trees are ideal, but it is necessary to find species that suit particular sites. Mixing of tree species that fulfil different purposes in the same site simultaneously is a possibility with interesting prospects.

This paper looks at the effect on growth performance of mixing some *Acacia* species between non-leguminous fast-growing *Eucalyptus camaldulensis* and an indigenous slow-growing *Dipterocarpus alatus* in northeast Thailand.

Study Site Characteristics

The study site is located at the Huay Tha Silvicultural Research Station at Si Sa Ket Province, northeast Thailand. It is a flat plain area at 130 m elevation, which was previously occupied by mixed deciduous forest with pine forest and scrub woodland. The climate of the area is generally hot, with a mean annual rainfall of approximately 1500 mm (114 rainy

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days per year and highest monthly rainfall of 300 mm in June). There is a long dry period from November to April. The average temperature is 26.5 °C, with a mean monthly range of 15.7–35 °C. The relative humidity has a minimum of 62% in March, and a maximum of 84% in September.

The soil is generally poor with respect to nutrients and organic matter. Parent materials are sandstone and other sedimentary rocks, giving a sandy loam soil texture. The low pH of 5.3 may be due to high leaching rates, thus the effective cation exchange capacity is low with an average of 3.0 me/100 g soil. These characteristics indicate low plant nutrient availability. Some surface soil chemical properties at the initial stage of the experiment indicate an average of 1.5% organic matter, 7.4 ppm P, 35.8 ppm K, 251 ppm Ca and 56.9 ppm Mg.

Materials and Methods

A field trial was laid out in May–June 1985 to compare the interrelationship of five *Acacia* seedlots with the non-leguminous fast-growing *Eucalyptus camaldulensis* and the indigenous slow-growing *Dipterocarpus alatus*. The *Acacia* seedlots comprised *A. leptocarpa* (*A. lep*), *A. cincinnata* (*A. cin*), *A. aulococarpa* (*A. aul*) and two seedlots of *A. auriculiformis* (*A. aur1* and *A. aur2*), these being one Australian and one local Thai seedlot respectively. Details of the layout of this trial are given in Fig. 1. There were four plots and each had the same structure with regard to the tree species. A field row of trees within a plot comprised a systematic mixture of acacias, eucalypt and dipterocarp with frequencies of 10, 5 and 5 trees respectively. Each of the five field rows in a plot used a different *Acacia* seedlot, as can be seen in Fig. 1, and will be referred to as five different mixture systems. Unfortunately the randomisation for the mixture systems was the same for each plot. The spacing between trees in a field row was 2 m and there was an 8 m gap between successive field rows; thus each plot had dimensions 40 × 40 m.

Even though each of the plots had the same mixture system, the crops used in the interrows differed between plots.

Crops used in the first three years were:

Plot	Years 1 & 2	Year 3
1	groundnut, garlic	pineapple
2	groundnut, tobacco	mulberry
3	kenaf, tobacco	mulberry
4	cassava	mulberry

The first year crops were planted at the same time as the trees. Each year the crops were planted to within 50 cm of the tree rows. In the third year, root pruning of trees in all plots was done by trenching to 45 cm depth and 30 cm width at a distance of 1.5 m from the tree rows. In order to compare the five *Acacia* seedlots in combination with the *Eucalyptus* and *Dipterocarpus* species, stem diameters at 30 cm above ground level were measured on all trees in June 1988 when the trees were 3 years old. The tree diameters were used as a measure of growth performance and were subjected to analysis of variance using the statistical package GENSTAT 5.

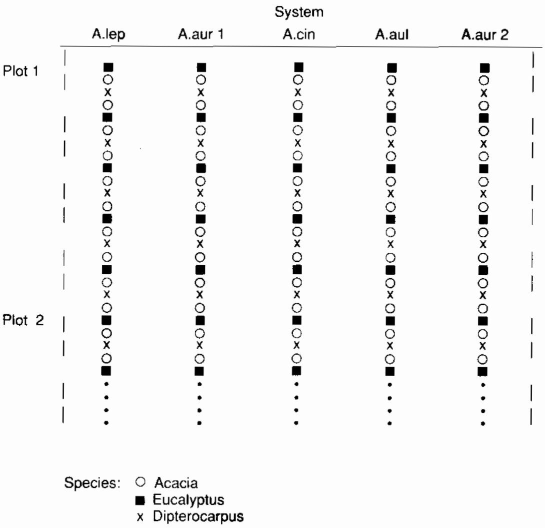

Fig. 1. Layout of trial.

Results and Discussion

The analysis of the tree diameter data separately for the acacias, eucalypt and dipterocarp species showed that the standard deviation between trees within species was linearly related to the species means. Therefore logarithms of the tree diameters were taken to stabilise the variance prior to calculating the combined analysis of variance given in Table 1. In this analysis:

1. The variation between the four plots (Table 1) may be due to a combination of environmental differences as well as effects induced by the different crops that were planted over the 3 years i.e. there is no replication of intercropping patterns. Therefore we have not called the interaction of plot with other factors a 'residual' term as would normally be done with a genuine blocking factor. The greater diameter growth in the first two plots (12.45 and 10.22 cm) could have been due to the benefits of the leguminous groundnut. Plots 3 and 4 had mean diameters of 8.53 and 10.00 cm respectively.

Table 1. Analysis of variance table for the logarithm of tree diameter.

Source of variance	Degrees of freedom	Mean square	Variance ratio
Plot Stratum			
Plot	3	2.41	
System Stratum			
System	4	0.66	8.3
Plot.System[1]	12	0.08	
Tree Stratum			
Species	2	60.18	492.7
System.Species	8	0.96	7.8
Plot.Species	6	0.14	1.1
Plot.System.Species[2]	24	0.12	1.0
Residual	321	0.12	

[1] Used as error in the System Stratum
[2] Used as error in the Tree Stratum

2. The factor 'System' in the analysis refers to the five mixing systems, each using a different *Acacia* seedlot and which are identified with the five field rows of trees in each plot (see Fig. 1). As the order of the mixing systems has not been randomised to the field rows (i.e. the *Acacia* seedlots are in the same order in each plot), some caution must be exercised in interpreting the system means from the analysis of variance, as any differences may be a combination of mixing system and environmental differences. However the results indicate that the Australian seedlot of *A. auriculiformis* (*A. aur1*) provided the best mixed system, followed by *A. leptocarpa*, *A. aur2*, *A. aulacocarpa* and *A. cincinnata*. Mean diameters were 11.21, 10.77, 10.40, 10.00 and 8.84 cm respectively.

3. The factor 'Species' in the analysis refers to the mixed trees in a field row, i.e. *Acacia, Eucalyptus* and *Dipterocarpus*. Differences in diameter are highly significant (Table 1) with *E. camaldulensis* (18.20 m) growing much faster than *D. alatus* (4.76 m).

4. Of particular interest in this analysis is the significant ($P<0.001$) interaction between the factors System and Species (Table 1). The interpretation of this interaction is that it makes a difference which *Acacia* seedlot is put in combination with the other two non-legume species. Among the five *Acacia* species included in the trials *A. auriculiformis* always proved to be the most vigorous and had the best survival, with the seedlot that originated from Oenpelli area, NT, Australia performing better than the local seedlot of *A. auriculiformis* (diameters of 15.97 cm and 13.63 cm respectively). The remaining *Acacia* species had mean diameters of 13.36, 10.52 and 8.78 cm for *A. leptocarpa*, *A. aulacocarpa* and *A. cincinnata* respectively.

5. Other interaction terms in the analysis of variance (Table 1) are non-significant. For example the three-factor interaction has almost the same mean square as the pooled between-tree, within-species residual. This lends some support to the use of this term as a residual in the analysis, bearing in mind that the trees were laid out in a systematic fashion (Fig. 1) within each field row. The number of degrees of freedom for the Residual (321) reflects the fact that there were 19 missing values in the data set.

6. The lack of appropriate replication and randomisation in the experimental design has to some extent limited the strength of the conclusions, particularly in relation to the comparison of intercropping patterns. More detailed experiments of mixed species systems are currently being planned.

Conclusions

There is potential for the use of *Acacia* species in agroforestry practices if the acacias are planted as three-tier mixing with the other different silvicultural characteristics and end-uses provided, as these studies were. There is both biological and economic buffering in systems in which there are productions of more than one species in the field. There are a wide range of suitable tree species mixtures as well as crops under an agroforestry system that have emulated to some degree the natural tropical ecosystem and its diversity, and have evolved through conscious intervention of farmers to meet their goals of covering all purposes with a sustainable system.

From a prolonged intercropping period point of view, these three-tier mixing systems could prove suitable for intercropping continuously until the canopy of the slowest growing species becomes closed. This may take up to 10 years compared to not more than 3 years for a single fast-growing species under the same spacing and practices. Under our practice all acacias will be cut at 3–4 years, leaves used for green manure, stem and branches for firewood. In this case, the open crown situation occurs again so that the intercropping practice could be continued.

The remaining two-tier mixing between *E. camaldulensis* and *D. alatus* with the spacing of 4 × 8 m will be maintained for intercropping. *Eucalyptus* will be the next harvested at 5 years. The main use for this tree is posts, poles or small construction. After year 5, only the slow-growing *D. alatus* with the spacing of 8 × 8 m will be left in the site. These practices appear complicated, but they seem reasonable from both the biological and management point of views for a sustainable agroforestry system in the tropics.

References

Benge, M.D. 1989. Little-known acacia promising trees for agroforestry. Agroforestry Today, 1 (4), 14–15.

Dommergues, Y.R. 1987. The role of biological nitrogen fixation in agroforestry. In: Steppler, H.A. and Nair, P.K.R., ed., Agroforestry: a Decade of Development. Nairobi, ICRAF, 245–271.

Langkamp, P.T., Swinden, L.B. and Dalling, M.J. 1979. Nitrogen fixation by *Acacia pellita* on areas restored after mining at Groot Eylandt, Northern Territory. Aust. J. Bot., 27, 353–361.

Langkamp, P.T., Farnell, G.K. and Dalling, M.J. 1982. Nutrient cycling in a stand of *Acacia holosericea*. Aust. J. Bot., 30, 87–106.

Roskoski, J.P. 1981. Nodulation and N_2-fixation by *Inga jinicuil*, a woody legume in coffee plantations. 1. Measurements of nodule biomass and field C_2H_2 reduction rates. Plant and Soil, 59, 201–206.

Plantation Development of *Acacia mangium* in Sumatra

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Abstract

This paper describes the seed sources, provenance trials, propagation techniques and development strategies for *Acacia mangium* in Sumatra, Indonesia. Commercial plantations of *A. mangium* began in the early 1980s, and in 1990 there were approximately 38 000 ha planted to supply pulpwood and sawn timber.

INDUSTRIAL scale plantation establishment of *Acacia mangium* in Sumatra, and other parts of Indonesia, began in the early 1980s. Planting has been concentrated in the lowlands, mainly below 300 m elevation. Most of the *A. mangium* plantations in Sumatra are for pulp wood, whilst some may be utilised for sawn timber.

Accurate data for areas of *A. mangium* plantations in Indonesia are scarce. It is estimated that at the end of 1990 there were approximately 38 000 ha of *A. mangium* plantations in Sumatra, most being under 7 years of age. Of this area, approximately 25 000 ha have been established in the last 2 years. Elsewhere in Indonesia, the area of *A. mangium* plantations is estimated to total less than 10 000 ha, located mainly in Kalimantan.

Seed Sources

Much of the *A. mangium* seed used in Indonesia has come from ex situ sources in Subanjeriji, South Sumatra, which are managed by P.T. Inhutani. This seed production area (total 490 ha) is composed mainly of stands of *A. mangium* (335 ha), *Eucalyptus urophylla* (105 ha) and *E. deglupta* (45 ha). Most of the area is divided into single provenance blocks of 10–20 ha, separated by 60 m wide strips. The stands were established between 1979 and 1985 in two generations. The first generation of *A. mangium* stands was planted using bulk seeds of Queensland provenances (Cassowary, Julatten, Mossman) and Indonesian provenances (Piru, Ceram; Sanga-Sanga, East Kalimantan; Sidei, Irian Jaya). Papua New Guinea provenances are not represented. The second generation of *A. mangium* stands was established from seed collected in the F_1 Subanjeriji plantations. *A. mangium* seed collected from the F_1 and F_2 stands inevitably contains crosses between origins. Seed from Subanjeriji also contains numerous *A. mangium* x *auriculiformis* hybrids. There are no known *A. mangium* isolated seed stands or family seed orchards yet producing seed in Indonesia. Some *A. mangium* bulk seed is imported.

Provenance trials

The oldest comprehensive *A. mangium* provenance trial in Indonesia was established in 1986, by the Ministry of Forestry/Finnida (Finnish International Development Agency) ATA-267 project, on an *Imperata* grassland site in South Kalimantan (Adjers and Hadi 1989). This trial of 30 provenances contains 14 from Queensland, 12 from Indonesia and 4 from Malaysia. Unfortunately, no provenances from Papua New Guinea were included. The seedlots are replicated 4 times in plots of 25 trees, at 3 × 3 m spacing, in a randomised complete block design. Provenances have been assessed for survival, number of leaders, height, dbh and crown diameter. Summary results at age 30 months are described below.

Survival varied between provenances from 92 to 100%. The average number of leaders varied from 1.11 (Bloomfield) to 2.25 (Sanga-Sanga). Provenance Claudie River displayed the best height growth (11.1 m), followed by Kuranda (10.0 m), and most

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other provenances were in the range 8.3–9.8 m. In general, the tallest provenances also had the best dbh development, namely Mossman (13.6 cm), Kuranda (13.1 cm) and Claudie River (11.7 cm). Crown diameter varied from 2.9 m (Sanga-Sanga) to 3.5 m (Claudie River). Queensland provenances had a wide and deep crown, whilst Indonesian provenances had less branches and a lighter crown. In conclusion, Claudie River grew fastest and had a straight stem and heavy crown. Kuranda and Cardwell also had good form, but grew slightly slower. Bloomfield had the best form. The Indonesian provenances displayed reasonable growth but their light crowns closed canopy later, making them less attractive for weedy sites. Two seedlots from Subanjeriji (origins unspecified) showed good growth with moderate form, but there was a lot of within-plot variation.

To date there is only very limited experience of the performance of Papua New Guinea provenances in Indonesia, but early results are promising.

Indah Kiat Pulpwood Plantations

P.T. Indah Kiat Pulp & Paper Corporation (IKPP) sister companies manage the largest *A. mangium* plantation estate in Indonesia, located in Riau province, lowland central Sumatra. This project has a formative influence on other projects and is taken as a case study.

In 1983 IKPP began the establishment of trial plantations of *A. auriculiformis, A. mangium, Leucaena leucocephala, E. alba, E. grandis, E. urophylla* and *Paraserianthes falcataria*. At the end of January 1991 IKPP had a total pulpwood plantation area of 27 000 ha. These plantations are 90% *A. mangium*, which was quickly selected as the principal species on the grounds of its hardiness, fast growth, health, low nutrient demands and promising pulp and paper qualities. Planting by IKPP has greatly increased during the last 2 years (Fig. 1). The target is to further increase planting to over 20 000 ha per annum, in line with the planned expansion of the pulp mill (present capacity 300 000 air-dried tonnes/annum).

The climate in lowland Sumatra is well suited to *A. mangium*, with even rainfall distribution and constant warm temperature. Mean annual rainfall is 2000–3000 mm. During the period 1977–1986 the annual number of rain days was approximately 100, with monthly averages varying from 12.1 days (250–300 mm) in October to 5.9 days (100–140 mm) for June in Riau (Department of Agriculture, Indonesia 1977–1986). Mean monthly temperatures are 25–28 °C throughout the year.

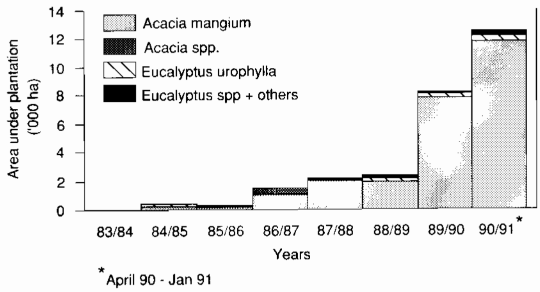

Fig. 1. P.T. Indah Kiat Pulp & Paper Corporation. Associated company annual pulpwood plantation establishment areas.

The topography of the IKPP concessions is moderately undulating, with elevations less than 100 m. The main soil types are red-yellow podsols and gley-humus soils of alluvial or sedimentary origin, and of loamy-sand or clay-loam texture. IKPP has established 52% (13 000 ha) of its plantations on former logged-over forest sites which are cleared to provide mixed tropical hardwood for the mill. The other 48% (12 000 ha) is planted on scrubland and open land on former shifting agriculture sites.

Since 1989, only selected seedlots of known provenances have been used and the seedlot of each stand is mapped. *A. mangium* seedlots have been planted in large uninterrupted blocks (e.g. 200–500 ha) for the creation of provenance conservation populations.

The polybag nursery system is being phased out and replaced by seedling production in 50 cm^3 plastic root trainer tubes. A centralised, modern nursery produces 10–12 million plants per annum, with the tubes hanging in trays on raised steel production lines. Direct sowing of *Acacia* seed in mist houses is used, and roots are air-pruned to avoid root coiling. 30 000 seedlings can be transported on a 6-tonne truck, with considerable savings in distribution costs.

Mechanised soil preparation (V-blade on forest sites and ripper/mounder on compacted sites) and disc harrow weeding is used on flatter sites, for both *Eucalyptus* and *Acacia*. On other sites, manual weeding is combined with herbicide eradication of *Imperata* patches.

Acacia is singled to leave only one leader at age 6 months. A no-thin regime is practised and the planned rotation length is 7 years on forest sites, and probably 8–9 years on agricultural sites. First measurement of permanent sample plots indicates an MAI of 35–45 m^3 stem over bark (sob)/ha/year on forest sites at age 6 years.

A comprehensive tree improvement program was begun in 1989. A systematic series of *Acacia* and *Eucalyptus* provenance and progeny trials is being established, as well as seed stands and seed orchards. The vegetative propagation of clones has begun. Other research has concentrated mainly in nursery, cultivation, fertilisation and wood property trials. Fertiliser trials on agricultural sites have shown a good early response to P and NPK applications within the first year, in terms of height, dbh and crown width development. One hundred ha of plantation trials have been established on a drained peat land site, and early growth of *Acacia* species has been good. Results are still very preliminary.

Future Plantation Development

Indonesia is beginning the large-scale development of forest plantations to support pulp and paper industries. Several companies have plans to implement planting programs in the order of 5000–15 000 ha/annum per project during the next 5 years. Many of these forests will be designated as 'HTI' (Hutan Tanaman Industri) industrial plantations under the Ministry of Forestry's Timber Estate Programme. Most plantations will be established on lowland sites where the topography is favourable and the population pressure is relatively low. Several plantations are planned for Sumatra, where there is a reasonable infrastructure for industrial development.

In the lowlands of the western half of Indonesia, where there is no prolonged dry period, eucalypts are susceptible to numerous pests and diseases, many soils are probably not fertile enough for *Gmelina arborea* and *A. mangium* is rapidly assuming the role as the dominant plantation species.

References

Adjers, G. and Hadi, T.S. 1989. Species and provenance selection for alang-alang sites. In: Adjers, G., Arisman, H., Utomo, D.I., ed., Proceedings of a Seminar on the Development of Reforestation Techniques in South Kalimantan Achieved by the ATA-267 Indonesia-Finland Mechanised Nursery and Plantation Project. Finnida, 30–52.

Department of Agriculture, Indonesia 1977–1986. Meteorological data reports for Duri and Siak Sri Indrapura, Riau Province.

The Role of *Acacia auriculiformis* in Afforestation in Karnataka, India

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Abstract

In India the demand for wood for firewood, pulp and sawn timber is increasing enormously due to rapid population growth. Fast-growing exotics have been tried and exotic acacias are performing very satisfactorily in western ghats — mountain ranges situated on the west coast of the southern Indian peninsula.

Acacia auriculiformis is a major afforestation species in the western ghats of Karnataka State in India because of its adaptability, productivity and utility. Four provenances were tried on three sites in Shimoga district of Karnataka, and observations indicate that the Springvale QLD and Balamuk PNG provenances are most suitable to this locality.

IN INDIA, the demand for wood for purposes such as firewood, pulp and timber is increasing enormously due to the fast-growing population. The existing natural forests are shrinking at the rate of 1.5 million hectares per year, due to tree felling to meet the demand for wood and using the land for agriculture, mining and other developmental activities. The gap between demand and supply of forest products is widening. To overcome this problem and to bridge the gap between demand and supply of forest products, state forest departments, forest corporations and forest-based industries have taken the initiative of introducing fast-growing exotic tree species for afforestation along with intensive management of the natural forests.

The western ghats of India run for 1600 km along the west coast in the southern Indian peninsula, with an average width of 120 km. They start in Maharashtra, pass through Goa, Karnataka, Tamilnadu and Kerala, and end at Kanya Kumari on the southern tip of India. The terrain is undulating with broad valleys. Soils originated from the parent material granite and gneiss. Soil ranges from lateritic stone to red clay and is moderately deep to very deep. Ground water table is very deep. The soil is slightly acidic with the pH ranging from 5.3 to 6.6 The area is rich in flora and fauna.

The forests of western ghats are tropical high-zone rain forests interspersed with grassy blanks. They receive southwest monsoon rains from June to September. The western boundary of Shimoga district in Karnataka State is where our trial plots are situated. About 25 km south-west of our trial plots at Agilubagilu and Brammadevaragadde is Agumbe, which receives the highest rainfall (>10 000 mm) in South India.

Acacia auriculiformis and some other Australian acacias were first tried in India in 1946, in West Bengal State. It became known locally as 'Bengali Jali'. In India, it has been a major species of afforestation for the past 25 years, particularly in the southern states — Andhra Pradesh, Kerala, Tamil Nadu, Karnataka, Maharashtra, Goa and Pondicherry. When compared with the local indigenous species *A. auriculiformis* is the most important and widely planted in Karnataka, because of its adaptability, utility and economic value.

Though the *Eucalyptus* species is said to be very fast growing with higher wood biomass percentage, much opposition by local villagers has hindered the planting of *Eucalyptus* species in the western ghats. Besides, as observed in the forest areas of western ghats near Agumbe and in Kerala state, it has suffered from 'Pink Disease', which affects normal growth and can mean failure of the entire crop. For these reasons the Australian acacias have an edge over eucalypts.

A. auriculiformis was introduced to Karnataka in 1964. The early plantations have now attained an average height of 25–28 m and average diameter at breast height (dbh) 30–37 cm, with a commercial bole

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of 10–12 m, in good soil of this region. The establishment of large-scale mechanised plantations was set in motion in 1982. Over 10 000 ha have been planted with this species up to the 1990 rains, with financial assistance from the Overseas Development Administration (ODA), U.K.

It is to be noted with concern that although *A. auriculiformis* has been found to be suitable for all purposes in India, no serious work appears to have been done to improve the tree form or to get genetic improvement in the species. The Mysore Paper Mills Ltd., Bhadravati, has initiated research studies in this species with financial assistance from the ODA and technical support from Oxford Forestry Institute (OFI), U.K. Species trials and provenance trials of proven species have been established at various locations in the western ghats region of Shimoga district since 1985.

Provenance Trials

Materials and Methods

Seeds of three provenances were obtained through Division of Forestry and Forest Products, CSIRO, Canberra, Australia. Details of seedlots are given in Table 1.

Seeds were treated in hot water and were sown in the nursery during Jan. 1985. One week after germination 4–5 cm seedlings were transplanted into 12.5 × 20 cm poly bags. Red earth and river sand were used as potting mixture in 1:1 ratio with a pinch of diammonium phosphate (DAP) in each bag. Poly bagged seedlings were maintained for a period of 5 months, by regular watering, weeding and shifting. During June–July 1985 the 30 cm seedlings were used in experimental trial plantings at different locations (Table 2).

The trial sites were clear-felled and burnt, then ripped at 3 m intervals along the contours with a D-50 bulldozer. The seedlings were planted at 1.5 m spacing within the ripped line. Randomised complete block design was used consisting of 5 replications and plot size of 7 × 7 plants. The inner 5 × 5 plants were measured for height, dbh and rate of survival from years 1–5.

Intercultural operations included scraping, soil working and fertiliser application (25 g NPK(15:15:15) per plant during the first year and 25 g NPK(15:15:15) plus 40 g rock phosphate during the second and third year) to each plant. Annual weeding, grass cutting and fire tracing were carried out for the first 3 years.

Table 1. Details of seed sources of *Acacia auriculiformis* provenances used in trials in western ghats of Shimoga district, Karnataka.

No.	Seedlot No.	Provenances	Latitude	Longitude	Altitude
1.	13684	Balamuk PNG	8°54′S	141°18′E	18 m
2.	13861	Springvale QLD	15°50′S	144°55′E	150 m
3.	13854	Oenpelli NT	12°20′S	133°04′E	50 m
4.*	—	Local source	13°51′N	75°12′E	600 m

* Seed collected from single tree of 1979 plants in Mandagadde, Thirthahalli in January 1985

Table 2. General locality factors of provenance trials of *Acacia auriculiformis* sites in western ghat of Shimoga District, Karnataka.

Sl No.	Site name	Latitude	Longitude	Altitude (m)	Mean annual rainfall (mm)	Ground water	Soil type	pH
1.	Agilubagilu THH	13°44′N	75°12′E	620	2606	very deep	sandy loam deep	5.6
2.	Brammadevaragadde THH	13°44′N	75°12′E	610	2606	very deep	red clay deep	5.8
3.	Kanase SAG	14°13′N	74°35′E	590	2765	very deep	red loam deep	5.7

THH — Thirthahalli Taluk Hq. SAG — Sagar Raluk Hq.
Rainy season southwest monsoon June to September — mean annual rainfall of past 10 years
Mean annual temperature — 25.5°C

Experimental Results

During the first year there was no significant difference in height between the provenances in any of the sites. Survival was 100% at all sites. Further results are given in Table 3.

In Agilubagilu site the Balmuk PNG and Springvale QLD provenances rivalled each other for top performance. At the end of the fifth year the Springvale provenance has overtaken the Balamuk in volume production followed by the local source and Oenpelli provenance (Table 3). The Springvale provenance has occupied the top position in respect of dbh followed by Balamuk, local source and Oenpelli. In respect of a height parameter the Balamuk provenance occupied the top position followed by the Springvale, local source and Oenpelli provenances.

Table 3. Results of 1985 *Acacia auriculiformis* provenance trials in three different locations measured at various ages.

No.	Provenance	Year	Mean ht (cm)	Mean Dbh (cm)	Volume (m^3) **	Stems Mean Number*	CAI (m^3)	MAI (m^3)
Agilubagilu — THH								
1.	Balamuk PNG	1	211	—	—	—	—	—
		2	454	4.0	5.3	—	—	—
		3	780	7.0	27.9	—	22.6	—
		4	985	8.0	46.7	—	18.8	—
		5	1235	10.0	90.6	1.3	43.9	18.1
2.	Springvale QLD	1	212	—	—	—	—	—
		2	457	3.8	4.8	—	—	—
		3	840	7.2	31.9	—	27.0	—
		4	1047	8.5	54.9	—	23.1	—
		5	1220	10.4	95.8	1.0	40.9	19.6
3.	Oenpelli NT	1	170	—	—	—	—	—
		2	460	3.2	3.4	—	—	—
		3	694	5.7	16.7	—	13.3	—
		4	843	6.0	22.0	—	5.3	—
		5	1029	6.7	33.6	2.0	11.5	6.7
4.	Local source	1	188	—	—	—	—	—
	M.gadde THH	2	398	3.3	3.1	—	—	—
		3	712	5.3	14.8	—	11.7	—
		4	866	5.9	22.0	—	7.2	—
		5	1033	7.2	38.9	2.1	16.9	7.8
Brammadevaragadde — THH								
1.	Balamuk PNG	1	227	—	—	—	—	—
		2	468	3.7	4.8	—	—	—
		3	791	6.9	27.9	—	23.1	—
		4	1015	7.8	44.8	—	17.0	—
		5	1150	8.9	67.4	1.4	22.6	13.5
2.	Springvale QLD	1	226	—	—	—	—	—
		2	460	3.7	4.6	—	—	—
		3	704	6.3	20.5	—	15.9	—
		4	995	7.7	43.6	—	23.1	—
		5	1182	9.0	69.9	1.2	26.3	14.0
3.	Oenpelli NT	1	184	—	—	—	—	—
		2	418	3.0	2.7	—	—	—
		3	654	5.6	15.2	—	12.5	—
		4	937	6.8	31.9	—	16.7	—
		5	1028	7.2	39.2	1.8	7.3	7.8
4.	Local source	1	201	—	—	—	—	—
	M.gadde THH	2	446	3.1	3.2	—	—	—
		3	678	5.2	13.2	—	10.1	—
		4	869	6.1	24.0	—	10.8	—
		5	1043	7.0	36.9	1.8	12.9	7.4

Table 3. *continued.*

No.	Provenance	Year	Mean ht (cm)	Mean Dbh (cm)	Volume (m^3) **	Stems Mean Number*	CAI (m^3)	MAI (m^3)
Kanase — SAG								
1.	Balamuk PNG	1	246	—	—	—	—	—
		2	477	3.6	4.6	—	—	—
		3	806	6.9	28.4	—	23.8	—
		4	1064	9.8	75.2	—	46.9	—
		5	1250	10.4	99.3	1.2	24.1	19.9
2.	Springvale QLD	1	225	—	—	—	—	—
		2	445	3.6	4.2	—	—	—
		3	776	6.7	25.2	—	21.1	—
		4	1077	8.9	62.7	—	37.5	—
		5	1317	10.2	99.5	1.1	36.8	19.9
3.	Oenpelli NT	1	225	—	—	—	—	—
		2	448	3.0	2.9	—	—	—
		3	802	6.8	27.0	—	24.1	—
		4	1017	8.8	57.2	—	30.2	—
		5	1220	10.2	92.3	1.7	35.2	18.5
4.	Local source M.gadde THH.	1	230	—	—	—	—	—
		2	454	3.0	3.0	—	—	—
		3	780	6.8	26.3	—	23.3	—
		4	956	8.1	46.0	—	19.7	—
		5	1187	9.2	73.4	1.7	26.4	14.7

** Volume — ($0.33 \times d^2 \times$ Ht.) @ 2222 trees/ha.
* — Surveyed at the end of year 5 below breast height

Among these four provenances, the Springvale provenance had a single stem per tree whereas the Oenpelli and local source provenances had two stems per tree. The Balamuk provenance had 1.3 stems per tree.

The results of Brammadevaragadde trial plot showed that the Springvale provenance has occupied the first place in all measured parameters followed by the Balamuk, Oenpelli and local source. In this trial plot the mean number of stems per tree was different from that observed for the Agilubagilu site. Springvale had 1.21 stems per tree. This was followed by Balamuk (1.39 stems per tree), Oenpelli (1.78 stems per tree) and local source provenance (1.82 stems per tree).

The third site at Kanase is about 75 km northwest of the previous two sites. This site is fairly level with red loamy soil. All four provenances in this site were growing well and the differences between these four provenances for the measured parameters were very small. Here also Springvale provenance was first in height and volume production, but was third in dbh. The Balamuk provenance occupied first place in dbh and second place in height and volume. The Oenpelli provenance occupied second position in dbh and third position in height and volume parameters. The local source was last in all parameters as at the other two sites.

The Springvale provenance has fewer stems per tree (1.08) followed by the Balamuk (1.20), Oenpelli (1.70) and local source (1.73).

The main objective of these trials, viz. to attain maximum yield in a unit area with single stem per tree, was fulfilled by the Springvale provenance followed by the Balamuk provenance.

The effect of planting site on these provenances can be interpreted based on the results obtained so far. The Springvale and Balamuk provenances have shown better performance in loamy soil (Agilubagilu and Kanase) than in clay soil (Brammadevaragadde).

The Oenpelli and local source provenances were always in third and fourth positions but within this broad framework have shown comparatively better performance in Kanase than in Agilubagilu and Brammadevaragadde sites.

In addition to the provenance trials, permanent sample plots of *A. auriculiformis* were laid out in 1985 plantations in Hosanagar Taluk of Shimoga district in Karnataka. The same measurements were taken as for the provenance trials, and the results are presented in Table 4. It was found that the growth and volume production were poorer than the Balamuk and Springvale provenances in the provenance trials. The mean number of stems per tree was also high, averaging 1.68–1.84 stems.

Table 4. Results of the permanent sample plots of *Acacia auriculiformis* laid out in 1985 MPM softwood plantation in Hosanagar Taluk of Shimoga District (western ghat), Karnataka.

Location	Age	Mean ht (cm)	Mean dbh (cm)	Volume (m^3) **	Stems (mean number)*	CAI (m^3)	MAI (m^3)
Behalli	2.9	668	5.0	8.9	—	—	—
	3.4	755	5.9	13.8	—	4.8	—
	4.0	865	6.5	19.2	—	5.5	—
	4.5	963	6.9	24.5	—	5.3	—
	5.0	1103	7.6	33.6	1.8	9.2	6.7
Kallugudda	2.9	813	6.0	15.5	—	—	—
	3.4	880	6.6	20.1	—	4.7	—
	4.0	1018	7.7	31.8	—	11.7	—
	4.5	1139	8.1	39.3	—	7.5	—
	5.0	1212	8.8	49.2	1.7	10.0	9.8

* Mean number of stems at end of year 5

** Volume (m^3) — ($0.33 \times d^2 \times$ ht.) @ 1600 trees/ha

Discussion and Conclusion

The results indicate considerable differences in performance between the seed lots of different provenances within sites and between the same seed lots in different sites, particularly after the third year. This is probably because of the edaphic factors such as loamy soil. The number of stems per tree may be genetically controlled rather than influenced by edaphic factors. The results of similar trials in Thailand (Pinyopusarerk and Puriyakorn 1987), Zimbabwe (Gwaze 1989), China (Yang Minquan et al. 1985) show that the Balamuk and Springvale provenances are more productive than local seed sources.

Due to easy establishment of the site and its adaptability in various soil conditions, the afforestation of the grassy blanks in this region with *A. auriculiformis* has greater advantage not only for immediate returns, but also offers the hope of getting back the original vegetation of these grassy blanks which were once covered with evergreen and semi-evergreen forests. These have vanished as a result of the destructive influence of various factors, e.g., the annual fire and biotic interference over many years.

The grassy blanks now give an appearance of evergreen forests due to the acacias planted in this region since 1965. At present it is very difficult to quantify the importance of this exotic tree species in this locality. But ideally it will be the nurse crop for indigenous species, and also improve the topsoil in these grassy blanks.

A. auriculiformis is now used as a small timber for furniture and building purposes after tests that showed its physical and mechanical properties compared favourably with teak (*Tectona grandis*) (Kumar et al. 1987). It is observed that the stem form of *A. auriculiformis* is only suitable for firewood and pulpwood. The provenance trials have shown the importance of selecting the most suitable provenance for this area of western ghats.

So far severe pests and diseases have not been observed in this locality. There have been some instances of wind damage causing uprooting of trees.

Flowering was observed in all four provenances in three sites. Sporadic flowering was noticed at age 30 months in all sites and in all provenances except Oenpelli. The seeds first collected have been tested for viability and found satisfactory. The Oenpelli provenance has not yet flowered.

Natural regeneration was observed by the authors in the older plantations of this species in this region and also all along the coastal line of Karnataka. The flowering is much earlier all along the coastal belt than in the uplands in the state. The form of the tree varies in different localities from bushy with heavy branches to single stems.

These early results of provenance trials are considered to be the most important, as they provide basic information for determining suitable provenances for future use in this locality.

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References

Gwaze, D.P. 1989. Growth and survival of Australian tree species in field trials in Zimbabwe. In Boland, D.J., ed., Trees for the Tropics. ACIAR Monograph No. 10, 129–138.

Kumar, P., Anathanarayana, A.K. and Sharma, S.N. 1987. Physical and mechanical properties of *Acacia auriculiformis* from Karnataka. Indian Forester, 113(8), 567–573.

Pinyopusarerk, K. and Puriyakorn, B. 1987. *Acacia* species and provenance trials in Thailand. In: Turnbull, J.W., ed., Australian acacias in developing countries. Proceedings of an international workshop held in Gympie, Queensland, Australia, 4–7 August 1986. ACIAR Proceedings No. 16, 143–146.

Yang Minquan, Bai Jiayu and Zeng Yutian 1989. Tropical Australian acacia trials on Hainan Island, People's Republic of China. In: Boland, D.J., ed., Trees for the Tropics. ACIAR Monograph No. 10, 89–96.

The Establishment and Tending of *Acacia mangium*

D.J. Mead* and R.R. Miller**

Abstract

Acacia mangium is now an important plantation species in the humid tropics of Asia, being relatively easy to grow and adaptable to a wide range of conditions. In Malaysia there has been interest in growing the species for high quality sawlogs as well as for pulpwood. This paper draws extensively on the authors' experience in Malaysia and also refers to work elsewhere in the region. The Malaysian material is based on a broad range of management regimes practiced at contrasting sites. Knowledge of rainfall, soil type, nutrition and growth habits and their relative effects on new and established plantings is used to draw up recommendations for optimising growth and gaining the desired harvest from *A. mangium* plantations.

ACACIA mangium has now become an important plantation species in the humid tropics of Asia. It first came to prominence in the late 1970s following its introduction to Sabah from Queensland in 1966. The first commercial plantations were undertaken by Sabah Forestry Development Authority (SAFODA) at Ulukukut and other dryland and degraded sites in Sabah. Since then it has become an important reforestation species in other parts of Malaysia and Southeast Asia. Its success is due to its extremely vigorous growth; its tolerance to very acid, low nutrient soils; its ability to compete and grow reasonably well where competition is severe, such as on *Imperata* grasslands; its relative freedom from diseases; its good wood properties which potentially make it acceptable for a wide range of end-uses; and its ease of establishment.

Little was known of the species' establishment and later tending requirements when the first major plantations were started; nor has much been published since. There has now been considerable experience with the species and research is increasing, although from a silvicultural point of view, much is still in the early stages.

This paper draws extensively on the authors' first-hand Malaysian experience, but also refers to work elsewhere in the region. In Malaysia, fortunately, both the objectives of management and sites planted cover the extremes. This allows us to suggest reasonable silvicultural guidelines.

In Malaysia there has been interest in growing the species for high quality sawlogs as well as for pulpwood. *A. mangium* has rapidly found acceptance as a pulpwood species, and is considered suitable for use in reconstituted board (Groome 1989). There have also been sawing and plywood trials in Malaysia and trees from natural stands are used as sawlogs and veneer in Queensland. The silvicultural requirements are different for such varied end-uses.

Again, the sites on which *A. mangium* is being planted in Malaysia vary from more fertile recently cleared jungle, through secondary 'belukar' scrub to very degraded soils covered with *Imperata cylindrica* grass. Climate, particularly the length of the growing season, also varies considerably between the major planting regions of Peninsular Malaysia and Sabah. These site differences influence establishment practices, fertiliser requirements, later tending and rotation lengths.

Silvics

A. mangium is from northern Queensland, Papua New Guinea and eastern Indonesia and prefers a humid tropical climate without frosts or prolonged cold temperatures. According to Pan Zhigang and Yang Minquan (1987), the trees grow slowly if mean monthly temperatures are below 17 °C. Trial plantings at higher elevations (1000–1500 m) at Lake Toba in Sumatra have not been very successful,

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although this may be due in part to a lack of *Rhizobium* for nitrogen fixation. The species is intolerant of severe droughts or excessively wet or droughty soils. Rainfall should preferably exceed 2000 mm/year (National Academy of Sciences 1983). In an earlier paper on the plantations in Malaysia, the authors illustrated the importance of the rainfall pattern, particularly the length of the dry season, on the growth rate of the species (Mead and Miller 1989). It appears that drought periods (defined as those having a monthly rainfall below the rate of open-pan evaporation) longer than about 2 months will reduce growth rates, and with very long drought periods (e.g. 6 months) the trees become very stressed, with foliage being lost and turning yellow. Experience in other countries does not contradict these observations, although further detailed studies would be useful.

At the other extreme, if the soils become waterlogged then the foliage again turns yellow. At Bengkoka we have also observed this yellowing on sites where there is temporary waterlogging from a period of heavy rain, and in such situations the trees quickly return to normal when the soils dry out. The yellowing of the foliage in both drought and waterlogged situations is associated with suboptimal foliage nitrogen levels of <2.0% dry weight (Table 1). This indicates that at least part of the effect is due to interference with symbiotic nitrogen fixation.

Table 1. Proposed diagnostic levels of *Acacia mangium* foliage.* Figures in brackets are tentative.

Nutrient	Critical	Satisfactory
N %	?	>3.0
P %	<0.13	0.13–0.15
K %	<0.6	>1.0
Mg %	<0.11	0.15–0.20
Ca %	<0.2	—
S %	(<0.10)	—
B ppm	<10	—
Zn ppm	(10)	—
Cu ppm	(3)	—

* The 5th and 6th leaf back from the bud of lateral, upper-crown branches should be sampled. This unpublished information is based on the senior author's studies for CFPP and SAFODA.

A. mangium is sensitive to soil conditions. It prefers fertile sites that have good drainage (but are not excessively well drained). The species tolerates a low pH (e.g. <4.0) and indeed natural stands in Papua New Guinea grow on such acid sites (Skelton 1987). Studies in Peninsular Malaysia, on sites where moisture was not excessively limiting, suggested that the Bray-2 phosphate level in the top 10 cm of the soil, two years after planting, should be >10 ppm to ensure good tree growth (Mead and Speechly 1989). At 4 ppm basal area would be reduced by 30–40%. The criterion for satisfactory foliage P levels was found to be 0.13–0.15% dry weight; this and other tentative criteria for interpreting foliage nutrient levels are given in Table 1. Soils derived from ultrabasic rocks in Bengkoka have been found to be unsuitable for *A. mangium* because of their very high levels of Mg and perhaps their high pH.

A. mangium shows strong apical dominance even where it is open grown (Mead and Speechly 1989). The crowns of open grown trees are naturally wider than those grown in closed stands, and have larger lateral branches. Mead and Speechly (1989) found a good relationship between stem diameter and crown diameter for open grown trees, and this was helpful for setting spacings which would maximise diameter growth.

In closed stands, up to about 12 m tall and planted at about 900 stems/ha, the length of the green crown is about 7 m, although the length appears to vary with site. The crowns are 'shy' and like many eucalypts they prefer not to interact. Crowns are highly light-demanding and their foliage mass response to thinning is often dramatic. It has been observed that some moribund branches in the lower crown and other adventitious shoots will produce new foliage following thinning. The effectiveness of this type of foliage increase, compared to normal crown response following a thinning, has not been quantified.

Branches are persistent as the species does not naturally prune itself as, for example, do the eucalypts. Stem rot sometimes develops from dead branch stubs (Tan and Douglass 1989). Fluting of the bole is often a problem.

In some locations *A. mangium* has a tendency to form multiple stems. The cause of these is not fully understood although it does appear partly related to soil fertility. Thus studies in Peninsular Malaysia have shown it is more frequent on ashbeds from burnt windrows than between them, and that this was related to a higher phosphate status in the trees (unpublished data). Baharuddin (1987) has also noted it is less frequent where there is competition; also it has been observed infrequently where the *Acacia* has been planted under pine. Although it is a problem on fertile, ex-jungle sites in Peninsular Malaysia and in Sumatra, it is not a major problem in Sabah.

Stem straightness also varies with site, being poorer on sites with higher fertility, where growth is fast. For example in Peninsular Malaysia estimates of acceptable stems for sawlogs may be as low as 10%, but in Sabah the degree of malformation is much less of a concern, with perhaps a third of the trees being acceptable (Mead and Speechly 1989; Mead and Miller 1989; Racz and Zakaria Ibrahim 1987). Furthermore, there are large provenance differences in both stem straightness and the frequency of multiple leaders.

The root system is described as being shallow, but vigorous, with most roots concentrated in the upper 28 cm (Pan Zhigang and Yang Minquan 1987). Limited observations in Peninsular Malaysia suggest that surface roots occupy the site rapidly; even 7-month-old trees were found to have lateral roots up to 3 m in length. *Rhizobium* nodules are common and the application of phosphate may facilitate their development on some sites. Inoculation in the nursery is important if the nursery soil lacks the symbiont. Ectomycorrhizas have been reported on the species (Sim Boon Liang 1987).

Ecologically the species is a fast-growing, short-lived pioneer (Skelton 1987). Thus, it is not surprising that it shows early and prolific seeding, rapid height growth after planting (up to 10 m in 2 years), with an early culmination of mean annual increment (MAI). At Sabah Softwoods Sdn. Bhd. (SSSB) unthinned stands planted at 1075–1680 stems/ha are reported to reach their maximum MAI in volume (to a 10 cm top) at 6 years after planting on high quality sites (>21 m^3/ha at 8 years) and at age 7 on poorer sites (Tan and Douglass 1989). The effect of thinning is to delay the age at which the MAI is greatest. Thus on the poorer sites at Bengkoka in Sabah, unthinned stands planted at 1100 stems/ha reached a maximum MAI of about 18 m^3/ha at 7 years while stands thinned to 550 stems/ha at 18 months reached their maximum mean volume increment a year later. Establishment practices and seed source have been reported as influencing growth rates (Mead and Speechly 1989; Miller and Hepburn 1989).

At conventional stockings of about 900–1000 stems/ha competition begins to influence diameter growth when the basal area reaches about 2–3 m^2/ha (Mead and Speechly 1989). Depending on site this can vary from 1 to 3 years after planting.

The species has the ability to coppice, although the vigour of the coppice shoots is less than that of planted stock or natural regeneration. At Bengkoka, it takes seedlings only 2 years to reach the height of coppice of that age. Natural seeding has been tried by SAFODA with mixed results; patchy stocking has been a problem. Best results are associated with soil disturbance or fire.

Establishment Practices

Site preparation and weeding

Previous vegetation, climate, topography, soil and nutrient conservation, cost, equipment and other social factors, all influence site preparation practices.

Where degraded jungle is being converted to plantations, felling followed by burning is to be preferred over windrowing and then burning (Mead and Speechly 1989). The latter practice leads to uneven growth, and lower overall productivity of the plantation. For example, measurements in Kemasul Forest in Peninsular Malaysia found that where windrowing and burning had occurred 35% of the area was covered by ashbed, compared to over 90% in an adjacent broadcast burnt area. Despite the application of fertiliser at planting, trees over the windrowed area as a whole, averaged only 80 cm in height at age 4–5 months, compared to 120 cm on the broadcast burnt site. The management difficulty is that burning can only occur in the dry season, which in some localities can be quite short.

The advantage of a good broadcast burn is that it not only releases nutrients in the biomass to the soil, but it improves access and kills coppice and seed. This latter reduces competition and weeding operations. The loss of volatile nutrients and erosion or nutrient runoff can, on some sites, be a cause of concern using a broadcast burn. Further investigations into alternative techniques, such as low-impact line blading or spraying, deserve study.

Poor secondary forest or scrub (belukar) may be handled in two ways. On easy topography (slopes <30%) at Bengkoka, SAFODA managers have used a twin-drum Marden chopper-roller successfully. This requires a D-6 or preferably a D-7 tractor and results in well chopped and compacted material. Productivity for flat country was 2.3 machine hours per hectare using a D-6 tractor. Burning after roller crushing produces a cleaner site for planting with reduced weed growth compared to an unburnt site. The value of retaining the chopped vegetation as a mulch to improve soil fertility has yet to be demonstrated for these sites.

The alternative is to hand cut and burn which requires 20–26 working-days/ha. The site is not usually as clean as after the roller crushing option, and so more weeding may be required as well. The preference usually depends on the relative costs, availability of labour and machinery and other social objectives.

Imperata grassland and broadleaf weeds, particularly *Eupatorium*, are best burnt to reduce the fire hazard, and this may be followed by chemical control. At Bengkoka trials have shown that spraying with glyphosate at 4 l/sprayed ha will give 6 months effective control for *Imperata* grass. Glyphosate is less effective with broadleaves but 3 months control may be obtained by including a pre-emergent spray such as simazine into the mix. Imazapyr has been found to be very effective on these weeds but has caused residual side effects even where it has not been sprayed onto the *A. mangium* itself. Complete surface cultivation was also tried at Bengkoka as a method of weed control but was not successful.

Most growers find it necessary to free the trees from weeds during the first year, and occasionally in the second year. The method and frequency will vary with site and the weed problem, as well as social objectives.

A clean burn of former jungle will reduce the weeding requirements to perhaps one circle slashing, but more weeding, paying particular attention to climbers, will be required following a poor burn. Wild bananas can be controlled by hand cutting or herbicide injection.

On dry grassland sites such as those at Bengkoka two hand-weedings in the first year are all that is required, particularly if there is good pre-plant weed control (Udarbe and Hepburn 1987). However, on wetter sites on clay soils such as in parts of South Kalimantan and Sumatra, *Imperata* grass is a stronger competitor and, unless effective control is achieved before planting, tree growth is very poor.

Belukar sites also require hand-weeding. At Bengkoka, strip weedings to 2 m width are scheduled at 2-month intervals.

Planting and initial spacing

The usual practice on recently burnt sites is to use either a poling system, perhaps associated with hand spraying operations, or to mark out the planting spots individually. In the Compensatory Forest Plantations Project (CFPP) of Peninsular Malaysia, trees are planted at 3 × 3.7 m (900 stems/ha), which on their sites results in good site occupancy within the first year. In Sabah at SSSB, trees are planted at 1075 and 1680 stems/ha on the better and poorer sites, respectively (Tan and Douglass 1989), while SAFODA commonly plant at 4 × 2 m (1250 stems/ha). SAFODA moved away from square to rectangular spacings after their trials at Bengkoka found little growth difference between the two options and because of considerable cost savings in planting and weeding due to fewer numbers of lines per hectare.

Apart from the need for site occupancy the choice of initial spacing is also governed by the purpose of the plantation, and the degree of malformation. For chipwood or fuelwood crops malformation is of less importance, although straight trees reduce harvesting costs. For high quality logs, sufficient numbers need to be planted to enable the selection of crop trees with excellent form. This will, as we have noted above, vary with site (and indeed with microsites where windrowing and burning have been used) and with genotype. Breeding and asexual propagating programs may well allow growers to use lower initial stockings in the future.

Fertiliser at establishment

The earlier practice of many growers was to apply about 100 g of rock phosphate into the planting hole, sometimes followed by a second fertiliser dressing at about the time of the first weeding (see, for example, Udarbe and Hepburn 1987). However, subsequent studies have concluded that the response to rock phosphate is small because of its placement and low solubility.

For the CFPP on Peninsular Malaysia's ex-jungle sites, Mead and Speechly (1989), on the basis of initial studies, recommended the following use of fertiliser for *A. mangium*:

- Broadcast burnt sites — no fertiliser required;
- Semi-mechanical prepared — between ashbeds apply at planting into two slits 15–20 cm from the seedling, a total of 100 g triple superphosphate (TSP)/tree. A second dressing of 150 g TSP, in a ring about 0.3–1.0 m from the tree, should be applied at 5–6 months. On erodible sites this dressing should be applied to 3–5 holes and covered with soil;
- Log-landings — increase the second dressing to 250 g/tree, and also rip the site to a depth of 60 cm.

On less fertile *Imperata* sites, such as at Bengkoka, we have found that N and a general trace element mix are advantageous in addition to the P when applied at planting. For example, the results of a trial on a Tanjung Lipat soil at Bengkoka showed that the best treatment resulted in a 4-month gain in diameter growth (Fig. 1). We would therefore suggest replacing the initial fertiliser dressing with 120 g of a 1:1 mixture of TSP and NPK blue (12:5:14 + TE). We have not yet tested if the second dressing should contain nutrients other than P.

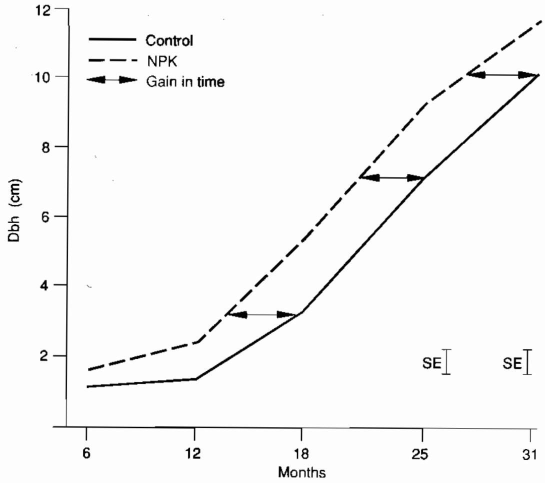

Fig. 1. Response in diameter to fertiliser in a trial at Bengkoka, Sabah. The fertiliser treatment consisted of 113 g Christmas Island rock phosphate applied in the planting hole, followed by 57, 113 and 170 g of NPK plus trace elements, applied at 2, 8 and 20 months, respectively. Data courtesy of SAFODA.

Singling

On sites where *A. mangium* develops multiple stems from its base the trees need to be singled before they are 1.5 m tall. Later singling runs the risk of butt rot entering the tree.

Tending Established Stands

Pulpwood schedules

Most current growers do not prune or thin stands that are being grown for products such as chipwood, pulpwood or firewood. Rotation length is normally set at about the culmination of the MAI. At SSSB, for example, the stands are being grown for chipwood and are felled at 6–7 years (Tan and Douglass 1989).

However, our studies have shown that there are advantages to selection thinning such stands. The economics of pulpwood-only crops are sensitive to tree size, straightness and degree of branching as well as yield. As noted earlier current *A. mangium* stands show considerable variability in malformation and straightness, so there can be considerable advantages in incorporating an early thinning to waste.

On low fertility sites such as at Bengkoka, where basal area capacity is only 20–25 m^2/ha, management trials have shown the final crop stocking should be around 600–700 stems/ha. Here trees are normally planted at 1250 stems/ha, and a stand improvement thinning is carried out at 18 months (4–5 m), which removes 50% of the stems, but only 25–30% of the basal area. Thinning, using bush knives, is cheap, taking about 4 working days/ha. Growth modelling indicates that yields at age 8 years from thinned stands should be within 5% of unthinned stands. Average piece size, however, increases from 0.18 to around 0.25 m^3/tree, which should reduce logging costs by 23–37%, depending on method. Final yields and piece sizes have still to be proven in practice.

There are extra costs and risks associated with thinning pulpwood crops, however. At Bengkoka, where fires are a major worry, the delay in canopy closure and the extra fuel on the ground from thinning increases the risk of fire loss.

Sawlog schedules

Growing high quality logs with *A. mangium* is not as straightforward as for chip or pulpwood. Pruning is required to overcome the degradation caused by branches and possible heart rot from dead branches. This should be carefully timed to keep the central defect core of the pruned log small. There must be sufficient selection to ensure that the final crop trees, at least for their lower log length, are free of malformation and are straight. Finally the diameter at harvesting needs to be as large as possible to obtain good grade recoveries.

Based on these restrictions Mead and Speechly (1989) suggested a radical pruning and thinning policy for growing sawlogs in Peninsular Malaysia. Pruning to 5.5 m was to be in two lifts at a very early age, and at the time of the second thinning the trees were to be given their first pre-commercial, selection thinning (Table 2). This part of the silviculture was to be completed by the time the trees are about 9 m tall, which in Peninsular Malaysia is before age two. They did not recommend thinning earlier than this because of the necessity to select the most vigorous trees with good boles; also competition had barely set in by this time. Later thinnings, which might be commercial, would eventually reduce the stands to a final crop stocking of about 100 stems/ha. The objective at all times was to keep the trees in a free-growing condition with large deep crowns, thus maximising diameter growth. A rotation of about 15 years was suggested.

A similar schedule has also been attempted on the less fertile sites in SAFODA's stands at Bengkoka (Table 2). The major difference here was that, because of location, no commercial thinnings were envisaged and the proposed rotation is longer.

At the time these schedules were proposed there was very little evidence to show that it was possible

Table 2. Thinning and pruning schedules for the production of high quality logs of *Acacia mangium.*

Operation	Fertile sites[1] Ht[3] (m)	Age (mo)	Stems/ha[4] (residual)	Infertile sites[2] Ht[3] (m)	Age (mo)	Stems/ha[4] (residual)
1st prune[5]	6.0	~12	900	5	18	500
Waste thin	9.0	24	(450)	5	18	(500)
2nd prune				8	30	250
High prune[5]	9.0	24	450	11	38	250
Thin[6]	13	36	(250)	11	38	(250)
Thin[7]	22	72	(150)			
Thin[7]	27	120	(100)			
Clearfell	28	180	—	23	240	—

[1] Adapted from Mead and Speechly, 1989
[2] Typical Bengkoka schedule
[3] Mean stand height
[4] Stems treated; numbers of residual stems/ha after thinning are given in brackets
[5] Mead and Speechly (1989) suggest pruning to a height where the stem diameter is 6 cm
[6] A commercial thinning, if markets exist
[7] Production thinning

to grow large saw or veneer logs. There is, however, some encouraging evidence from a thinning trial at Bengkoka. This shows that the diameter growth of *A. mangium* is very responsive to extra growing space (Table 3).

Table 3. Growth of *Acacia mangium* after thinning to different stockings at age 6 years. Trial data from Bengkoka, Sabah (unpublished data, courtesy of SAFODA).

Treatment[1]	Stocking Stems/ha	23-month increment Diam[2] (mm)	Height[3] (m)
Control	900	18	4.1
50% thin.	550	31	4.4
75% thin.	275	43	3.4
90% thin.	110	78	3.1

[1] Thinning as a percentage of trees planted (1150 stems/ha)
[2] Average increment of the diameter at breast height
[3] Average height increment of the 100 largest diameter trees

However, it has still to be shown whether the 50 cm diameter trees at age 15, that Mead and Speechly (1989) were suggesting as desirable, can be routinely obtained. However, even if such diameters are not always obtained, we believe that because of advances in utilisation technology, larger sized pruned logs will be sought after and put to high quality uses. This has happened in Australia, where new technology is allowing relatively small eucalypt logs to be utilised for end-uses such as furniture.

The economics of growing sawlogs has still to be proved. At the present time there are too many uncertainties to make the exercise meaningful.

Later fertiliser applications

There have been no satisfactory fertiliser trials to judge the requirements of this species for fertiliser applied to established stands. However, unless the sites are very infertile, it is unlikely that unthinned, closed stands would respond to additional P or to other fertilisers. On the other hand, stands which, on the basis of foliage tests, are below the critical level are likely to respond if the fertiliser is applied immediately following thinning. Thus, if the foliage P level is <0.12–0.13% then a broadcast application of 40 kg/ha P may be advisable, particularly where large high quality logs are desired (Mead and Speechly 1989).

Conclusions

Acacia mangium has proved easy to grow and adaptable to a wide range of conditions. However there are climatic and soil limitations that the grower must consider. In particular growth is slow where moisture is limiting, and on many sites additional P is required. Sometimes N and trace elements are of benefit as well.

Establishment practices and schedules for smallwood production are generally proven. There are also good prospects for growing higher quality logs, but the proposed schedules are more tentative. They are based on silvicultural principles backed by some investigations and operational experience, but they are unproven in that no stands have completed their rotations following such schedules.

There is a need for continuing research and development to further refine the silvicultural schedules. This, combined with a strong tree improvement program and work in the areas of harvesting, utilisation and marketing, should ensure a bright future for the species.

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References

Baharuddin J. 1987. An appraisal of the compensatory plantation programme in Peninsular Malaysia. Paper presented to Seminar on the future role of forest plantations in the national economy and incentives required to encourage investments in forest plantation development, Kota Kinabalu, Sabah, November 1987. 29 p.

Groome, J.G. 1989. Acacias in South East Asia. Paper presented to Regional symposium on recent developments in tree plantations of humid/subhumid tropics of Asia. Universiti Pertanian Malaysia, June 1989. 18 p.

Mead, D.J. and Miller, R.R. 1989. Contrasting plantation projects in Malaysia. Paper presented to N.Z. Asia Conference, University of Canterbury, Christchurch, New Zealand, 1989. 11 p.

Mead, D.J. and Speechly, H.T. 1989. Growing *Acacia mangium* for high quality sawlogs in Peninsular Malaysia. Paper presented to Regional symposium on recent developments in tree plantations of humid/subhumid tropics of Asia. Universiti Pertanian Malaysia, June 1989. 17 p.

Miller, R.R. and Hepburn, A.J. 1989. A review of the growth of *Acacia mangium* at the Bengkoka Afforestation and Settlement Project, North Sabah. Paper presented to Regional symposium on recent developments in tree plantations of humid/subhumid tropics of Asia. Universiti Pertanian Malaysia, June 1989.

National Academy of Sciences 1983. Mangium and other fast-growing trees for the humid tropics. National Academy Press. 237 p.

Pan Zhigang and Yang Minquan 1987. Australian Acacias in The Peoples Republic of China. In: Turnbull, J.W., ed., Australian Acacias in developing countries: proceedings of an international workshop held at the Forestry Training Centre, Gympie, Qld., Australia, 4–7 August 1986. ACIAR Proceedings No. 16, 136–138.

Racz, J. and Zakaria Ibrahim 1987. Growth of *Acacia mangium* in Peninsular Malaysia. In: Turnbull, J.W., ed., Australian Acacias in developing countries: proceedings of an international workshop held at the Forestry Training Centre, Gympie, Qld., Australia, 4–7 August 1986. ACIAR Proceedings No. 16, 154–156.

Sim Boon Liang 1987. Research on *Acacia mangium* in Sabah: a review. In: Turnbull, J.W., ed., Australian Acacias in developing countries: proceedings of an international workshop held at the Forestry Training Centre, Gympie, Qld., Australia, 4–7 August 1986. ACIAR Proceedings No. 16, 164–166.

Skelton, D.J. 1987. Distribution and ecology of Papua New Guinea acacias. In: Turnbull, J.W., ed., Australian Acacias in developing countries: proceedings of an international workshop held at the Forestry Training Centre, Gympie, Qld., Australia, 4–7 August 1986. ACIAR Proceedings No. 16, 38–44.

Tan, K.C. and Douglass, R. 1989. Harvesting and plantation management in the tropics — a case study. Paper presented to the 13th Commonwealth Forestry Conference, Rotorua, New Zealand, September 1989. 18 p.

Udarbe, M.P. and Hepburn, A.J. 1987. Development of *Acacia mangium* as a plantation species in Sabah. In: Turnbull, J.W., ed., Australian Acacias in developing countries: proceedings of an international workshop held at the Forestry Training Centre, Gympie, Qld., Australia, 4–7 August 1986. ACIAR Proceedings No. 16, 157–159.

The Role of Acacia and Eucalypt Plantations for Honey Production

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Abstract

Large areas of land in Southeast Asia are being planted to acacia and eucalypt species for timber, paper and pulp production. The potential of these plantings for honey production has not been evaluated, although a number of these species are attractive to bees.

Acacia species provide pollen, the main protein source for bee hive nutrition, while eucalypts provide nectar, the main energy source. A management system for honey production incorporating acacia and eucalypt plantations is presented.

The role of bees in pollination is also discussed.

THE significance and value of 'minor' products from forests are often overlooked, for a variety of reasons. One is statistical coverage. FAO does not report such products in its *Yearbook of Forest Products*. In the absence of such data, the value of the products can easily be disregarded, especially in comparison with that of timber, which can be relatively easily quantified. Non-wood products, often sold locally, are difficult to monitor and easy to ignore.

It has been suggested that the annual collection of fruit and latex in perpetuity could have a greater value than sustainable timber harvest in tropical rainforest: the former could account for as much as 90% of the total value, and the latter 10% (Peters et al. 1989). A detailed survey of the honey industry on part of the New South Wales South Coast (Cocks and Dennis 1980), indicated that in an average year, 30% of the economic value of the eucalypt forest came from honey production. In a year when honey production is higher this value can double. The forest also served as an important winter and drought refuge area for bees; the economic value of this is less easily established but could be considerable.

Large areas of land in Southeast Asia are being planted to acacia and eucalypt species for timber, paper and pulp production. On small privately owned farms a range of tree species is being planted to produce poles, stakes, charcoal and firewood. The potential of these plantings for honey production has not been evaluated although a number of these species are known to be attractive to bees. Honey production requires minimal capital and can supplement income for forestry employees and farmers. An ACIAR project is being developed in Indonesia to assist small landholders to maximise honey production and to investigate the potential of honey bees in plantations.

The Australian beekeeping industry is mainly confined to the natural eucalypt forests; migration patterns have been developed to take advantage of irregular flowering. Under satisfactory management in Australia an annual average production of 110 kg per hive is possible (Kleinschmidt 1988). On a good honey flow, colonies of 50 000 bees can produce about twice as much honey as colonies with 35 000 bees. To achieve such high production rates, colonies require a vigorous queen bee, nectar stimulation and pollen with an adequate protein level.

In this paper we review management techniques to obtain maximum honey production with the honey bee (*Apis mellifera*) and examine the potential role of acacia and eucalypt plantations.

Nutrition

Bees collect two floral products, nectar and pollen, which provide all of the food necessary for larval growth and metamorphosis and for adult development and functions (Dietz 1975). Honey bees have

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evolved various mechanisms for processing nectar and pollen so that the food fed to each stage and caste is ideally suited to their needs. It is important to understand the role of these two foods so hives can be managed to ensure maximum honey production.

Nectar

Nectar is a plant secretion that contains mainly sugars and water. Eucalypts are usually a good source of nectar, while many acacias produce little or none. It is secreted from nectaries in flowers and extra-floral nectaries in the petioles of some species or via plant-sucking insects (honeydew). Honey bees obtain most of their energy from carbohydrates in the form of sugars. Sugar is also a necessary stimulus for oviposition and the resulting larva then influence pollen foraging behaviour. Nectar is collected by foraging workers then carried back to the hive and processed into honey. Water content is then reduced to less than 18% to protect the nectar from yeasts before being stored for future use. Honey contains sugars which constitute 95–99% of the solids. Honey is basically a source of energy and a material to be converted into fat and glycogen (Dietz 1975). Protein content of honey is usually less than 0.2% (Winston 1987).

Pollen

Pollen is virtually the only source of protein naturally available to bees (Kleinschmidt 1988). Protein influences the rate of breeding and bee longevity, making pollen the single most important factor in colony population and honey production. Pollen also provides the sterols, vitamins and minerals necessary for growth and reproduction. Pollen, through its protein component, is essential for growth of emerging young bees and the development of the pharangeal glands (Dietz 1975).

Pollen with less than 20% crude protein cannot satisfy colony requirements for optimum production (Kleinschmidt 1988). A strong colony requires about 55 kg of pollen per year. A very high workload would occur if the pollen available was of low value and large volumes had to be collected. If pollen supply is limited bees use their body protein to continue brood rearing; their body protein can decrease from about 54 to 27% as a result. At 27% brood rearing ceases. Such colonies require at least 12 weeks adequate nutrition for optimum breeding to restore full production.

Longevity is also related to the level of body protein. Under conditions of heavy honey flow bees in colonies which experience a rapid decrease in body protein lived 20–26 days whereas those in colonies which maintained body protein above 40% had a life span of 46–50 days (Kleinschmidt and Kondos 1977).

An economical, effective long-term substitute for pollen is not available. Large stocks collected during periods of pollen abundance can be stored, but within two years stocks lose significant value for colony restoration.

Pollen Protein

There is considerable variability in the nutritive value of pollen from different plants, partly because of the different amount of protein in pollens. Crude protein levels in pollen are between 24 and 29% for acacia and between 20 and 33% for eucalypts (Kleinschmidt 1988).

Both quality and quantity of pollen protein can independently, or in combination, influence supply of essential amino acids which ultimately become available to the bees. Often insufficient eucalypt pollen is available to meet the protein requirements necessary to maintain body protein during conditions of heavy honey flow. On many eucalypt flows in Australia, at least 80% of the pollen gathered comes from acacia species and/or ground cover. Although colony strength on most eucalypt honey flows declines rapidly, the rate of decline can be slowed by building strong colonies capable of maintaining a large brood area. If acacias are in flower near the eucalypts a steady input of pollen from the former can help the colony to maintain protein levels. Thus siting of hives is important in hive management to ensure maximum production.

Extra-floral Nectaries

Nectar glands are borne on the rachis of the pinnate-leaved acacias and on the phyllode margin, generally near the base, in other acacia species. Glands secrete nectar intermittently, often with a clear peak in activity during anthesis. Some species, e.g. *A. melanoxylon*, secrete nectar only during the months when flowers are produced (Milton and Moll 1982). This is not the case for *A. mangium* growing in northern Australia, where heavy secretion has been observed when flowers were not present (A.R. Griffin pers. comm.). Many acacia species however do not secrete nectar from these organs at any stage. It has been postulated that nectar secreted by extra-floral nectaries close to flowers may act as an additional attractant to pollinators while others consider it as an attractant for ants who then provide a protection against predation. Water in extra-floral nectaries may also be an important reward for ants tending nectaries, especially in arid regions (Olesen 1988).

Freshly-secreted nectar is reported to be rich in sugars (Table 1). Evaporation increases concentration until towards the end of the flowering season many glands are blocked with sugar crystals. L. Thomson (pers. comm.) noted this in *A. acradenia* and other acacia species growing in arid regions.

Table 1. Sugar concentrations of fresh nectar samples from extra-floral nectaries.

Acacia Species	Sugar conc. (%)	Ref. No.
A. auriculiformis	33–60	1
A. longifolia	50–60	2
A. mangium	64	1
A. mangium	27–29	3
A. mearnsii	40	1
A. terminalis	16 (8–50)	4
A. holosericea	72–81	1

1 Measured by the authors with a hand-held refractometer
2 Milton & Moll (1982)
3 C. Widjaya (pers. comm.)
4 Knox et al. (1985)

The plants were grown under glasshouse conditions in Canberra, where sugar concentrations are higher than in the field. A detailed study is required to document environmental effects on concentrations.

Honey Dew

In addition to nectar, bees gather honey dew and other sweet exudates of plant origin. Honey dew, excreted by plant-sucking insects, is waste carbohydrate within the plant sap (Clemson 1985). Scale insects from families such as Cocciodae, Aphodae and Jassidae release this carbohydrate waste as droplets that are gathered by bees, especially when there is a scarcity of nectar-producing flora in the area. Many acacia species growing in humid areas are reported to produce honey dew (L. Thomson pers. comm.). In some countries honey dew has economic value and suitable markets — often paying premium prices — have developed (Dietz 1975).

Pollen Collection and Body Protein Levels

The availability of flowers within easy reach of the hive tends to influence what is collected. Workers tend to prefer nectar collection (Free 1970), which may be energetically more efficient than pollen collection. The energy returns for pollen show approximately an 8:1 ratio on flight energy expended per calorie of pollen collected, but a 10:1 ratio for nectar collection (Seeley 1985). However, workers will travel further for a pollen load than for nectar, possibly because a full load of pollen is lighter and takes less time per flower than to collect a full load of nectar (Winston 1987).

Pollen Collection and Bee Performance

Example 1

Pollen traps were inserted in 12 hives located near mature *A. mearnsii* trees in the vicinity of a large population of flowering flatweed (*Hypochoeris radicata*). In year 1 bees collected up to 4.43 kg of pollen per hive in 18 days whilst in year 2 they collected 2.44 kg in 22 days. Between 70 and 90% of pollen in year 1 was collected from the flatweed, a protein source of low-value (14–19%). Year 1 had a light acacia flowering and little pollen was collected from this source (Moncur and Somerville 1989). Year 2 had a very heavy acacia flowering: up to 35% of the pollen collected was from the acacias and only 40% from the flatweed. In year 1 no honey was produced and brood area declined. In year 2 a good quantity of honey was produced and the strength of the hives increased. Flatweed is a low-value pollen (Stace 1988) and although flatweed is collected in large quantities, it is only beneficial to hive performance if sufficient high-quality pollen is collected at the same time, e.g. from *A. mearnsii* (24% protein).

Example 2

Winter ironbark (*E. siderophloia*) is an important honey tree in southeastern Queensland, but it is known to be a relatively poor pollen producer. Bees working this species recorded a 16% reduction in body protein levels (Kleinschmidt 1988). This reduction was overcome only when late-flowering *A. ixiophylla* started producing substantial amounts of pollen. This acacia provided pollen of good quality to maintain protein levels of bees near 40%.

Flowering Times

In their natural distribution most eucalypts do not flower every year, and marked irregularity exists in their flowering behaviour. For many species there appears to be a characteristic time of the year in which flowering takes place, but, in some species, no definite periodicity can be established. This is often the case with trees grown as exotics. Some species normally flower every year, but many, including most of the important honey producing eucalypts, normally flower every second year. Environmental factors such as drought or prolonged heavy rain may affect the normal rhythm of flowering.

It is essential to document the flowering cycle of all flora in the area where the hives are to be situated. A knowledge of the pollen protein values is also important so appropriate hive management techniques can be practised. To ensure maximum honey production on a yearly basis the beekeeper must undertake some migration between flows. Good sites providing high protein levels need to be identified so hive populations can be built up before moving to a heavy flow.

Pollination

Inadequate pollination can result in reduced or delayed yields and unacceptable fruit shape. Honey bees are known to play a leading role in pollen transfer in many agricultural and horticultural species (McGregor 1976; Gill 1989). Gill estimated that the value of honeybee pollination in Australia was between $A214 million up to around $A4 billion with a 'most likely' value of around $A1 billion.

Eucalypts are insect pollinated and honey bees have been recorded as effecting pollination and increasing seed yield (Loneragan 1979). In Zimbabwe honey bees are believed responsible for a considerable improvement in viable seed production in eucalypt seed orchards (Van der Lingen pers. comm.).

Self-incompatibility has been reported in many acacia species (Kenrick and Knox 1989) and insects are essential in the transfer of pollen for high pod yields. The introduction of honey bees by the authors (see above) slightly increased pod yields in *A. mearnsii* but yields were very low considering the vast number of flowers formed. It requires only one polyad to block each stigma from outcrossed pollen, so selfing in this mass-flowering species appears to be a major limitation to pod production (Moncur and Somerville 1989).

Management System for Maximum Production

To obtain maximum production beekeeping must be considered an all year round occupation which may well include a migration component. In this paper we have reviewed various aspects of beekeeping and these are presented in a flow chart (Fig. 1) as a guide for decision making.

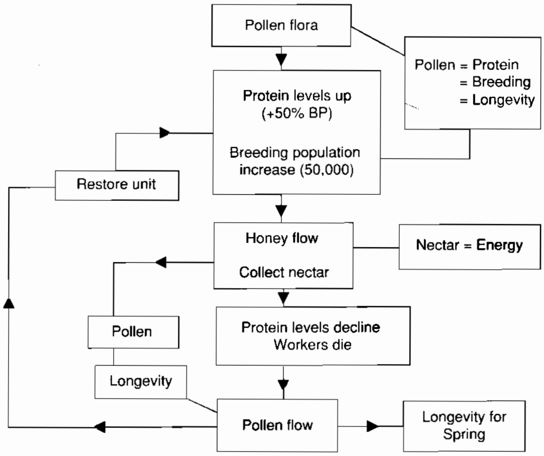

Fig. 1. Managing bees for honey production.

Prior to a 'honey flow' hives are placed in flora with a high protein level to build up bee numbers in the hives and increase their body protein levels (important for longevity). When body protein levels increase to around 50% (after periodic sampling) the hives can be placed in the 'honey flow'. If this flow is deficient in protein the beekeeper will need to decide when to remove the hives for restoration. If no high-protein flora is available for restoration, supplementary feeding may be considered an economically viable option. It is important that the beekeeper knows the potential value of a range of sites to ensure a year-round range of options.

Potential of Plantations for Beekeeping

Acacia and eucalypt plantations represent a valuable source of rural income through honey production. Eucalypts are an important source of nectar, while acacias provide essential protein to maintain bee populations and longevity. Some acacias also provide nectar via extra-floral nectaries although quantitative data on the importance of these are lacking.

Where eucalypts are the major nectar source, their main flowering time needs to be established. To build up the hive population in expectation of the eucalypt honey flow, hives can be placed near acacia plantings. *A. mangium* and *A. auriculiformis* are known to flower all year in tropical areas (W. Subansenee (pers. comm.) Thailand; A. Griffin (pers. comm.) Malaysia) and are a source of pollen (protein), while some nectar from the extra-floral nectaries could promote oviposition.

The potential of honey bees to pollinate these species and increase seed yields and seed quality via pollen transfer is an added bonus for seed orchards. Beekeeping has a relatively small labour requirement and can be undertaken on a family basis by forestry employees.

It is not likely that a sufficiently large area will be planted by the small farmers to make any noticeable improvement in honey production, but planted trees may be useful in providing stimulation for brood rearing and to keep hives in good health prior to a major honey flow.

Trees of value to beekeepers, whether for nectar production or as a source of high grade pollen, should be given high priority when selecting species for major tree planting programs. Trees suitable for bee forage should also be planted near large plantations to ensure maximum advantage can be obtained at major honey flows.

References

Clemson, A. 1985. Honey and Pollen Flora. Inkata Press, Melbourne.

Cocks, K.D. and Dennis, D. 1980. Apiculture In: Fleming, P.M. and Stokes, J., ed., Land use on the South Coast of New South Wales, Volume 4. Land function studies. CSIRO, Canberra.

Dietz, A. 1975. Nutrition of the adult honey bee. In: The Hive and the Honey Bee. Illinois, Dadant & Sons, 125–156.

Free, J.B. 1970. Insect Pollination of Crops. London, Academic Press.

Gill, R. 1989. The value of pollination services in Australia. Aust. Beekeeper 91, 256–274.

Kenrick, J. and Knox, R.B. 1989. Quantitative analysis of self incompatibility in trees of seven species of *Acacia*. J. Heredity 80, 240–245.

Kleinschmidt, G.T. 1988. Apiculture production and research. Queensland Agriculture College, Lawes.

Kleinschmidt, G.T. and Kondos, A. 1977. The effect of dietary protein on colony performance. In: Harnaj, E., ed., Proc. 26th Int. Cong. Apic., Adelaide. Apimondia, Bucharest.

Knox, R.B., Kenrick, J., Bernhardt, P., Marginson, R., Beresford, G., Baker, I. and Baker, H.G. 1985. Extrafloral nectaries as adaptions for bird pollinators in *Acacia terminalis*. Amer. J. Bot., 72, 1185–1196.

Loneragan, O.W. 1979. Karri (*Eucalyptus diversicolor* F. Muell.) phenological studies in relation to reforestation. For. West. Aust. Bull. 90. (Forest Dept., Perth).

McGregor, S.E. 1976. Insect pollination of cultivated crop plants. Agric. Handbook, U.S. Dept. Agric, No. 496.

Milton, S.J. and Moll, E.J. 1982. Phenology of Australian acacias in the S.W. Cape, South Africa and its implications for management. Bot. J. Linnean. Soc., 84, 295–327.

Moncur, M.W. and Somerville, D. 1989. The use of honey bees for pollen transfer and increased pod set in black wattle (*Acacia mearnsii*). Aust. Beekeeper, 91, 75–89.

Olesen, J.M. 1988. Floral biology of the Canarian *Echium wildpretii*: bird-flower or a water resource to desert bees. Acta. Bot. Neerl., 37, 509–513.

Peters, C.M., Gentry, A.H. and Mendelsohn, R.O. 1989. Valuation of an Amazonian rainforest. Nature, 339, 655–666.

Seeley, T.D. 1985. Honey Bee Ecology. Princeton, Princeton Univ. Press.

Stace, P. 1988. Pollen-quality flatweed. Aust. Beekeeper, 90, 2.

Winston, M.L. 1987. The Biology of the Honey Bee. Harvard University Press, Massachusetts.

Tannin Analysis of *Acacia mearnsii* Bark — a Comparison of the Hide-powder and Stiasny Methods

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Abstract

Black wattle (*Acacia mearnsii* De Wild) bark is an important source of tannin for leather tanning, water-proof wood adhesives and some other uses. The hide-powder method has been used in tannin analysis for leather tanning and the Stiasny method for wood adhesives. However, the hide-powder method is both laborious and time-consuming and large quantities of material are required while the Stiasny method is a rapid and reliable method and requires only small amounts of sample.

The tannin contents of the bark samples from 18 provenances of black wattle in Australia have been determined by both the hide-powder and the Stiasny methods and the results have been statistically analysed for correlations between the hide-powder and the Stiasny results.

The analysis reveals that the correlation between one of the values obtained from the hide-powder analysis and the value from the Stiasny analysis is marginally significant at 5%. However, since only 22.2% of the variation in the hide-powder method is explained by the results from the Stiasny method, the Stiasny method cannot be recommended for predicting the results from the hide-powder method.

BLACK wattle (*Acacia mearnsii* De Wild) bark is an important source of tannin for leather tanning, waterproof adhesives and other uses. Black wattle was introduced into China in the 1950s but was only recently identified by the Chinese Government as a promising species for tannin production.

In 1985, CSIRO, in collaboration with the Chinese Academy of Forestry, commenced the research project entitled 'Wattle silviculture and the utilisation of tannin extracts'. New genetic resources of *A. mearnsii* have been introduced into China from Australia through the establishment of provenance trials and seedlings and orchard/progeny trials.

Yazaki et al. (1990) reported that bark samples of black wattle trees were collected from 22 provenances in Australia. The bark of 94 individual black wattle trees from 20 of these provenances was analysed by the Stiasny method, which can provide an estimate of the polyflavanoid compounds that react with formaldehyde to form adhesive.

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The hide-powder method has been used in tannin analysis for leather tanning but is both laborious and time-consuming, while the Stiasny method is regarded as a rapid and reliable method for estimating wood adhesives. Since large amounts of bark samples are required for the hide-powder analysis, the tannin contents of the bark samples from 18 of these 20 provenances have been determined by both the hide-powder and Stiasny methods. The results have been statistically analysed to find any correlation between these two methods, with a view to replacing the laborious hide-powder method with the rapid Stiasny method.

Materials and Methods

Bark collection

The bark samples of *A. mearnsii* were collected in Australia in January and February 1987 from 22 locations selected on the basis of bioclimatic factors (Table 1). The details on provenance sampling, within-provenance sampling, within-tree sampling and the preparation of bark samples have been described by Yazaki et al. (1990).

Table 1. Bark samples of *A. mearnsii.*

Provenance No.	Climatic grouping*	State	No. of trees sampled	Average measurements of tree: Bark thickness (radial) (mm)	Diameter (dbhob) (cm)	Height (m)
1	G	NSW	5	8.5	18.4	10.7
2	H	NSW	5	6.9	16.9	10.1
3	G	NSW	5	8.0	20.1	9.3
4	G	NSW	5	7.1	18.3	12.0
5	K	NSW	2	6.8	16.8	14.0
6	E	NSW	5	6.5	18.1	13.6
7	E	NSW	5	6.3	18.8	15.0
8	H	NSW	5	6.1	14.8	10.2
9	H	Vic	5	5.7	15.2	10.8
10	C	Vic	5	7.4	19.8	10.9
11	C	Vic	5	7.4	19.0	9.7
12	J	Vic	2	5.4	16.3	10.3
13	B	Vic	5	7.0	18.5	10.5
14	B	Vic	5	8.3	20.6	13.5
15	A	SA	5	7.7	23.7	11.3
16	B	Tas	5	7.5	18.2	10.1
17	B	Tas	5	7.2	16.6	10.1
18	F	Tas	5	7.7	17.7	9.8
19	F	Tas	5	8.7	19.6	11.0
20	F	Tas	5	7.1	17.5	10.0

* After Booth et al. 1989.

Tannin analysis

The freeze-dried bark samples were sent by air from Canberra to Nanjing and stored at −10 °C. The dried bark samples from five individual trees in each provenance were mixed and ground to pass through a 2.5 mm retaining screen in a Wiley mill. The ground bark (15–20 g) from each provenance was extracted with hot water (2 l), from which the tannin content was determined by the hide-powder method according to the Chinese National Standard GB 3615-81, by which the total solids (T.S.), total soluble solids (S.S.) and non-tannin (N.T.) were determined and the tannin content was calculated by an equation: tannin content = S.S. − N.T.

Stiasny reaction

Approximately 1 l was taken from each hot-water extract solution (2 l) and then freeze-dried. The freeze-dried samples were dried further over phosphorus pentoxide in a high vacuum at 55 °C for 30 min, and then the amounts of polyflavanoid components in the dried samples were determined by the Stiasny method. The details of the Stiasny reaction have been described by Yazaki et al. (1990).

Results and Discussions

Tannin contents in *A. mearnsii* bark

The climatic grouping and average measurements of trees such as bark thickness, diameter at breast height over bark (dbhob) and height from each provenance are shown in Table 1. The tannin contents in the bark samples were determined by the hide-powder method (except for the bark samples from provenances No. 5 and 12 due to the insufficient amounts of the samples) and the results are summarised in Table 2.

The mean values of tannin contents in the barks from provenances in Tasmania, Victoria, South Australia and New South Wales were 46.9, 46.6, 39.4 and 38.8%, respectively. The statistical analysis revealed that these mean values are significantly different between Tasmania–Victoria and South Australia–New South Wales groups. Similar results have already been reported on the extractives yields and polyflavanoid contents in 94 bark samples from 20 provenances, which were determined by the Stiasny method (Yazaki et al. 1990).

Stiasny reaction precipitate

The Stiasny values of hot-water extractives sampled from the 18 provenances are shown in Table 2. An

Table 2. Tannin content in bark determined by the hide-powder method and Stiasny values of extracts from the bark sampled from *A. mearnsii* in Australia.

Provenance No.	State	Total solids (T.S. %)*	Insolubles (%)*	Soluble solids (S.S. %)*	Non-tannin (N.T. %)*	Tannin content (Tan. %)*	Tan. × 100 / S.S. (%)	Tan. × 100 / T.S. (%)	Stiasny Value (%)
1	NSW	55.0	5.3	49.7	14.3	35.4	71.2	64.4	81.5
2	NSW	55.0	3.8	51.2	14.2	37.0	72.3	67.3	82.2
3	NSW	56.8	4.8	52.0	12.6	39.4	75.8	69.4	80.5
4	NSW	56.3	4.4	51.9	11.6	40.3	77.7	71.6	86.2
6	NSW	54.8	3.8	51.0	11.8	39.2	76.9	71.5	86.1
7	NSW	55.8	3.8	52.0	10.7	41.3	79.4	74.0	87.1
8	NSW	58.2	3.6	54.6	15.4	39.2	71.8	67.4	86.1
9	Vic	59.8	2.9	56.9	14.1	42.8	75.2	71.6	82.5
10	Vic	62.7	3.9	58.8	15.2	43.6	74.2	69.5	85.1
11	Vic	67.3	5.1	62.2	12.7	49.5	79.6	73.6	85.2
13	Vic	67.2	4.8	62.4	14.4	48.0	76.9	71.4	86.2
14	Vic	66.6	4.1	62.5	13.6	48.9	78.2	73.4	86.2
15	SA	56.5	4.5	52.0	12.6	39.4	75.8	69.7	85.9
16	Tas	67.1	5.6	61.5	12.7	48.8	79.4	72.7	81.5
17	Tas	62.3	4.8	57.5	12.6	44.9	78.1	72.1	81.4
18	Tas	65.6	4.5	61.1	14.8	46.3	75.8	70.6	81.8
19	Tas	68.4	4.6	63.8	12.3	51.5	80.7	75.3	89.5
20	Tas	60.8	4.6	56.2	13.0	43.2	76.9	71.1	82.4

* % based on weight of oven-dry bark

Table 3. Correlation matrix of total solids, insolubles, soluble solids, non-tannin, tannin content, tannin content/soluble solids, tannin content/total solids and Stiasny values.

	Total solids	Insolubles	Soluble solids	Non-tannin	Tannin content	Tan./S.S.	Tan./T.S.
Insolubles	0.365						
Soluble solids	0.992**	0.243					
Non-tannin	0.191	−0.171	0.223				
Tannin content	0.963**	0.296	0.963**	−0.048			
Tan./S.S.	0.553*	0.288	0.536*	−0.699**	0.743**		
Tan./T.S.	0.580*	0.022	0.602**	−0.580*	0.777**	0.955**	
Stiasny value	0.166	−0.267	0.210	−0.263	0.288	0.381	0.472*

* Significant at 5% level

** Signficant at 1% level

analysis of variance on Stiasny value reveals that mean values at State level are not significantly different. The same results were also obtained in the Stiasny values of the extractives sampled from the 94 *A. mearnsii* trees (Yazaki et al. 1990).

Correlations between Stiasny value and hide-powder results

One of the objectives in this study was to establish the feasibility of replacing the laborious hide-powder method with the rapid Stiasny method.

The correlation matrix of the variables in Table 2 is shown in Table 3. No significant correlations between Stiasny values and other variables from the hide-powder method have been found except the correlation ($r = 0.472$) between Stiasny values and tannin contents in the total solids (Tan./T.S. × 100, %) which is marginally significant at 5% ($p = 0.048$). This means if we regress tannin contents in total solids on Stiasny values, only 22.2% of the variation of the tannin contents in total solids is explained by the Stiasny values ($r^2 = 0.222$). These results indicate that there is no possibility of replacing the hide-powder method with the Stiasny method for the determination of the tannin contents in extracts and barks from *A. mearnsii*. Furthermore, a plot of tannin contents in total solids vs Stiasny values showed a weak relationship between these two variables.

Conclusions

The bark of *Acacia mearnsii* trees from provenances in both Tasmania and Victoria contained more tannin than those in South Australia and New South Wales. Although the correlation between tannin contents in the total solids and Stiasny values is marginally significant at 5%, Stiasny values are not recommended for predicting tannin contents derived from the hide-powder method.

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References

Booth, T.H., Searle, S.D. and Boland, D.J. 1989. Bioclimatic analysis to assist provenance selection for trials. New Forests, 3, 225–234.

Yazaki, Y., Zheng, G. and Searle, S.D. 1990. Extractives yields and polyflavanoid contents of *Acacia mearnsii* barks in Australia. Australian Forestry 53 (3), 148-153.

Planning of Pulpwood Production from Plantations

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Abstract

The selection of species for pulpwood plantations is a multi-stage process which has to satisfy a variety of requirements. Firstly the species has to grow well in the climatic, soil and environmental conditions. The growth rate of pulpwood needs to be measured in terms of the mass of wood produced, not simply as mean annual increment of volume. Next the wood must be suitable for the proposed pulping process and the pulp must be of sufficiently high quality for the envisaged paper products. Finally, the system must be optimised to provide maximum amount of high quality pulp per hectare per year.

The selection of potentially suitable species can be facilitated by considering the environmental conditions of their natural habitat. The environmental range can be extended using data from surveys of species and provenance trials. Data bases are available to aid the selection of species for various soil and climatic conditions.

The suitability of the wood for various pulping processes and the resultant pulp quality is reported in the pulp and paper research literature. This information can be used for preliminary screening of the potential plantation species. A grading scheme has been developed for classifying pulpwood for chemical pulping and for the classification of pulp for various paper products. The classification schemes are illustrated with results from pulping tests on various plantation species.

In the planning of hardwood plantations for the supply of pulpwood to a mill, the selection of species will firstly depend on its growth potential in the proposed plantation area. For pulpwood, the weight of oven-dry wood produced per hectare per year is a more meaningful measure of growth than the rate of volume production.

The next step is to select from the species with good growth potential, those with the best pulpwood qualities. The term 'pulpwood quality' does not have a simple definition because different pulping processes and products have different wood quality requirements. This second level of selection can be said to depend on a three-way interaction of the characteristics of the pulpwood, the response to the selected pulping process and the suitability of the pulp for different products. For many species background information on pulpwood quality can be found in the pulp and paper literature. The interpretation of this information can present a few problems.

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The third stage in the selection process will involve species and provenance trials followed by pulpwood quality assessment of the material from the trials. The following discussion is confined to the first two stages of selection, with emphasis on pulpwood production for use in the kraft pulping process for the manufacture of various paper grades.

Species Selection

The selection of species for pulpwood plantations could be facilitated with a computerised data base containing information for matching species to soil, climatic and other environmental conditions. The data base would also need to contain information on wood and pulping properties of the species. As yet such data bases are in the early stages of their development, but they are quickly evolving into effective systems for improving species selection for pulpwood plantations.

For example, Webb et al. (1984) have used published information of species occurrence to develop a software package, INSPIRE, for species selection.[1] The information in the INSPIRE data bases can be readily edited as new data becomes available. The restrictions of the system are the limited number of options in various fields. The potential use of a species for pulpwood is simply a yes/no entry and the classification of wood density into only three groups is too coarse for pulpwood quality assessment.

Notwithstanding the various limitations, INSPIRE is a good example of a knowledge base for the selection of plantation species which include soil and climatic conditions as well as wood utilisation.

A more comprehensive computerised system for the study of climatic profiles of species has been discussed by Booth (1987). It consists of two parts — CLIMSIM compares climate of a trial site with locations in Australia and BIOCLIM is used to analyse the climatic requirements for species. The analysis includes information from trials to give expanded climatic profiles for the species. For example, as shown by Booth et al. (1988), the useful climatic range of *Eucalyptus grandis* is much wider than that reported by Webb et al. (1984). A computerised slide show, *'Which Tree Where'*, illustrates the principles of the software and depicts sites in Africa[2] with climate suitable for *E. grandis*.

Another development in this area is the joint CSIRO Division of Forestry and the Queensland Forest Service modular data base TREDAT (Brown et al. 1989). It is a very comprehensive data base for recording information from plantation, species and provenance trials. At present it has five modules for recording site information including climatic conditions, management history, performance, details of botanical identity and project description. The very extensive performance module includes perceived use with pulpwood, at this stage, simply as a yes/no entry. To integrate pulpwood data, a separate module will have to be added to TREDAT for recording information from pulpwood tests.

Having selected species for the given environmental conditions, the next step is to select from these the species with the best pulpwood potential. To assess the suitability of the wood for pulping, it is necessary to interpret results from laboratory pulping tests.

[1] The software is available on request on a 3½ or 5¼ inch, IBM format, disk. It is menu-driven and simple to use.

[2] The demonstration program, which requires an EGA or VGA colour screen, is also available on both disk sizes.

Pulping and Bleaching

Pulping processes can be classified according to the form of energy used to separate the fibres, namely mechanical, chemical and heat energy. In most processes more than one form of energy is used.

Chemical pulps are produced with chemicals and heat (about 2 hours at 165–170 °C). For hardwoods the main pulping agent is caustic soda. When used alone it is known as the *soda process*, in combination with sodium sulfide it becomes the *kraft process*, and with anthraquinone, the *soda-AQ process*. In wood, fibres are held together with lignin which represents about a quarter of the weight of the wood. Most of the lignin as well as extractives and other wood components are removed during chemical pulping. A good yield for chemical pulp is about 50% (oven-dry pulp on oven-dry wood basis).

Well cooked chemical pulps are bleached for use in printing and writing papers. It is a multistage process. During pulping, the lignin is extensively modified and has to be removed before the pulp can be bleached. A basic laboratory bleaching sequence (CEHD) uses chlorine to degrade the lignin, alkali (caustic soda) to extract it and hypochlorite and chlorine dioxide to bleach the pulp. (Such simple bleaching sequences are now being superseded by more complex ones aimed at improving the quality of the effluents.)

Semi-chemical pulps are produced by pre-treating chips with chemicals and reducing them to pulp in a refiner. In the neutral sulfite semi-chemical *(NSSC) process* the chips are cooked (160–180 °C) with chemicals prior to mechanical refining. The pulp yield is about 75% and the pulp, which is usually dark in colour, is used mostly in packaging papers. In the *cold soda process* chips are soaked in caustic soda solution and then refined giving pulp yields up to 90%. Pulps from light coloured woods can be bleached by decolourising the lignin. The pulps are used in newspapers and magazine papers.

Assessment of Pulpwood Quality

Information on pulpwood quality is found in various pulp and paper journals. The kraft process is the most widely used chemical process for hardwoods and the pulps are suitable for a variety of products. The results from laboratory tests usually include basic density of wood, pulping and bleaching results, and papermaking and paper strength data. From this mass of information it is necessary to extract the most relevant data for the planning of the establishment of pulpwood plantations.

From the grower's viewpoint, some of the more important factors to be considered in relation to pulpwood quality are (a) the suitability of the species for the proposed pulping process (b) the quality of the pulp and (c) pulpwood productivity in terms of pulp yield per cubic metre of wood.

There is no standard method for classifying pulpwood and it may not be possible to create a universally acceptable scheme. One of the problems is that quality is intrinsically tied up with economic factors. For example, the advantage of high pulp yield could be negated by having wood of low basic density which will limit pulp production because of reduced digester productivity. Each case needs to be considered on its merits with due regard to the economic implications.

The information on pulp quality is difficult to interpret because a range of tests are used to describe paper properties, with different tests being relevant for different paper products. For example, packaging papers need to be strong whereas printing and office papers should have good optical and surface properties with just adequate strength. The other complication is that pulp is mechanically treated (beaten) prior to papermaking. Beating decreases pulp freeness, i.e. reduces the ease of water removal, and increases paper density and strength. In commercial papermaking, chemical pulps are usually beaten to 250–400 Canadian standard freeness (Csf). Papermakers prefer pulps of high freeness and good strength properties.

The plot in Fig. 1 shows some of the more important test results for unbleached kraft pulp of *Acacia mearnsii* (from Fang et al. these proceedings). The area of primary interest is in the freeness range 400–250 Csf, i.e. for pulps beaten for 2000 revolutions or more in a PFI mill. The results are fairly typical in that tear and tensile indices increase and bulk (reciprocal of paper density) decreases with beating.

A simple grading scheme for the characterisation of hardwoods for the production of kraft pulp is set out in Table 1. The importance of each property will depend on the economic framework for the particular situation. As a rough generalisation, pulpwood productivity and possibly pulp yield may be more important than strength properties, especially for office papers.

The strength requirements for various paper grades are not generally published by the paper companies and there are very few national standards for product specifications. The Australian Standard 1079-1983 for paper used in the packaging of sterile goods specifies a tensile index of about 40. With reference to the classification scheme in Table 1, commercial packaging papers have tear and tensile indices in the TR1-TR3 and TS3-TS4 ranges respectively, whereas office papers have lower strength requirements and generally fall in the TR4 and TS4 ranges (McKenzie 1990). Printing papers must have smooth surfaces and be opaque. Papers of high bulk (low density) can be treated to attain the desired properties. The bulk should not exceed about 1.5 cm^3/g (density of about 0.65 g/cm^3) for many applications.

Results from pulping tests of various *Acacia* species are presented elsewhere in these proceedings (Clark et al.; Fang et al.).

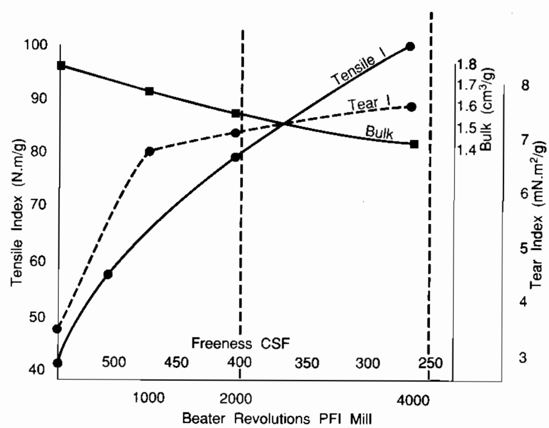

Fig. 1. Variation in paper properties with beating of *Acacia mearnsii* unbleached kraft pulp (from Fang et al. these proceedings).

Economic Considerations

Different units are used to express pulpwood growth, to sell wood and to calculate freight rates. For example, plantation growth is usually expressed as the mean annual increment (MAI) of volume, pulpwood may be sold on a green or oven-dry weight basis, while the shipping freight for chips is often charged per unit volume. The conversion from one to another set of units is most important for the economic assessment of pulpwood quality. Equations for the conversion of units are given in Appendix 1.

Table 1. Classification of hardwoods for the production of kraft pulp.

Pulping characteristics (Kappa No. ~20)		
Pulpwood productivity (kg pulp/m^3 wood)		
PP1	Excellent	more than 300
PP2	Very good	271–300
PP3	Good	231–270
PP4	Moderate	191–230
PP5	Low	151–190
PP6	Very low	150 or less
Pulp yield (oven-dry pulp to oven dry wood)		
Y1	Very good	more than 53%
Y2	Good	48.1–53%
Y3	Moderate	43.1–48%
Y4	Low	43 or less
Active alkali (as Na_2O on o.d. wood)		
AA1	Low	13% or less
AA2	Moderate	13.1–16%
AA3	High	16.1–18%
AA4	Very high	more than 18%
Papermaking properties (freeness not less than 250 Csf)		
Tear index (milliNewtons.m^2/g)		
TR1	Excellent	more than 12
TR2	Very good	9.5–12
TR3	Good	7.0–9.4
TR4	Moderate	4.5–6.9
TR5	Low	less than 4.5
Tensile index (Newtons.m/g)		
TS1	Excellent	more than 100
TS2	Very good	81–100
TS3	Good	61–80
TS4	Moderate	41–60
TS5	Low	40 or less

Having selected potentially suitable plantation species, the next step is to determine the plantation area required to supply a proposed pulpmill. Pulpmills are designed to produce a given amount of pulp per annum. Pulpmill capacity is defined in terms of annual air-dry pulp production. Air-dry pulp consists of 10% of water and 90% of dry-matter. For example, a modern world scale kraft pulpmill may be designed to produce 400 000 t of air-dry pulp. Some aspects of the mill design, such as the digester capacity and the size of the chemical recovery system will depend on basic density of the wood, pulp yield and pulping chemical requirements. The plantation area to supply the mill will also depend on the anticipated MAI.

To calculate the plantation area, pulpwood volume has to be converted to the equivalent oven-dry weight of wood and finally to air-dry pulp, i.e.,

MAI(wood vol.) –> MAI(pulpwood) –> MAI(pulp)

The conversion factor from volume to the equivalent oven-dry weight of wood (PW) is basic density (BD).

$$PW = MAI*BD/1000 \text{ (t/ha/y)}$$

where,

BD = kg of oven-dry wood/cubic metre of green wood

Two species, such as *Acacia auriculiformis* (BD = 500 kg/m^3) and *Paraserianthes falcataria* (BD = 240 kg/m^3) may have the same MAI, about 20 m^3/ha/y, but, because the woods are of different density, *A. auriculiformis* will produce twice as much pulpwood as *P. falcataria.*

The weight of pulp which can be produced from 1 cubic metre of wood, i.e. pulpwood productivity (PP), depends on basic density of wood and pulp yield (Y).

$$PP = BD*Y/100 \text{ (kg/m}^3\text{)}$$

where,

Y = 100*(oven-dry weight of pulp)/(o-d weight of wood)

As a rough approximation, commercial eucalypts yield about 250 kg of kraft pulp per cubic metre of wood. Pulpwood productivity for some commercial and potential tropical plantation species is tabulated in Table 2. The acacias have high pulpwood productivity.

The weight of pulp produced per hectare of plantation per annum, i.e., plantation pulpwood productivity (PPP), involves pulp yield as well as basic density and MAI, viz.,

$$PPP = PP*MAI/1000 \text{ (t/ha/y)}$$

Table 2. Pulpwood productivity (PP) of kraft pulp (Kappa No. ~20) for selected plantation species.

Species	Age (years)	PP (kg/m^3)
Paraserianthes falcataria	7	126*
Anthocephalus chinensis	9	138*
Sesbania grandiflora	4½	165*
Gmelina arborea	5	181*
Eucalyptus deglupta	10	182*
Leucaena leucocephala	4	240*
Acacia auriculiformis	10	275*
Acacia aulacocarpa	12	330**

* From Logan (1981)

** Clark et al. (these proceedings)

Pulpmills are designed to produce a certain tonnage of pulp per year (tpy). The plantation area (PA) required to supply a mill of a given capacity can be calculated from

$$PA = \text{Pulpmill capacity/PPP (ha)}$$

For example, to supply a 400 000 tpy pulpmill with a species having the following characteristics, BD = 600 kg/m^3, Y = 50% and MAI = 15 m^3/y, the required area will by 80 000 ha.

Conclusions

The selection of species for pulpwood plantation requires maximisation of growth in terms of the mass of wood substance produced. The wood must be suitable for the selected pulping process and the pulp should be of adequate quality for the proposed paper products. Information on suitable environmental conditions for species growth is recorded in forestry publications and is collated in various data bases. The latter can be used for the initial screening of potential species.

Data from pulping tests are available in the pulp and paper research literature. This information needs to be interpreted by the plantation grower to select from the potential species those with the best pulpwood potential.

Pulpwood productivity, which is defined as kilograms of pulp produced per cubic metre of wood, is probably the most important attribute of plantation-grown pulpwoods. For the production of kraft pulp it varies from about 120 to more than 300 kg/m^3. A grading scheme has been developed for the classification of pulpwood productivity.

Pulp quality must be adequate for the envisaged paper products. The proposed grading scheme for chemical pulps is based on the general range of laboratory test results. It embraces the pulp quality requirements for most packaging and printing papers which can be produced from hardwood pulps.

The application of the concept of plantation pulpwood productivity can help in developing plantation strategies to obtain optimum pulp yields.

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The ideas on pulpwood plantations stem from discussions with my colleagues over many years. In particular, thanks are due to Alan Logan whose interest in acacia plantations never diminished, Huntly Higgins who inspired a generation of researchers in the pulp and paper area and Frank Phillips whose organisational skills left nothing to chance.

References

Booth, T.H. 1987. Selecting *Acacia* species for testing outside Australia. In: Turnbull, J.W., ed., Australian acacias in developing countries. ACIAR Proceedings No. 16, 74–76.

Booth, T.H., Nix, H.A., Hutchinson, M.F. and Jovanovic, T. 1988. Niche analysis and tree species introduction. For. Ecol. Manage., 23, 47–49.

Brown, A.G., Wolf, L.J., Ryan, P.A. and Voller, P. 1989. Tredat: A tree crop data base. Aust. For., 52(1), 23–29.

McKenzie, A.W. 1990. Study of paper properties of Australian commercial papers. Laboratory report, CSIRO Div. Forest Products, Melbourne.

Webb, D.B., Wood, P.J., Smith, J.P. and Henman, G.S. 1984. A Guide to Species Selection for Tropical and Sub-Tropical Plantations. Commonwealth Forestry Institute, Oxford. Tropical Forestry Paper No. 15.

Appendix

Glossary and conversion factors

Basic density (BD) of wood
BD = kg of oven-dry (o-d) wood/cubic metre of green wood (kg/m^3)

Bulk — reciprocal of paper density, i.e., volume of paper per gram of pulp (cm^3/g).

CEHD — Chlorine-alkali Extraction Hypochlorite-chlorine Dioxide bleaching sequence.

Csf — Canadian standard freeness, a measure of pulp drainage (mL).

Dry-matter content (DM) = 100*(o-d weight)/(green weight) (%).

Grammage — mass of paper per square metre (g/m^2).

Green Weight (GW) = tonne per m^3 of wood = BD/10*DM (t/m^3).

Kappa number — a measure of residual lignin in pulp, 7–8 points in Kappa number corresponds to approximately 1% of lignin.

Mean-Annual-Increment (MAI) = the average pulpwood volume per hectare per year produced over the rotation cycle (m^3/ha/y).

NSSC — neutral sulfite semi-chemical pulp process.

Packing fraction, PF = volume of chips produced from 1 m^3 of wood (PF ~2–2.2).

Pulpwood productivity, PP = kg of o-d pulp per m^3 of wood = BD*Y/100 (kg/m^3).

Plantation pulpwood productivity (PPP) = tonnes of o-d pulp produced per hectare per annum = MAI*(BD/1000)*Y/100 (t/ha/y).

Mass (o-d) of pulpwood (PW) produced per hectare per year PW = MAI*BD/1000 (t/ha/y).

Screened pulp yield, Y = 100*(o-d weight of pulp)/(o-d weight of wood) (%).

Tear Index (TR) — tearing strength of paper corrected for paper grammage (milliNewtons.m^2/g).

Tensile Index (TS) — a measure of paper strength in tension corrected for paper grammage (Newtons.m/g).

Pulping Properties of Tropical Acacias

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and Wang Jingxia**

Abstract

Bleached kraft (sulfate) and unbleached neutral sulfite semi-chemical (NSSC) pulps were prepared from Queensland-grown 12-year-old *Acacia aulacocarpa*, 10-year-old *A. cincinnata* and *A. crassicarpa* of unknown age. The basic densities were 598 kg/m^3 for *A. aulacocarpa*, 580 kg/m^3 for *A. cincinnata* and 638 kg/m^3 for *A. crassicarpa*. The screened yields from the kraft process were 55.4% for *A. aulacocarpa*, followed by 53.1% for *A. cincinnata* and 47.2% for *A. crassicarpa*. The pulp yields from the NSSC process followed the same ranking. The *A. aulacocarpa* kraft pulp could be bleached to 84.6% ISO brightness with moderate chemical consumptions, compared to only 76.7 and 72.2% ISO for the *A. cincinnata* and *A. crassicarpa* pulps respectively.

The bleached kraft pulp from *A. aulacocarpa* was the strongest, followed by *A. crassicarpa* and then *A. cincinnata*. However, all three acacias would be suitable for a wide range of end products. The NSSC pulps would be strong enough to supplement kraft pulps in unbleached packaging products.

A. aulacocarpa compares favourably with *A. mangium* and *A. auriculiformis*, especially in terms of pulp yield per cubic metre of wood. *A. cincinnata* is also acceptable but further samples of *A. crassicarpa* of known age are needed to verify the suitability of this species as pulpwood.

In many countries plantation-grown trees will become increasingly important for the supply of industrial wood. CSIRO has conducted species and provenance trials which have identified several acacias with good potential for tropical and subtropical plantations (Brown 1990). Since acacias may be grown for pulpwood, it is highly desirable to assess the pulping and papermaking properties of these species.

This paper reports results from ACIAR project 8849, subproject D, which studied wattle pulping. It is a joint project of the Chinese Academy of Forestry Research Institute of Chemical Processing and Utilisation of Forest Products, Nanjing and the CSIRO Division of Forest Products, Melbourne.

The paper details the results of pulping and papermaking tests on native grown *Acacia aulacocarpa, A. cincinnata* and *A. crassicarpa*, species which have shown good growth in ACIAR trials (D.J. Boland, pers. comm.). The results are compared with those of *A. mangium* and *A. auriculiformis*, gathered both from the literature and from special tests carried out as part of this project. These two species have been introduced into several tropical and subtropical countries and are grown in commercial plantations. *A. auriculiformis* is preferred in India and China and *A. mangium* in Malaysia, where it is used in the Sabah Forest Industries pulp and paper mill at Sipitang. Since both species have been extensively tested for pulping, they provide a suitable frame of reference for evaluating the pulping and papermaking properties of the three lesser-known acacias.

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Materials and Methods

Sampling

Three trees from each of *A. aulacocarpa, A. cincinnata* and *A. crassicarpa* were sampled. The trees were growing in a native forest near Kuranda (lat. 16° 49 'S, long. 145° 38 'E) some 15 kilometres northwest of the city of Cairns, Queensland. The annual median rainfall in the area is in the range 1600–2400 mm (Anon. 1986) and the soil is classified as a structured loam with high initial fertility (Anon. 1980). The sample trees ranged in breast height diameter from 20 to 26 cm and merchantable height from 7 to 13 m. The ages of the trees were 12 years for *A. aulacocarpa* and 10 years for *A. cincinnata*. The age of the *A. crassicarpa* trees could not be determined.

A single billet was taken from each tree in rotation from the butt, middle and top log. The roundwood billets were transported to the CSIRO laboratories in Melbourne, where they were debarked and then chipped in a pilot-scale chipper. After air drying, the woodchips were mixed and screened, removing fines and any material thicker than 8 mm. Composite chip mixtures were prepared to represent each species by taking a mass equivalent to a volume ratio of 4:3:2 for the butt, middle and top logs respectively.

The sampling of three 9-year-old *A. mangium* trees from Sabah and the sample processing is described by Logan and Balodis (1982). The 10-year-old *A. auriculiformis* sample is a composite of the butt logs of three trees from the East Sepik Province, Papua New Guinea.

Basic density

The basic densities of the woodchips were determined using Australian Standard AS 1301.1s-79 (Table 1). The densities of the *A. aulacocarpa* and *A. cincinnata* samples fall within the range of those reported for *A. auriculiformis*. The density of the *A. crassicarpa* sample is higher than all published results of *A. mangium* and *A. auriculiformis* (Table 2) except for one sample of 20-year-old *A. auriculiformis* which had a density of 685 kg/m^3 (Mohd. et al. 1986). Wood from native *A. crassicarpa* has been previously reported to have a basic density of 620 kg/m^3 (Turnbull 1986). In contrast, the density of a 4-year-old plantation-grown sample of *A. crassicarpa* from China was reported to be only 470 kg/m^3 (Pan et al. unpubl.). The reasons for this difference in density are not certain, but may include genetic makeup, growing conditions and tree age.

Pulping properties

The three acacia species were separately pulped using both the kraft and the neutral sulfite semi-chemical (NSSC) processes. The method used to prepare the kraft pulps at a Kappa number of about 20 was the same as that described by Fang et al. in these proceedings. *A. aulacocarpa* gave the highest yield of screened kraft pulp followed by *A. cincinnata* and *A. crassicarpa* (Table 1). Compared with the screened yields reported for *A. mangium* and *A. auriculiformis* (Table 2), the yields from *A. aulacocarpa* and *A. cincinnata* are similar or better, while the yield from *A. crassicarpa* is lower than for most other acacia samples. The yield from the Australian *A. crassicarpa* sample was also 3.7% (oven-dried (o.d.) wood basis) lower than that from the 4-year-old sample grown in China (Pan et al. unpubl.). In terms of pulpwood productivity, which is defined as the mass of pulp produced per cubic metre of wood, *A. aulacocarpa* out-performed all the other acacias, while *A. cincinnata* and *A. crassicarpa* were comparable with *A. auriculiformis* but better than *A. mangium* (Tables 1 and 2).

Table 1. Pulping properties of acacias from Queensland.

Species	Basic density kg/m^3	Pulping process	* Screened yield %	* Screen rejects %	† Kappa number	‡ Pulpwood productivity kg/m^3
A. aulacocarpa	598	Kraft	55.4	0.6	19.3	331
12-year-old		NSSC mild	77.0	1.5	125	460
		NSSC severe	67.4	0.8	93	403
A. cincinnata	580	Kraft	53.1	1.3	20.6	308
10-year-old		NSSC mild	73.1	1.8	113	424
		NSSC severe	62.6	1.9	85	363
A. crassicarpa	638	Kraft	47.2	0.2	20.3	301
Age unknown		NSSC mild	70.8	1.8	151	452
		NSSC severe	58.3	1.8	111	372

* o.d. wood basis
† screened pulp
‡ Pulpwood productivity per cubic metre of wood = Screened yield × Basic density/100

Table 2. Kraft pulping results for *A. mangium* and *A. auriculiformis*.

Origin	Age years	Number of trees sampled	Basic density kg/m³	Active alkali % Na_2O	Screened yield % o.d. wood	Pulpwood productivity kg/m³	Kappa number	Ref.
A. mangium								
Thailand	1		380	12.0	47.0	179	20.0	1
Thailand	2		380	15.0	53.0	201	20.7	1
Taiwan	4		400	13.0	56.8	227	18.7	2
China	6	1	490	14.0	54.6	268	19.7	3
Sabah	9	3	420	14.0	52.3	220	21.0	4
Sabah	9	4	483	15.0	48.0	232	18.5	5
A. auriculiformis								
Thailand	1		480	12.0	48.8	234	17.4	1
Thailand	2		480	15.0	56.7	272	16.8	1
Taiwan	4		580	15.0	51.3	298	17.5	2
Malaysia	7	3	579	13.0	47.3	274	19.8	6
PNG	10	3	497	13.0	55.0	284	19.9	4
Sarawak	12		635	17.0	45.7	291	21.9	7
PNG	13		516	13.0	53.1	274	19.3	7
Malaysia	20	2	685	14.0	44.5	305	20.6	6

References: 1 Yantasath 1986
2 Ku and Chen 1984
3 Pan and Lu 1988
4 Logan and Balodis 1982
5 Peh et al. 1982
6 Mohd et al. 1986
7 Logan 1986

The NSSC pulps were prepared using 500 g o.d. wood, a liquor to wood ratio of 3.5:1 and two sets of pulping conditions, termed mild and severe. The mild conditions consisted of a liquor charge of 15% Na_2SO_3 and 3.5% Na_2CO_3, 1.5 hours to reach 170°C, followed by 2 hours pulping. Under the severe conditions, the liquor charge was increased to 25% Na_2SO_3 and 5.8% Na_2CO_3, the pulping temperature was increased to 180°C and the pulping time to 3 hours. At the completion of each cook, the woodchips were defibrated in a 203 mm diameter laboratory Bauer refiner, using one pass at 1.3 mm clearance with breaking plates followed by three passes at 1.3, 0.25 and 0.13 mm clearance respectively with rubbing plates.

The trends evident in the kraft pulping results are repeated in the NSSC pulping results (Table 1), although the yields are of course higher than those from the kraft process. *A. aulacocarpa* and *A. cincinnata* had similar or better screened yields than those reported for *A. mangium* and *A. auriculiformis* (Logan 1986; Logan and Balodis 1982; Niyomwan et al. 1983; Pan and Lu 1988). *A. crassicarpa* appears to be more difficult to pulp, as the screened yields were lower and the Kappa numbers were higher. These latter results are in contrast with those reported by Pan et al. (unpubl.), who found the NSSC screened yields of Chinese-grown 4-year-old *A. crassicarpa* to be quite comparable with those of *A. mangium* and *A. auriculiformis*.

Black liquor properties

The swelling volumes and viscosities of the kraft black liquors were measured to determine their likely behaviour during the chemical recovery process. Black liquors with high viscosity can decrease recovery section throughput by reducing flow rates during evaporation, while low swelling volumes indicate poor burning properties. The black liquor viscosities at 40% total solids were interpolated from viscosity measurements over a range of black liquor concentrations and the black liquor swelling volumes were measured using the method devised by Baklien (1960).

The black liquors from *A. aulacocarpa* and *A. cincinnata* were higher in swelling volume than *A. crassicarpa*, although the viscosities of the black liquors from all three acacias were similar (see Table 3). Since published data on the black liquor properties of *A. mangium* and *A. auriculiformis* are rare, the samples of 9-year-old *A. mangium* from Sabah and 10-year-old *A. auriculiformis* from PNG were pulped to provide black liquor samples. The results from these samples (Table 3) are very similar to those of *A. aulacocarpa* and *A. cincinnata*. When compared to eucalypts, the black liquors from all the acacias have satisfactory viscosities and, with the exception of *A. crassicarpa*, they have fair to good swelling properties.

Bleaching properties

A quantity of the Kappa number *c*.20 kraft pulp from each species was bleached using a chlorination, alkali extraction, hypochlorite and chlorine dioxide (CEHD) bleaching sequence, as described by Fang et al. (these proceedings). For comparison, the kraft pulps made from the 9-year-old *A. mangium* and the 10-year-old *A. auriculiformis* referred to above were also bleached using the same procedure.

The *A. aulacocarpa* pulp had the highest brightness and the highest yield on bleaching, with results comparing favourably with those of *A. mangium* and *A. auriculiformis* (Table 4). The *A. cincinnata* and *A. crassicarpa* pulps were more difficult to bleach and their final pulp brightnesses were substantially lower. However, their pulp yields (unbleached pulp basis) were satisfactory.

In some of the bleaching trials (results not given), the freeness of the *A. mangium* bleached pulp decreased to a greater extent than for any of the other acacias pulps. *A. mangium* may be susceptible to fibre damage during the bleaching process.

Papermaking properties

The papermaking properties of the bleached kraft pulps and the unbleached NSSC pulps were determined according to Australian Standards AS 1301.203s-80, AS 1301.209rp-89 and AS 1301.208s-89, after conditioning the sheets in an atmosphere at 50% rh and 23 °C (AS 1301.415m-85).

Table 5 gives the papermaking properties of the bleached kraft pulps. In tear strength, the *A. aulacocarpa, A. crassicarpa* and *A. mangium* pulps were similar to each other, stronger than the *A. cincinnata* pulps but weaker than the *A. auriculiformis* pulps. These results are consistent with the fibre lengths measured by a Kajaani FS-200 fibre analyser; 0.98 mm (weight-weighted averaged) for *A. aulacocarpa*, compared with 0.94 mm for *A. crassicarpa* and 0.83 mm for *A. cincinnata*. In terms of tensile and bursting strengths, the *A. aulacocarpa* pulps were stronger than the *A. cincinnata* and *A. crassicarpa* pulps but weaker than the *A. mangium* and *A. auriculiformis* pulps. According to the

Table 3. Properties of kraft black liquors.

Species	Active alkali (% Na_2O)	Pulp Kappa no.	Total solids of unevaporated black liquor (%)	Swelling volume/g T.S. (mL)	Viscosity at 40% T.S. (m Pa.s)
A. aulacocarpa	13.25	19.3	13.8	47	20
A. cincinnata	13.75	20.6	13.9	33	26
A. crassicarpa	17.5	20.3	17.0	5	20
A. mangium	13.5	20.9	14.1	45	21
A. auriculiformis	12.75	19.8	14.0	35	18

For eucalypts, good black liquors have viscosity <16 m Pa.s and swelling volume >40 mL/g Total Solids, fair 60 and 30, and poor >200 and <10 respectively (Oye et al. 1977).

Table 4. Bleaching properties of kraft pulps.

Property	*Acacia aulacocarpa*	*Acacia cincinnata*	*Acacia crassicarpa*	*Acacia mangium*	*Acacia auriculiformis*
Chlorine demand %	3.9	3.3	3.7	4.0	3.8
Total chlorine used					
in C and H stages %	4.9	4.3	4.9	5.0	5.3
Chlorine dioxide consumed %	0.34	0.34	0.40	0.35	0.34
Pulp yield %					
on unbleached pulp	97.0	96.3	95.4	95.4	95.1
on o.d. wood	53.8	51.1	45.0	49.2	51.8
Brightness (% ISO)					
Pulp	84.6	76.7	72.2	83.2	84.2
Handsheets	84.7	77.4	74.4	82.4	83.3

Table 5. Papermaking properties of bleached kraft pulps.

Beating revs. PFI	Freeness CSF	Handsheet properties (60 g/m² grammage) Bulk cm^3/g	Tear index $mN.m^2/g$	Tensile index N.m/g	Burst index $kPa.m^2/g$	Brightness %	Opacity %
A. aulacocarpa							
0	380	1.70	8.7	54	2.8	82.3	76.6
2000	368	1.51	9.2	89	5.7	81.3	73.1
4000	288	1.42	9.3	100	7.1	80.5	70.0
8000	151	1.35	9.1	110	8.2	79.6	68.6
A. cincinnata							
0	361	1.66	4.4	43	2.0	73.8	78.2
2000	318	1.45	7.2	74	4.1	71.9	72.5
4000	204	1.38	7.8	90	6.0	70.2	69.7
6000	107	1.33	7.7	100	6.6	69.2	67.0
A. crassicarpa							
0	395	1.67	6.7	44	2.3	71.4	79.2
2000	330	1.50	9.0	76	4.5	69.4	76.0
4000	263	1.41	8.8	83	5.5	68.0	73.3
8000	129	1.29	8.8	95	6.9	66.3	70.5
A. mangium							
0	402	1.35	8.6	82	5.6	82.3	
1000	382	1.25	8.4	103	7.4	80.3	
2000	341	1.23	7.8	114	8.6	79.2	
4000	249	1.19	7.4	125	9.3	78.3	
A. auriculiformis							
0	318	1.55	11.6	75	4.5	81.9	
1000	299	1.46	10.6	98	6.4	80.3	
2000	262	1.41	11.3	111	7.7	79.7	
4000	187	1.31	10.3	123	9.1	78.7	

grading scales of Balodis (these proceedings), the bleached pulps from all of these acacias would be suitable for a wide range of printing and writing and general purpose packaging papers. In the case of *A. cincinnata*, some beating may be needed to develop the pulp strength needed.

Table 6 gives the papermaking properties of the unbleached NSSC pulps from the three acacias. The *A. aulacocarpa* pulp was generally the strongest, followed by the pulps from *A. crassicarpa* and *A. cincinnata*. None of these acacias have NSSC papermaking properties to match those reported for *A. mangium* and *A. auriculiformis* (Logan and Balodis 1982). However, with appropriate beating, the pulps of *A. aulacocarpa, A. cincinnata* and *A. crassicarpa*, particularly after severe condition cooks, would have sufficient strength to supplement hardwood kraft pulp in unbleached packaging products.

Conclusion

The results of the pulping and papermaking tests show that *A. aulacocarpa* has excellent potential as a source of fibre for pulping and papermaking. Pulp yields were high from both the kraft and the NSSC processes, and the kraft pulp could be readily bleached to a high brightness. The pulp properties would be suitable for a wide range of printing and writing and general purpose packaging papers.

A. cincinnata also had acceptable pulp yields, but the kraft pulp was harder to bleach. The paper strength properties were not as good as those of *A. aulacocarpa*, although still adequate for most end uses if the pulp was sufficiently well beaten.

The *A. crassicarpa* pulp would also be acceptable for a wide range of end products. The pulp yields, black liquor swelling properties and bleaching results were poorer than those of the other acacias, but the results are still within the range of commercial pulpwoods. Better results have been reported for plantation-grown trees from China (Pan et al. 1990) and it may be that further samples of known age from other locations will be required before the usefulness of this species as pulpwood can be definitely established.

Table 6. Papermaking properties of unbleached NSSC pulps.

Beating revs. PFI	Freeness CSF	Handsheet properties (60 g/m² grammage) Bulk cm^3/g	Tear index $mN.m^2/g$	Tensile index N.m/g	Burst index $kPa.m^2/g$	CMT crush index $N.m^2/g$
A. aulacocarpa, mild conditions:						
0	669	2.39	3.4	23	0.8	0.7
2500	602	2.07	5.4	37	1.6	2.3
5000	509	1.91	5.8	49	2.4	3.7
10000	301	1.71	7.1	69	3.8	5.8
15000	144	1.61	6.9	81	4.8	6.6
A. aulacocarpa, severe conditions:						
0	690	2.26	5.0	27	1.0	1.2
2500	556	1.79	7.7	66	3.5	4.2
5000	413	1.62	8.5	81	5.1	6.4
10000	172	1.47	7.9	98	7.0	7.0
A. cincinnata, mild conditions:						
0	586	2.27	3.1	24	1.0	1.5
2500	376	1.85	4.8	49	2.4	4.2
5000	199	1.64	5.7	66	3.8	5.9
10000	46	1.45	5.8	84	5.2	6.2
A. cincinnata, severe conditions:						
0	640	2.09	3.7	28	1.0	1.7
2500	391	1.65	5.8	65	3.6	5.8
5000	198	1.51	6.3	85	5.1	7.1
10000	42	1.35	6.4	94	6.6	5.4
A. crassicarpa, mild conditions:						
0	628	2.54	2.6	15	0.7	0.7
2500	466	2.15	4.6	35	1.8	2.3
5000	320	1.96	5.7	49	2.7	3.7
10000	112	1.74	6.1	67	4.0	5.6
A. crassicarpa, severe conditions:						
0	692	2.26	3.6	24	0.8	0.9
2500	534	1.82	6.4	58	2.9	4.0
5000	361	1.66	7.6	75	4.5	6.0
10000	104	1.49	7.4	95	6.3	7.1

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References

Anon. 1980. Atlas of Australian Resources, Third Series, Volume 1, Soils and Land Use. Division of National Mapping, Canberra.

1986. Atlas of Australian Resources, Third Series, Volume 4, Climate. Division of National Mapping, Canberra.

Baklien, A. 1960. The effects of extraction on black liquor from eucalypt pulping. Appita 14, 1, 5.

Brown, A. 1990. Australian tree resources. In: Lucas, S., ed., Report of the Division of Forestry and Forest Products, 1988–1989. CSIRO, 10–11.

Ku, Y.C. and Chen, H.T. 1984. Study on the pulping of fast growing acacia species. Bulletin of Taiwan Forestry Research Institute No. 416, Taipei, Taiwan.

Logan, A.F. 1986. Australian acacias for pulpwood. In: Turnbull, J.W., ed., Australian acacias in developing countries. ACIAR Proceedings No. 16, 89–94.

Logan, A.F. and Balodis, V. 1982. Pulping and papermaking characteristics of plantation-grown *Acacia mangium* from Sabah. The Malaysian Forester, 45, 2, 217–236.

Mohd. Nor B. Mohd. Yusoff, Khoo, K.C., Lee, T.W. and Peh, T.B. 1986. Sulphate pulping of *Acacia auriculiformis* from Peninsular Malaysia. The Malaysian Forester, 49, 1.

Niyomwan, N., Kamolratanakul, A. and Hanjangsit, L. 1983. Potential of fast growing trees as raw material for the pulp industry in Thailand. 37th Appita Annual Conference Preprint, Mt. Gambier, South Australia.

Oye, R., Längfors, N.G., Phillips, F.H. and Higgins, H.G. 1977. The properties of kraft black liquors from various eucalypts and mixed tropical hardwoods. Appita, 31, 1, 33–40.

Pan, Z. and Lu, X. 1988. Study of the pulping characteristics of *Acacia mangium* in China. Proceedings of the Use of Australian Trees in China Workshop. Guangzhou, China.

Peh, T.B., Khoo, K.C. and Lee, T.W. 1982. Sulphate pulping of *Acacia mangium* and *Cleistopholis glauca* from Sabah. The Malaysian Forester, 45, 3, 404–418.

Turnbull, J.W. 1986. Multipurpose Australian Trees and Shrubs: lesser-known species for fuelwood and agroforestry. ACIAR Monograph No. 1, 316 p.

Yantasath, K. 1986. Field trials and testing of selected species of fast growing nitrogen-fixing trees. Presented at the ACIAR/NFTA Workshop, Gympie, Australia.

Kraft Pulping Properties of *Acacia mearnsii* and *A. silvestris*

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Abstract

Kraft (sulfate) pulps were prepared from native Australian-grown *Acacia mearnsii* and *A. silvestris* using 13% active alkali. Both species yielded about 53% of screened pulp of Kappa number 20. The pulps were bleached using a CEHD sequence to a brightness of 81% and bleached yield of 50% on oven-dry wood basis.

The papermaking properties of both unbleached and bleached pulps are very similar for the two species and the pulps would be suitable for a wide range of paper and paperboard products. Tests on spent pulping liquors suggest that the recovery of pulping chemicals may be easier from acacia than from mature eucalypt black liquors. Basic density of the *A. mearnsii* wood was 610 kg/m³ and that of *A. silvestris* 550 kg/m³.

OF the 850 Australian acacias (Pedley 1987), very few are grown in commercial plantations. During the last decade there has been an upsurge in interest in *A. mangium* for pulpwood plantations, e.g., in Sabah, Malaysia (Udarbe and Hepburn, 1987), but by far the largest plantations are those of *A. mearnsii*. Although this species is grown primarily for the production of tannin from its bark, the wood is used for pulping in South Africa and also exported as woodchips. *A. mearnsii* is one of the group of 36 Australian bipinnate acacias, most of which are found along the southeastern coast of Australia. Boland (1987) suggests that some of the related species may be worth exploring for commercial utilisation.

Logan (1987) has reported pulping results for a commercial chip sample of *A. mearnsii* (from South Africa) as well as for samples of other bipinnate acacias, namely *A. dealbata, A. decurrens* and *A. elata*. All of these are shown to produce good pulpwood — high kraft pulp yield, low pulping chemical usage and good paper strength properties.

A. silvestris is the largest of the bipinnate acacias with tree height around 20 m (Boland 1987). It occasionally reaches 30 m and it can be coppiced (Turnbull 1986). The species may be suitable for planting in areas with warm, subhumid climate. A comparison of pulping and papermaking properties of *A. silvestris* with those of *A. mearnsii*, which is a commercial pulpwood species, should provide information on the relative quality and suitability of *A. silvestris* as a potential pulpwood species.

For further comparison, test results are included for a commercial eucalypt export sample (Phillips and Logan 1977) and for a sample of 20–30-year-old eucalypt regrowth (Mamers et al. unpubl.) from the same general area as the *A. silvestris* and *A. mearnsii* samples. The export chips are derived from sawmill off-cuts and low quality logs from mature trees. The regrowth eucalypts are generally regarded as the best pulpwood from the coastal forests.

Methods

Sampling

The samples were collected on the South Coast of NSW, *A. mearnsii* from Batemans Bay and *A. silvestris* from Narooma. Three trees were sampled from each species. These ranged in diameter at breast height over bark (dbhob) from 14 to 18 cm for *A. mearnsii* and from 19 to 25 cm for *A. silvestris*, with merchantable lengths in the range 6–16 m. A single wood sample was taken from each tree in rotation from the butt, middle and top log. Age of the trees

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could not be determined. In the preparation of species mixtures the chips were combined in the ratio 4:3:2 from the butt, middle and top log respectively.

Processing

Basic density of the chip samples was determined according to Australian Standard AS 1301.1s-79. The chips were pulped in a multi-vessel digester (each vessel of 3-litre capacity) using a range of alkali concentrations. The pulping conditions were: 500 g oven dry (o.d.) wood, 3.5:1 liquor to wood ratio, 25% sulphidity (as Na_2O), 75 min to bring to temperature, then 2 hours at 170 °C. The pulps were screened on a 0.2 mm slotted Packer screen and Kappa number of the screened pulp was measured according to Appita standard method P201m-86.

The pulps were bleached using a standard chlorine-alkali extraction hypochlorite-chlorine dioxide (CEHD) bleaching sequence. The bleaching conditions are given in Table 1.

From each species a bleached and an unbleached pulp was evaluated. Handsheets were prepared according to Australian Standard AS 1301.P203s-80 from both unbeaten and beaten pulp, and tested according to AS 1301.P208s-83. The pulps were beaten in a PFI mill using 24 g (o.d.) pulp charge, 10% stock concentration and 1.77 N/mm beating load (AS 1301.P202s-80).

Tests on spent pulping liquor (black liquor) included total solids content, viscosity at 40 °C and 40% total solids, and determination of swelling volume. For total solids content, a liquor sample of known mass was evaporated and dried at 105 °C. The viscosity of the black liquor was measured at 40 °C for a range of solids content with an Epprecht rheometer. The value at 40% total solids was interpolated from a plot of viscosity *vs* solids content (semi-logarithmic scale). The swelling volume was determined on a small volume of black liquor, which was evaporated to dryness and then heated in a furnace at 400 °C until the swelling peak of the residue was reached. The swollen volume is reported per gram of total solids (ml/g).

Results and Discussion

Pulping

The results of wood characteristics and pulping tests are shown in Table 2. Screened pulp yield of the acacias is considerably higher than that of the eucalypt export mixture, more like that of the regrowth eucalypts.

Basic density of the bipinnate acacias is in the range of commercial pulpwoods. In plantation-grown material basic density can be optimised for particular pulp products. For example, the optimum basic density of plantation-grown *Eucalyptus grandis* for the production of bleached kraft pulp is considered to be between 500 and 600 kg/m^3 (Brandao 1984). It is a compromise between wood costs and pulp quality. High density woods have cost advantage in wood handling and processing, but are disadvantaged because of reduced paper strength. However, pulps from high density eucalypt woods produce paper with higher opacity which is advantageous for printing papers (Higgins et al. 1973). The strength of printing papers is usually not as critical as that of packaging papers (e.g. Balodis, these proceedings) and therefore the acceptable basic density range will also depend on the product type. Within a species, e.g. *Eucalyptus grandis*, paper strength decreases with increasing basic density (Vasconcellos Dias and Claudio-da-Silva 1985). In the planning of acacia pulpwood plantations there is a need to study the effect of basic density on pulping and paper-making properties.

Table 1. Conditions for pulp bleaching.

Bleaching stage	Reagent	Concentration of reagent (% on o.d. pulp)	Stock concentration (% o.d.)	Temperature (°C)	Time (h)
C	Cl_2/H_2O	*	3	20	1
E	NaOH	1.5	12	60	1
H	NaOCl	1.5	10	40	2
	NaOH	0.5			
D	ClO_2	0.5	6	70	2
	NaOH	0.25			

* Chlorine demand for *A. silvestris* and *A. mearnsii* is given in Table 3.

Table 2. Wood characteristics and properties of unbleached sulfate pulps from *A. silvestris, A. mearnsii*, other bipinnate acacias and a commercial eucalypt chip mixture from southeast Australia.

Species	Age	Basic density (kg/m³)	Active alkali (%)	Yield (%) Unscr.	Yield (%) Scr.	Yield (%) Reject	Kappa no.	PP* (kg/m³)
A. mearnsii	—		12.0	56.3	52.5	4.22	26.8	
		608	13.0	54.3	52.8	1.64	20.0†	321
			14.0	54.2	53.7	0.49	17.7	
A. silvestris	—		12.0	57.0	52.8	4.20	30.1	
		551	13.0	55.1	53.3	1.56	20.3†	294
			14.0	54.0	53.3	0.32	16.5	
A. dealbata[1]	—	553	13.5		52.8	0.7	20.7	292
A. decurrens[1]	9	457	15.0		55.9	—	18.7	255
A. elata	—	520	13.0		55.1	1.3	24.0	286
A. elata[1]	c15	672	13.0		58.7	0.1	13.1	394
A mearnsii[1]	10	598	13.0		52.4	1.7	21.0	313
A mearnsii[2]	10	590	17.5		52.8	0.3	20.1	312
Export eucalypts[3]	—	615	16.0		45.0	<0.1	22.8	278
Regrowth euc.[4]	20–30	585	11.5		53.7	—	21.2	314

† Pulps used in bleaching experiments
* PP is pulpwood productivity, i.e. kilograms of pulp per cubic metre of wood. PP = basic density × (screened pulp yield/100)
[1] From Logan (1987)
[2] From Palmer et al. (1982)
[3] From Phillips and Logan (1977)
[4] From Mamers et al. (unpubl.)

Table 3. Properties of bleached kraft pulps.

Property	*Acacia mearnsii*	*Acacia silvestris*	Export* eucalypts	Regrowth† eucalypts
Chlorine demand %	5.1	4.7	3.8	4.0
Total chlorine used in C and H stage	6.2	5.9	5.2	4.7
Pulp yield %				
on unbleached pulp	94.5	94.3	93.6	94.7
on original wood	49.9	50.2	42.1	50.9
Pulp brightness (% ISO)	81.2	80.8	88.4	84.7
Handsheet brightness (% ISO)	77.1	75.6	87.9	79.7

* From Phillips and Logan (1977). The pulp from the export chips had a longer treatment time for the H and D stages than the other pulps, which may account for the higher brightness value.
† From Mamers et al. (unpubl.)

Pulp production per cubic metre of wood is relatively high for most of the acacias. The exceptionally high pulpwood productivity for the *A. elata* from Logan (1987) is for a sample from a tree grown in a garden in Western Australia. In a subsequent test on a sample from a small tree (12.5 cm dbhob) from southeastern New South Wales, the pulpwood productivity for *A. elata* (Table 2) was about the same as for the other bipinnate acacias.

From the results in Table 2, basic density of *A. mearnsii* is higher than that of *A. silvestris*, while the pulping properties of the two species are nearly identical.

The bleaching results are listed in **Table 3**. The chlorine demand is higher for the acacias than for reference samples. Neither of the acacia pulps attained the brightness levels of the eucalypts or those of the tropical acacias, *A. mangium* and *A. auriculiformis* (Logan and Balodis 1982). The bleaching properties of the acacia pulps will need to be investigated because many commercial paper products require pulps of brightness in the high 80s.

Papermaking

Results from the paper tests are assembled in Table 4. The *A. silvestris* pulps produce better bonded sheets

Table 4. Papermaking properties of unbleached (ub.) and bleached (bl.) sulfate pulps.

Property	Beating rev. (PFI)	*A. mearnsii*		*A. silvestris*		Mixed eucalypt export chips*		Regrowth eucalypts†	
		ub.	bl.	ub.	bl.	ub.	bl.	ub.	bl.
Freeness (Csf)	0	547	354	563	336	575	567	477	550
	1000	468	301	473	319	481	458	399	—
	2000	397	227	409	257	325	372	271	395
	4000	267	111	302	133	118	215	127	225
Bulk (cm^3/g)	0	1.81	1.72	1.55	1.54	2.13	2.08	1.79	1.76
	1000	1.67	1.55	1.47	1.45	1.84	1.81	1.55	—
	2000	1.58	1.47	1.39	1.37	1.70	1.70	1.48	1.51
	4000	1.43	1.35	1.33	1.27	1.55	1.59	1.37	1.40
Tear index ($mN.m^2/g$)	0	3.6	5.0	4.4	6.0	4.8	4.7	7.4	6.0
	1000	6.8	7.0	7.4	7.1	8.0	7.0	10.0	—
	2000	7.1	7.6	7.6	7.2	9.6	8.5	10.6	10.5
	4000	7.6	7.8	7.7	7.4	10.5	8.9	9.5	9.9
Tensile index (N.m/g)	0	41	46	48	58	30	22	64	49
	1000	65	70	77	86	49	38	97	—
	2000	79	87	95	98	64	50	107	89
	4000	99	105	109	115	79	65	120	108
Burst index ($kPa.m^2/g$)	0	1.6	2.1	2.1	2.9	1.0	0.8	3.6	2.7
	1000	3.3	3.7	4.0	5.1	2.6	1.9	5.8	—
	2000	4.5	5.1	5.5	6.5	3.8	2.8	7.3	6.0
	4000	6.2	6.6	6.7	7.9	5.4	4.2	7.9	7.5
Opacity (%)	0		79.1		77.6		74.3		75.5
	1000		76.6		75.4		72.3		—
	2000		74.0		71.3		70.6		69.3
	4000		72.0		67.4		69.0		66.1

* From Phillips and Logan (1977)
† From Mamers et al. (unpubl.)

than *A. mearnsii*. At a given number of beater revolutions, which is proportional to beating energy input, the papers are denser (lower bulk) and stronger (higher tensile and burst index). These differences may be due to *A. silvestris* having lower basic density and fibres with thinner walls than *A. mearnsii*. Thin-walled fibres collapse to form ribbons that bond strongly to each other, giving paper with high tensile and burst index.

The tear index is about the same for the two acacias, as are the changes in freeness with beating. The paper strength levels for pulps from both species are adequate for printing and writing papers and also for general purpose wrapping and packaging papers.

A comparison of the acacia and reference eucalypt pulp reveals some interesting differences. Bleaching reduces freeness of unbeaten acacia pulps but not of the eucalypt pulps. The acacia pulps may be damaged by the higher chlorine demands or the damage may be caused by the CEHD bleaching sequence. The change in freeness with beating is less for the acacia than the eucalypt pulps. The elucidation of these anomalies will need more detailed investigation of the bleaching and papermaking properties of acacia pulps.

Chemical recovery

The properties of black liquors can cause problems in chemical recovery operations. The best liquors are those which have low viscosity at high solids contents and burn well in the recovery furnace. The burning properties are associated with swelling volume. The best liquors are from young eucalypts, the least desirable from old eucalypts which have high viscosity and low swelling volume (Oye et al. 1977). As a rough guide, eucalypt black liquors can be classified as good (viscosity 16 mPa.s, swelling volume 40 ml/g), fair (60, 30) and poor (200, 10). The results from the tests of the acacia black liquors are listed in Table 5.

If the classification system of the eucalypts applies to the acacias, the black liquors from *A. mearnsii* and *A. silvestris* would be good to fair.

Conclusions

Basic density of *A. mearnsii* (608 kg/m^3) is higher than that of *A. silvestris* (551 kg/m^3). Both species can be readily pulped by the kraft process, yielding 53% pulp on oven-dry weight basis. Pulp productivity of *A. mearnsii* is about 320 kg per cubic metre of wood, and about 295 kg for *A. silvestris*. The unbleached pulps would be suitable for the production of a variety of packaging papers.

The bleached pulp yield for both species was about 50% on oven-dry wood basis, with brightness of 81%. This brightness level would not be sufficient for some of the higher grade papers. With lower chlorine consumption the pulps from eucalypt reference samples could be bleached to higher brightness. There are indications that the standard CEHD bleaching sequence alters the pulp, resulting in decreased freeness. A more detailed investigation of the bleaching properties of these pulps would be desirable, both with respect to chlorine consumption and pulp brightness. The bleached pulps have adequate strength for most grades of printing and writing papers.

The recovery of pulping chemicals from the black liquor of *A. mearnsii* and *A. silvestris* should not present special difficulties because their black liquor properties are similar to those of eucalypt regrowth. Of the two, the black liquor from *A. silvestris* has the best properties.

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References

Boland, D.J. 1987. Genetic resources and utilisation of Australian bipinnate acacias (Botrycephalae). In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, 29–37.

Brandao, L.G. 1984. Presentation. The Marcus Wallenberg Foundation Symposia Proceedings. 1. The new eucalypt forest, Fallun, Sweden, 3–15.

Higgins, H.G., de Yong, J., Balodis, V., Phillips, F.H. and Colley, J. 1973. The density and structure of hardwoods in relation to paper surface characteristics and other properties. Tappi, 56(8), 127–131.

Logan, A.F. 1987. Australian acacias for pulpwood. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries, ACIAR Proceedings No. 16, 89–94.

Logan, A.F. and Balodis, V. 1982. Pulping and papermaking characteristics of plantation-grown *Acacia mangium* from Sabah. Malaysian Forester, 45(2), 217–236.

Oye, R., Langfors, N.G., Phillips, F.H. and Higgins, H.G. 1977. The properties of kraft black liquors from various eucalypts and mixed tropical hardwoods. Appita, 31(1), 33–40.

Palmer, E.R., Gibbs, J.A. and Dutta, A.P. 1982. Pulping trials of wood species growing in plantations in Kenya. Report of the Tropical Products Institute, L61, v + 55 p.

Pedley, L. 1987. Australian acacias: taxonomy and phytogeography. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, 11–16.

Table 5. Properties of black liquors.

Property	*Acacia mearnsii*	*Acacia silvestris*	Mixed eucalypts	
			export*	regrowth†
Active alkali (as % of Na_2O)	13	13	16	11.5
Kappa number	20.0	20.3	22.8	21.7
Total solids (TS) of unevaporated black liquors (%)	14.4	14.3	16.5	14.7
Swelling volume (mL/g TS)	25	48	9	24
Viscosity (mPa.s) at 40% TS, 40°C	47	43	165	159

* From Phillips and Logan (1977)
† From Mamers, et al. (unpubl.)

Phillips, F.H. and Logan, A.F. 1977. The pulping and papermaking potential of tropical hardwoods. IV A quality assessment of pulps from the forest resources of Vanimo, Papua New Guinea. CSIRO Aust. Div. Chem. Technol. Tech. Paper No. 8.

Turnbull, J.W. (ed.) 1986. Multipurpose Australian trees and shrubs: lesser known species for fuelwood and agroforestry. ACIAR Monograph No. 1, 316 p.

Udarbe, M.P. and Hepburn, A.J. 1987. Development of *Acacia mangium* as a plantation species in Sabah. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, 157–159.

Vasconcellos Dias, R.L. and Claudio-da-Silva, Jr., E. 1985. Pulp and paper properties as influenced by wood density — same species and age of *Eucalyptus*. Papermaking raw materials: their interaction with the production process and their effect on paper properties. Vol. 3 1985, Fundamental Research Symposium London. Mechanical Engineering Publications, 7–36.

The Utilisation Potential of *Acacia shirleyi* in the Northern Territory, Australia

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Abstract

Acacia shirleyi (lancewood) is a source of hard, durable timber suitable for construction and as fuelwood. This paper looks at the prospects for commercial exploitation of natural stands, which presently cover around 27 000 km² of the Northern Territory, Australia.

Discussion covers the species' characteristics in relation to present and potential uses, possible markets, and accessibility for harvesting and transportation. Difficulties such as high costs of extraction in a harsh, remote environment together with extra penalties for long distance road hauling and shipping are highlighted.

ACACIA shirleyi (lancewood) has long been highly regarded by the Aboriginal population. The hard, durable timber has been particularly favoured for the fashioning of hunting spears and is an excellent fuelwood.

The early European migrants on the other hand, had a very different view and historically regarded lancewood as a hindrance to early exploration and development. Even today it is regarded by pastoralists as an impediment to grazing rather than as a resource.

The dense stands are virtually impenetrable by vehicle and the closed canopy ensures that there are few grasses or shrubs in the understorey to provide a food source for cattle. The only utilisation value until now has been for construction purposes, mainly involving posts and rails for fencing and for the construction of stock yards. In recent years there has been growing interest in its possible commercial potential.

The lancewood resource in the Northern Territory is extensive, covering in excess of 27 000 km² and if managed properly could become a small but very valuable forestry industry. This paper describes the natural distribution, wood properties and potential utilisation of *A. shirleyi*.

Description

A. shirleyi grows up to 20 m in height and 60 cm in diameter, with rough, deeply fissured bark and dense, bluish foliage. It occurs commonly in dense monospecific stands and has been recognised as a distinctive vegetation formation for the recent vegetation mapping project carried out by the Conservation Commission of the Northern Territory (Wilson unpubl.).

Because of the isolation of the lancewood communities in the Northern Territory and the fact that the stands are virtually inaccessible, there has been very little in the way of ecological studies carried out on these communities. Floristic, ecological and timber volume data have been gathered for two areas for which a licence to harvest lancewood has been granted. However there is still a large amount of work to be carried out over the entire range of the lancewood communities. A large survey program is scheduled for 1991/92 to carry out a resource and ecological assessment to enable informed decisions on the conservation and utilisation of the resource.

Distribution

A. shirleyi has an extensive distribution that stretches in an arc from inland southern Queensand to the base of the Cape York Peninsula and across the Barkly Tableland into the central north of the Northern Territory. This species rarely extends into coastal areas (Beadle 1981).

In the Northern Territory lancewood occurs in extensive tracts from 14–18 °S. Its distribution and abundance is clearly evident from aerial photography and broad vegetation patterns are easily defined on

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satellite imagery. The Conservation Commission has just completed a 1:1 000 000 mapping project which has broadly documented the lancewood resource. Wilson (unpubl.) has categorised the areas covered by lancewood in the Northern Territory:

- *A. shirleyi* open-forest: 20 211 km^2
- *A. shirleyi* low open-forest: 2130 km^2
- *A. shirleyi* scattered within *Eucalyptus dichromophloia*: 5130 km^2.

It is now proposed to carry out classification of digital satellite data using Microbrian to delineate areas of lancewood at a scale of 1:250 000 and to undertake the additional mapping of two areas at a scale of 1:100 000.

Whilst lancewood is typified as existing in dense monospecific stands, it is sometimes associated with the tall shrub *Macropteranthes kekwickii* and occasionally *Eucalyptus dichromophloia* and *E. brevifolia*.

In the region near the Gulf of Carpentaria lancewood is restricted to rises and hills and especially lateritic escarpments, on moderate to well drained lithosols (Aldrich and Wilson 1990). However, in the Daly Waters region, the species covers large flat areas of shallow gravelly soils on well drained sites.

Wood Properties

The timber produced by *A. shirleyi* is characteristically very hard, strong and heavy with an air dry density of around 950 kg/m^3 (Turnbull 1986). The heartwood is an attractive dark brown with a distinctive, pale sapwood which is fairly narrow.

Lancewood logs are often fluted and fire scars are common. Where fire damage is significant there is also the possibility of damage by insects such as termites. Because of the deeply fissured bark and fluted lower trunk it is quite often difficult to recognise damaged trees in the field. Small amounts of superficial checking have also been observed from logs cut and left out in the field.

Utilisation Potential

A. shirleyi is a very hardy tree which has potential as a shade or shelterbelt tree for semiarid areas with gravelly, well-drained soils. Turnbull (1986) suggests that it is unlikely to tolerate frosts, poorly drained or heavy clay soils, and that the wide geographic range suggests that provenance testing will be desirable to select the best seed source.

The leaves and bark are sometimes eaten by cattle in periods of drought when all other food sources have been exhausted but the tree is mainly used to provide wood products.

The timber is widely used for construction but Turnbull (1986) states that there are conflicting reports regarding the durability of posts in contact with the ground. Although the cut posts split at the ends fairly readily, they are often left in the field for up to six months before having the ends docked prior to use.

The timber has a number of other possible uses. There is a small, specialised market in Australia for craft purposes, which would be ideally suited to using offcuts from any substantial logging exercise. The major demand would be for wood turning and possibly parquetry flooring. Overseas demand is expected to be for interior decorating, parquetry flooring, high quality veneer and for specialised industrial purposes such as shuttles and spindles.

The amount of defect within the wood is an important variable that is yet to be accurately assessed. The majority of the lancewood communities are subjected to fairly severe wildfires at relatively frequent intervals and the amount of defect could be expected to vary a great deal within regions. Visual assessment of fire damage or insect attack is often difficult, but major defect seems to be a common problem throughout the lancewood resource and will have an important effect on the economic viability of any harvesting operation.

Another problem that will have an impact on the viability of the project is the distance from major transportation routes and markets. The Daly Waters area, for instance, where a large amount of the resource is situated, is some 600 kilometres from Darwin, the closest port. There are no rail facilities so all timber will need to be trucked to the port, which, combined with double handling will lead to high transportation costs. In addition, extraction costs in the field will be high due to the difficulties of operating in a harsh environment.

The Environment Unit of the Conservation Commission has drawn up a comprehensive set of environmental guidelines and conditions to apply to any harvesting operation, and the ongoing research program will ensure that the conservation status of *A. shirleyi* is not endangered by any potential commercial operation.

References

Aldrich, J.M. and Wilson, P.L. 1990. Land Systems of the Southern Gulf Region, Northern Territory. Technical Report 42. Conservation Commission of the Northern Territory.

Beadle, N.C.W. 1981. The Vegetation of Australia. Cambridge, Cambridge University Press.

Turnbull, J.W. (ed.) 1986. Multipurpose Australian Trees and Shrubs. Lesser-known species for fuelwood and agroforestry. ACIAR Monograph No. 1, Canberra.

Performance Studies

Performance of *Acacia* Species in Thailand

Pravit Chittachumnonk and Sumet Sirilak*

Abstract

Twelve Australian *Acacia* species were introduced in field trials in Thailand. These field trials were established in 1985 as a collaborative research project between the Royal Forest Department (RFD) of Thailand and CSIRO Division of Forestry with support from the Australian Centre for International Agricultural Research (ACIAR) of Australia.

A total of 23 seedlots of the 12 *Acacia* species were planted in six trial sites throughout Thailand. The growth performance at 36 months after planting showed a very significant difference between species and seedlots. The best three species were *Acacia crassicarpa, A. auriculiformis* and *A. aulacocarpa* all from Papua New Guinea which exhibited good growth performance at almost every trial site. On the other hand, *A. aulacocarpa* from Queensland, *A. cincinnata, A. shirleyi, A. melanoxylon* and *A. polystachya* were the slowest growing *Acacia* species in all trial sites.

Survival percentage between species also showed significant differences within sites except at Sisaket which showed the best survival percentage in all species. Trial sites at Chanthaburi and Prachuap Kiri Khan (Sai Thong) had the overall lowest survival percentage. However, *A. auriculiformis* showed the best survival percentage at all sites followed by *A. aulacocarpa* and *A. crassicarpa*.

In Thailand, the forest area in 1961 was 273 000 km^2 or 53% of the total area of the country. It decreased to 156 000 km^2 or 30% by 1982. Thailand has a population of about 55 million people and 80% of them live in rural areas where wood is the main source of energy for cooking and heating. Rapid deforestation has resulted in shortage of fuelwood and construction timber and soil erosion in many places. One measure to alleviate these problems is to establish forest plantations with tree species that are fast-growing, nitrogen-fixing and capable of surviving in grossly disturbed habitats.

Acacia auriculiformis has been used as a plantation species with notable success throughout Thailand. However, there are many other Australian acacias which have never been tried but may be better adapted. Following the establishment of ACIAR, a project on Australian Hardwoods for Fuelwood and Agroforestry was set up in 1985 as a collaborative effort between the Royal Forest Department (RFD) and CSIRO Division of Forestry. 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 (Fig. 1). Previous assessments of these field trials 6, 12 and 24 months after planting have been reported (Pinyopusarerk and Puriyakorn 1986; Pinyopusarerk and Boland 1987; Puriyakorn, et al. 1988 and Pinyopusarerk 1989). This paper reports growth and survival of the *Acacia* species 36 months after field establishment.

Materials and Methods

The trials were established at six locations selected to represent a range of climatic and geographic conditions in Thailand as detailed in Table 1. Seed for all plantings was supplied by CSIRO's Australian Tree Seed Centre. Details of seedlots are given in Table 2. The number of seedlots used at each site varied but most seedlots were planted at four to six

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Fig. 1. Location of 1985 trial sites in Thailand.

sites. Seedlings raised from these seedlots were grown in nurseries near each planting site. No inoculation with microorganisms was made.

Prior to the rainy season the trial sites were cleared, burned and disc-ploughed twice in cross directions. Herbicide (Roundup at 1:100 in aqueous solution) was sprayed over each planting spot two to three weeks before planting. The trials were laid out in a randomised complete block design with three replicates. Each treatment comprised 25 trees arranged in a plot of 5 × 5 trees at a 2 × 2 m spacing. Field planting took place during June-August 1985 at each site. Seedlings were approximately 6 months old from germination to outplanting. Following cultivation, 50 g of a complete fertiliser (15-15-15) was given once to each plant one month after planting and at the beginning of the rainy season in the second year. Weed competition in the trial areas was kept to a minimum by frequent application of slash-weeding or chemical spraying. Frequency of weed control was on an as-required basis.

All trees were measured for height growth, diameter at breast height (dbh) and survival, every 6 months after planting until 3 years. Analyses of variance were made for plot-mean data at each planting site, and F-test used to test the significance of differences between seedlot means. For survival, arcsin transformations were applied before analysis. Duncan's new multiple range test procedure (Duncan 1955 outlined in Steel and Torrie 1981) was used to test the significance of the differences between seedlot means.

Table 1. Climatic and site details for Australian tree species trials in Thailand.

Trial site	Lat (°N)	Long (°E)	Alt (m)	Mean annual rainfall (mm)	Mean annual temperature (°C)			Soil type
					Max.	Min.	Av.	
1. Ratchaburi Experiment Station, Ratchaburi	13°25′	99°50′	30	800	30.5	23.5	29.3	Red yellow lateritic, sandy loam; pH 4.9–5.2
2. Sai Thong Experiment Station, Prachuap Khiri Khan	11°25′	99°27′	50	1500	34.1	20.2	27.2	Red yellow podzolic; sand, loamy sand, sandy clay loam; pH 4.9
3. Huai Tha Experiment Station, Si Sa Ket	14°53′	104°27′	130	1200	31.6	22.9	27.3	Low humic grey; sandy loam; pH 4.4–5.4
4. Sakaerat Thai/Japan Project, Nakorn Ratchasima	14°13′	101°55′	550	1200	31	20.7	25.9	Red yellow podzolic; loam, clay loam; pH 4.9–5.2
5. Khao Soi Dao Seed Orchard, Chanthaburi	13° 0′	102°15′	200	1300	32.6	21.4	27	Grey podzolic; sandy loam, sandy clay loam; pH 6.2
6. Huai Bong Experiment Station, Chiang Mai	18°10′	98°25′	880	1000	29.8	18.2	24	Lateritic; loamy sand, sandy loam; pH 5.5–5.6

Results

Height growth

Analysis of data (Table 3) indicated that there were significant differences in height growth between seedlots of the same species and between trial sites. The species that showed the best height growth at age 3 years in all experimental sites except Chantaburi and Huai Bong was *A. crassicarpa* which had heights of 14.8 m, 10.2 m, 9.7 m and 8.7 m at Sai Thong, SiSaKet, Sakaerat and Ratchaburi respectively.

Next in height growth were *A. auriculiformis, A. difficilis* (which was planted only at Ratchaburi and Sai Thong), *A. aulacocarpa, A. leptocarpa, A. holosericea* and *A. mangium*. However, in Chanthaburi and Huai Bong trial sites, most *Acacia* species grew slowly except *A. aulacocarpa* (13688) and *A. auriculiformis* (13861) which showed acceptable height growth of 6.5 m and 5.2 m respectively.

The species with the lowest height growth in these trials were *A. cincinnata, A. aulacocarpa* (seedlots 13866, 13877), *A. shirleyi, A. melanoxylon* and *A. polystachya*.

Comparison of height growth data 6, 12 and 24 months after planting showed a consistent trend in height growth of all species. Those species which grew vigorously at the early stage of the field trials were still growing very well.

Diameter growth

Diameter growth of *Acacia* species also showed significant differences within species and between trial sites (Table 4). The general trend of diameter growth corresponded closely with height growth. At 36 months after planting, *A. crassicarpa* had the best diameter growth in all trial sites except Chanthaburi and Huai Bong where *A. auriculiformis*, seedlots 13854 and 13861, were the best, respectively. Other species with fast diameter growth were *A. auriculiformis* (13684, 13686), *A. difficilis, A. leptocarpa, A. aulacocarpa* (13688, 13689), *A. mangium* and *A. holosericea.*

Acacia species which grew slowly in diameter at almost all trial sites were *A. melanoxylon, A. polystachya, A. shirleyi* and *A. cincinnata*. However, *A. cincinnata* still showed satisfactory diameter growth at Sakaerat trial site.

Table 2. Origin data for Australian seedlots used in field trials in Thailand.

	CSIRO seedlot number	No. of parent trees in collection	Location	Lat. (S)	Long. (E)	Alt. (m)
1985 Planting						
Acacia						
aulacocarpa	13688	6	Keru, PNG	8°32′	141°45′	40
aulacocarpa	13689	5	Oriomo River, PNG	8°48′	143° 9′	20
aulacocarpa	13866	6	Garioch, QLD	16°40′	145°18′	400
aulacocarpa	13877	10	Julatten Area, QLD	16°35′	145°25′	410
auriculiformis	13684	17	Balamuk, PNG	8°54′	141°18′	18
auriculiformis	13686	10	Iokwa, PNG	8°41′	141°29′	35
auriculiformis	13854	200	Oenpelli, NT	12°20′	133° 4′	50
auriculiformis	13861	4	Springvale Holding, QLD	15°50′	144°55′	150
cincinnata	13864	5	Shoteel, QLD	16°57′	145°38′	440
crassicarpa	13680	21	Wemenever, PNG	8°51′	141°26′	30
crassicarpa	13681	10	Mata, PNG	8°40′	141°45′	30
crassicarpa	13683	15	Woroi Wipim, PNG	8°49′	143° 0′	20
crassicarpa	13863	5	Shoteel, QLD	16°57′	145°38′	440
difficilis	14623	41	Daly Waters, NT	16°21′	133°22′	235
flavescens	14175	9	Mt. Molloy, QLD	16°40′	145°18′	400
holosericea	14660	26	Turkey Creek, WA	17° 4′	128°12′	400
leptocarpa	13653	1	Starcke Holding, QLD	14°16′	144°26′	2
leptocarpa	13691	4	Woroi Wipim, PNG	8°52′	143° 3′	30
mangium	13621	9	Piru, Ceram, Indonesia	3° 4′	128°12′	150
mangium	13846	75	Mossman, QLD	16°31′	145°24′	60
melanoxylon	14176	10	Atherton, QLD	17°17′	145°26′	1002
polystachya	13871	4	Bridle, L.A., QLD	16°58′	145°37′	480
shirleyi	14622	10	Daly Waters, NT	16°19′	133°23′	255

Table 3. Mean height growth (m) of *Acacia* species and provenance trials in Thailand at age 36 months.

Species	Seedlot	Ratchaburi	Sai Thong	SiSaKet	Sakaerat	Chanthaburi	Huai Bong
Acacia							
aulacocarpa	13688	6.4 cd	11.4 cdef	8.2 bcd	6.9 de	6.5 a	3.2 c
	13689	6.4 cd	11.3 def	8.4 bc	8.0 b	5.4 abc	3.8 b
	13866	4.9 ef	6.3 ijk	5.0 fg	4.8 hi	3.5 de	2.7 cd
	13877	4.9 ef	7.1 hijk	4.3 gh	5.4 gh	2.5 e	1.8 ef
auriculiformis	13854	5.6 def	11.8 cde	9.1 abc	7.8 bc	6.3 ab	4.8 a
	13861	6.0 de	11.7 cde	8.9 abc	8.2 b	6.3 ab	5.2 a
	13684	7.3 bc	12.3 cd	9.0 abc	8.5 b	6.2 ab	4.1 b
	13686	7.5 abc	12.4 cd	—	—	—	—
cincinnata	13864	4.6 f	7.7 ghi	4.3 gh	6.9 de	2.8 e	—
crassicarpa	13863	5.8 def	10.5 ef	9.5 ab	7.1 cd	—	—
	13681	8.0 ab	12.8 bc	9.5 ab	9.3 a	—	3.8 b
	13683	8.7 a	14.8 a	10.2 a	9.7 a	4.8 abcd	—
	13680	8.7 a	13.9 ab	9.2 abc	—	4.7 bcd	—
difficilis	14623	8.0 ab	8.6 g	—	—	—	—
flavescens	14175	5.8 def	8.4 gh	5.0 fg	4.6 ig	2.3 e	—
holosericea	14660	7.7 ab	8.8 g	5.8 ef	6.5 def	4.6 bcd	3.9 b
leptocarpa	13653	6.8 bcd	10.2 f	7.8 cd	6.3 ef	4.7 bcd	2.6 d
	13691	7.5 abc	11.7 cde	8.8 bc	—	3.8 cde	2.2 de
mangium	13621	6.1 cd	7.4 ghij	5.4 fg	3.5 kl	3.4 de	1.3 g
	13846	7.2 bc	8.7 g	6.8 de	5.9 fg	3.8 cde	—
melanoxylon	14176	—	5.9 k	—	2.3 m	—	1.6 fg
polystachya	13871	3.4 f	6.1 jk	3.4 h	3.0 lm	2.4 e	1.4 fg
shirleyi	14622	6.2 cd	—	5.3 fg	3.9 gk	—	—
Grand mean		6.5	10.0	7.2	6.3	4.4	3.0
F-test (seedlots)		13.73***	38.12***	24.893***	78.725***	7.441***	69.504***

*** indicate significance at the 0.1% level. Means followed by the same letter are not significantly different ($p<0.05$) by Duncan's Multiple Range Test.

Comparison of diameter growth data at 6, 12 and 24 months after planting also showed the same trend as in height growth; those which grew vigorously at the early stage of the field trial were still producing the best diameter growth.

Survival

Analysis of survival data (Table 5) indicated that there were significant differences between species at almost all trial sites, except at SiSaKet which showed no significant difference between species. The species that showed the best survival was *A. auriculiformis* (13861). Next in survival were *A. aulacocarpa* and *A. crassicarpa* while the species with the lowest survival were *A. melanoxylon* and *A. shirleyi*. Survival was lowest at the Chanthaburi and Huai Bong sites.

Discussions and Conclusions

There were marked differences in all growth parameters. Furthermore, differences in growth between provenances of the same species were also highly significant. *Acacia crassicarpa* (13683) was the most vigorous species and exhibited impressive growth performance in all trial sites. Other fast-growing species were *A. auriculiformis* (13684) and *A. aulacocarpa* (13689) both from Papua New Guinea.

Some species grew well at particular planting sites, e.g. *A. difficilis* (14623) at Ratchaburi, *A. leptocarpa* (13653, 13691) at SiSaKet, and *A. cincinnata* at Sakaerat. *A. holosericea* (14660) and *A. mangium* (13846) also grew satisfactorily. The slowest growing species were *A. shirleyi* (14622), *A. melanoxylon* (14176), *A. polystachya* (13871), *A. aulacocarpa* (13866, 13877) from Queensland and *A. cincinnata* (13864).

Major differences were observed between provenances of *A. aulacocarpa*. Provenances from Papua New Guinea grew much faster than those from northern Queensland, they also had many individual trees of excellent stem form and strong apical dominance.

The superior growth rates of *A. crassicarpa, A. auriculiformis* and *A. aulacocarpa* compared with

Table 4. Mean dbh (cm) of *Acacia* species and provenance trials in Thailand at age 36 months.

Species	Seedlot	Ratchaburi	Sai Thong	SiSaKet	Sakaerat	Chanthaburi	Huai Bong
Acacia							
aulacocarpa	13688	6.8 bcde	10.1 efg	6.8 cd	6.5 cde	5.9 ab	2.6 e
	13689	6.6 bcdef	11.3 def	6.8 cd	7.3 bcd	5.3 abc	3.4 cd
	13866	5.1 gh	5.1 j	4.4 ef	5.2 g	2.3 de	1.4 fg
	13877	5.5 efgh	5.9 j	3.2 fg	5.8 efg	1.8 e	1.2 fg
auriculiformis	13854	5.5 efgh	9.8 fg	8.6 abc	8.0 ab	6.8 a	4.7 ab
	13861	5.4 fgh	9.0 gh	7.8 bc	7.4 bc	5.7 abc	5.3 a
	13684	6.9 abcde	12.0 cd	8.1 abc	8.6 a	6.1 ab	4.4 b
	13686	7.8 ab	11.5 de	—	—	—	—
cincinnata	13864	4.4 hi	5.8 j	3.8 fg	7.2 bcd	2.3 de	—
crassicarpa	13863	6.3 bcdefg	9.9 fg	9.5 ab	6.4 def	—	—
	13681	8.2 a	13.2 bc	9.9 a	7.7 ab	—	4.1 bc
	13683	8.3 a	14.9 a	9.3 ab	8.7 a	4.4 bcd	—
	13680	8.2 a	13.4 b	9.4 ab	—	4.0 bcd	—
difficilis	14623	7.3 abcd	7.6 hi	—	—	—	—
flavescens	14175	5.7 efgh	7.6 hi	4.9 ef	3.7 h	1.5 e	—
holosericea	14660	6.0 defg	6.2 ij	4.9 ef	5.2 g	3.0 de	2.8 de
leptocarpa	13653	6.0 defg	9.0 gh	8.3 abc	5.4 fg	3.9 bcd	1.9 f
	13691	6.5 bcdefg	9.5 g	7.4 cd	—	2.6 de	1.6 f
mangium	13621	6.2 cdefg	5.6 j	4.7 ef	2.7 i	2.2 e	0.8 g
	13846	7.6 abc	8.8 gh	5.9 de	5.8 efg	3.4 cde	—
melanoxylon	14176	—	4.7 j	—	1.2 j	—	0.6 g
polystachya	13871	3.5 i	4.9 j	2.1 g	2.2 i	1.8 e	0.7 g
shirleyi	14622	6.1 cdefg	—	4.5 ef	2.0 ij	—	—
Grand mean		6.4	8.9	6.5	5.6	3.7	2.5
F-test (seedlots)		7.763***	40.809***	18.555***	56.725***	6.415***	42.332***

*** indicate significance at the 0.1% level. Means followed by the same letter are not significantly different ($p < 0.05$) by Duncan's Multiple Range Test.

other *Acacia* species were consistent over the 36-month period and any changes in this trend are not anticipated. From a plantation forestry viewpoint, these species would be the outstanding candidates. However, marked variation between provenances such as that shown by *A. aulacocarpa* suggests that further provenance trials with a wider range of provenance material is necessary. Provenance trials of *A. auriculiformis* and *A. aulacocarpa* are already underway and will include *A. crassicarpa* as soon as seed becomes available. In addition, silvical characteristics (e.g. growth and yield) and response to silvicultural treatments (e.g. spacing and fertilisation) of these species are being investigated. Wood properties (physical and chemical), especially those of *A. crassicarpa* and *A. aulacocarpa*, need to be examined.

A. leptocarpa is moderate in growth rate, is frequently single-stemmed and has light branching. These characters are an advantage in agroforestry practice because they do not restrict intercropping. The potential use of *A. leptocarpa* as well as other nitrogen-fixing acacias in agroforestry should be examined.

Other slow-growing species, while not suitable as plantation species, may be utilised for other purposes. Trees of *A. polystachya* are generally multistemmed from ground level, very often as many as 7–8 stems. This species could be useful for Ratchaburi area where small-sized firewood is greatly needed for the potteries. *A. shirleyi* has a narrow crown and greyish-green phyllodes and looks very attractive especially when in full flowering period. This acacia would make an excellent ornamental for landscaping.

The results of these RFD-CSIRO field trials have indicated that if *Acacia* species are to be used in forest plantations, site conditions, species, and provenances should be carefully matched so that maximum growth and yield can be ensured. Mismatching of species and provenances to the prevailing site conditions will certainly produce poor plantations that cannot cover the cost of establishment.

Table 5. Mean survival arcsin % transformation of *Acacia* species and provenance trials in Thailand at age 36 months.

Species	Seedlot	Ratchaburi	Sai Thong	SiSaKet	Sakaerat	Chanthaburi	Huai Bong
Acacia							
aulacocarpa	13688	62.5 abcdefgh	80.7 abcd	82.3	81.1 ab	53.3 cde	66.9 bcd
	13689	66.0 abcdefg	57.8 def	86.2	74.4 abc	50.9 def	66.5 bcd
	13866	86.2 a	77.8 abcd	86.2	58.7 cde	49.4 def	69.9 bc
	13877	44.7 hi	47.0 fg	82.3	77.8 ab	33.3 f	51.0 e
auriculiformis	13854	82.1 ab	90.0 a	90.0	90.0 a	86.2 ab	86.2 a
	13861	78.3 abc	84.5 abc	90.0	90.0 a	90.0 a	90.0 a
	13684	76.7 abc	86.2 ab	90.0	90.0 a	43.0 ef	76.7 ab
	13686	69.6 abcdef	57.8 def	—	—	—	—
cincinnata	13864	24.3 i	50.4 efg	73.9	67.6 bcd	42.7 ef	—
crassicarpa	13863	50.2 defgh	73.7 abcde	82.3	76.7 ab	—	—
	13681	—	63.4 bcdef	77.3	71.1 bc	—	41.5 e
	13683	71.5 abcde	64.0 bcdef	84.5	75.7 ab	51.7 def	—
	13680	84.5 ab	86.3 ab	84.5	—	42.3 ef	—
difficilis	14623	73.0 abcd	65.9 bcdef	—	—	—	—
flavescens	14175	61.1 bcdefgh	45.1 fg	86.2	48.2 ef	43.8 ef	—
holosericea	14660	73.9 abcd	—	43.7	67.9 bcd	67.5 cd	23.1 f
leptocarpa	13653	80.7 abc	66.8 abcdef	78.5	73.4 abc	71.5 bc	44.6 e
	13691	48.1 efgh	61.54 cdef	86.2	—	63.3 cd	55.7 cde
mangium	13621	46.1 fghi	52.4 ef	75.4	55.7 de	36.0 ef	18.3 f
	13846	57.4 cdefgh	71.8 abcde	82.3	76.5 ab	54.8 cde	—
melanoxylon	14176	—	29.4 g	—	43.8 ef	—	23.4 f
polystachya	13871	86.2 a	66.7 abcdef	80.7	69.6 bcd	66.6 cd	53.2 de
shirleyi	14622	40.0 hi	—	80.7	35.5 f	—	—
Grand mean		65.5	65.534	83.12	69.7	55.7	54.8
F-test (seedlots)		5.634***	4.729***	1.219NS	9.976***	8.272***	26.435

*** indicates significance at the 0.1% level. NS indicates not significant at the 5% level. Means followed by the same letter are not significantly different ($p<0.05$) by Duncan's Multiple Range Test.

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References

Pinyopusarerk, K. and Puriyakorn, B. 1986. Acacia species and provenance trials in Thailand. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, 143–146.

Pinyopusarerk, K. and Boland, D.J. 1987. Assessment of early growth of some Australian acacia and casuarina species in field trials in Thailand. Paper presented to a Workshop on the Contribution of Biological Nitrogen Fixation to Plant Production 3–7 August 1987. Bogor, Indonesia.

Puriyakorn, B., Pinyopusarerk, K. and Luangviriyasaeng, V. 1988. Assessment of Early Growth of Australian Tree Species Trials in Thailand. Paper presented to the Fourth Seminar on Silviculture 18–22 January 1988. Pattaya, Thailand.

Steel, R.G. and Torrie, J.H. 1981. Principles and Procedures of Statistics, McGraw-Hill Book Company, Singapore, 633 p.

Performance of *Acacia* Species on Four Sites of Sabah Forest Industries

Sim Boon Liang and Edmund Gan*

Abstract

Results on fourth year assessment of mortality, height, diameter and wood density (using a PILODYN wood tester), and stem borer attack on 16 provenances of five *Acacia* species at four sites are discussed.

In general, all five acacias grew faster on well drained, deep, loamy soil and weed-free sites. Under these ideal conditions, *A. mangium* and *A. crassicarpa* were superior to the others in terms of height and diameter. On weedy sites and shallow, sandy soils *A. crassicarpa* outperformed *A. mangium* and almost all provenances of the other species. At the highland site all species were comparable, except *A. auriculiformis*, which generally fared less well.

Estimates of the adaptability and stability parameters suggested that *A. crassicarpa* was the most suitable species over the four test localities. Although superior in growth, *A. crassicarpa* had the disadvantage of being highly susceptible to stem (pinhole) borer attack. At the provenance level, the PNG provenances of *A. auriculiformis* and *A. mangium* were faster growing than the local seed sources.

Estimation of wood density using the PILODYN suggested that *A. auriculiformis*, *A. aulacocarpa* and *A. mearnsii* have higher wood densities than *A. mangium*. Wood density varied with site and appeared to be higher on good sites where diameter growth was faster.

Acacia mangium originates from the humid tropics of northern Australia, Papua New Guinea and eastern Indonesia. Since its introduction to Sabah, Malaysia in 1966, it has become an important plantation species. On poor sites, such as eroded, rocky, thin mineral, acidic soils and hillslopes infested with weeds, it notably outperformed other species such as *Gmelina arborea* and *Eucalyptus deglupta*, both of which are among the most rapidly growing trees in the humid tropics (National Research Council 1983).

Because of the successful introduction of *A. mangium*, keen interest was generated to test the suitability of other related acacias such as *A. aulacocarpa, A. crassicarpa* and *A. auriculiformis*. These species appear to be adaptable, colonising species which may grow well on poor soils. Hence, they may provide alternatives to *A. mangium* when there is a need to alleviate the underlying dangers of monoculture. Since there is limited experience with these species, this trial was established to test them on a range of sites.

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Materials and Methods

Provenance seedlots of the five species were obtained from the CSIRO Division of Forestry in Canberra, from the Forest Research Centre and Sabah Softwood in Sabah, from South Africa and by collection from exotic stands in Sabah. Details of seedlots are given in Table 1.

Trial sites

The four trial sites represent a range of environmental conditions found within the Sabah Forest Industries (SFI) boundaries. A description of the sites is given in Table 2.

The series of sites varies in the following characteristics: altitude, temperature, soil and ground weed.

Experimental design

A randomised complete block design (RCB) with 16-tree square plots was employed at all four trial sites. Four replicates were planted at each site at 3 × 3 m spacing.

Table 1. *Acacia* species and provenances.

Species	Provenance	Latitude	Longitude	Altitude (m)
A. mangium	PNG	—	—	—
A. mangium	Tawau, Sabah	4°25 'N	118°00 'E	—
A. mangium	Tamparuli, Sabah	6°10 'N	116°20 'E	600
A. auriculiformis	Balamuk, PNG	8°54 'S	141°18 'E	18
A. auriculiformis	Iokwa, PNG	8°41 'S	141°29 'E	35
A. auriculiformis	Bula, PNG	9°09 'S	141°20 'E	5
A. auriculiformis	Yigo, Guam	16°35 'N	45°25 'W	450
A. auriculiformis	Sepilok, Sabah	—	—	—
A. crassicarpa	Wemenever, PNG	8°42 'S	141°24 'E	30
A. crassicarpa	Mata, PNG	8°40 'S	141°45 'E	30
A. crassicarpa	Oriomo, PNG	8°49 'S	143°09 'E	20
A. crassicarpa	Woroi/Wipim, PNG	8°49 'S	143°00 'E	20
A. aulacocarpa	Keru, PNG	8°32 'S	141°45 'E	40
A. aulacocarpa	Oriomo, PNG	8°48 'S	143°09 'E	20
A. aulacocarpa	Iokwa, PNG	8°41 'S	141°29 'E	35
A. mearnsii	South Africa	—	—	—

Table 2. Site characteristics.

Site characteristics	Site A	Site B	Site C	Site D
Altitude (m)	100	500	650	1300
Mean annual rainfall (mm)	3100	3100	3200	2000
Mean annual temperature (°C)				
max	32	28	32	25
min	21	21	21	15
Local relief	slope	flat	ridge top	slope
Aspect	NW	E	SE	SW
Parent material	mudstone/sandstone	sandstone	mudstone/sandstone	mudstone/sandstone
Soil family	Kumansi	Kapilit	Kumansi	Kumansi
Soil texture				
Surface	clay	sandy loam	clay	sandy clay loam
Subsurface	clay loam	sandy clay loam	clay loam	clay
Soil depth (cm)	>100	<100	>100	>100
Soil pH	4.9–5.6	4.7–5.1	4.1–5.3	4.3–5.1
Drainage	free draining	free draining, surface runoff	free draining	free draining
Ground conditions prior to planting	weedy	weedy	clean	clean

Assessments

Height, stem diameter at 1.3 m and percentage mortality were assessed each year. In the fourth year, the incidence of stem (pinhole) borer attack was also assessed and the wood density was measured using a PILODYN.

Statistical analysis

Arithmetic means were calculated for all measured traits by provenance. Analysis of variance was done for each site as well as for all sites combined. In the analysis, block effects within sites were not considered, owing to the unbalanced nature resulting from dead or missing trees.

For all four tests, regressions of the mean performance for any single trait of a provenance at each location were established on the mean performance of all provenances at each location. By means of this regression analysis, genotype × environment interactions may be broken down into different components — one involving adaptation and the other stability. In this study, the techniques of Finlay and Wilkinson (1963) and Eberhart and Russell (1966) were used, i.e., the regression coefficient b is used to measure adaptation while the variance of the mean square of deviations from regression, S^2d, is used to estimate relative stability. However, as the coefficient of determination, r^2, accomplishes essentially the same purpose, it is used to substitute for S^2d in this study.

Results and Discussion

Mortality

The results are summarised in Table 3. Among the species, *A. mearnsii* showed the highest mortality particularly on lower altitude sites (site A and B). Differences between the other species were less significant.

The combined analysis over the four sites showed that there was a highly significant difference among the sites, accounting for 28% of the total variation. This was mainly the result of higher mortality of most of the species at site D where the trees were attacked by the brown root disease. Species/provenance difference was not significant at $P<0.01$.

Height

Over the four sites, *A. crassicarpa* had the highest mean height, indicating that the species has a better site tolerance. The superiority of this species over the others was most apparent on shallow, sandy soil (at site B). On such sites, *A. aulacocarpa* was also found to be generally superior to *A. mangium*.

The slower growing species included *A. auriculiformis* and *A. mearnsii*. Generally, *A. auriculiformis* was shorter on the good lowland and highland sites. The species appeared unable to keep up with the other acacias (i.e. *A. mangium, A. crassicarpa* and *A. aulacocarpa*) on favourable sites, although it could tolerate poor and harsh ground conditions. *A. mearnsii* was the poorest performer on all the lowland sites.

Although variations in height among the species were great, within-species differences were less significant. Among the four *A. crassicarpa* provenances, differences were not statistically significant. However, within the *A. mangium* and *A. auriculiformis* provenances, the superiority of the PNG provenances over the other exotic provenances was evident.

Table 3. Mortality at the four sites.

Species	Provenance	Mean mortality (%)			
		Site A	Site B	Site C	Site D
A. mangium	PNG	21	4	—	46
	Tawau, Sabah	50	12	21	48
	Tamparuli, Sabah	33	25	31	67
A. auriculiformis	Balamuk, PNG	35	10	8	44
	Iokwa, PNG	19	6	—	—
	Bula, PNG	33	6	48	—
	Yigo, Guam	21	6	19	58
	Sepilok, Sabah	52	4	14	77
A. crassicarpa	Wemenever, PNG	31	10	44	58
	Mata, PNG	52	14	44	58
	Oriomo, PNG	29	10	35	37
	Woroi/Wipim, PNG	35	21	25	37
A. aulacocarpa	Keru, PNG	25	17	37	—
	Oriomo, PNG	12	4	25	46
	Iokwa, PNG	25	4	35	58
A. mearnsii	South Africa	95	87	46	44
Overall mean		36	15	31	52
LSD ($P < 0.01$)		9	15.5	27.5	26.5

Among the four sites, height growth was generally better on the highland (site D). These results were in contrast to those obtained in the first year of measurement (Sim and Gan 1988).

The combined analysis of variance indicated insignificant site species/provenance (spp/prov) interaction at $P < 0.01$, with interaction contributing only 8% to the total variation. On the other hand, site and spp/prov effects over the 4 sites were more significant, accounting for 25 and 34% of the total variation respectively. A summary of the results is given in Table 4.

Table 4. Height at the four sites.

Species/Provenance	Mean ht (m)			
	Site A	Site B	Site C	Site D
Acacia mangium				
PNG	15.61	13.04	—	16.32
Tawau, Sabah	11.48	9.56	15.16	16.08
Tamparuli, Sabah	12.29	10.58	12.78	20.17
Acacia auriculiformis				
Balamuk, PNG	12.10	13.99	12.51	14.31
Iokwa, PNG	14.91	13.07	—	—
Bula, PNG	11.59	12.27	12.48	—
Yigo, Guam	10.85	9.42	10.76	12.69
Sepilok, Sabah	9.87	11.51	10.12	12.74
Acacia crassicarpa				
Wemenever, PNG	17.46	15.78	14.87	23.25
Mata, PNG	15.73	15.43	14.60	18.74
Oriomo, PNG	15.44	17.43	15.15	18.31
Woroi/Wipim, PNG	15.04	17.65	16.04	20.18
Acacia aulacocarpa				
Keru, PNG	14.03	14.71	12.51	—
Oriomo, PNG	13.93	16.26	14.19	15.69
Iokwa, PNG	11.59	14.23	12.55	15.98
Acacia mearnsii	7.93	9.67	8.21	16.89
Overall mean	13.23	13.49	13.00	17.14
LSD ($P < 0.01$)	3.84	3.12	2.38	7.06

Diameter

The results (given in Table 5) indicated that differences between the species were greatest at site B where the soil was shallow and sandy. On this site, the performance of *A. crassicarpa* was found to be much better than the other species. For instance, the Woroi/Wipim provenance grew twice as fast as the *A. mangium* (Tawau). The mean dbh of the *A. crassicarpa* (Woroi/Wipim) was 16.7 cm while that of the *A. mangium* (Tawau) was only 8.4 cm. In fact, all provenances of *A. crassicarpa*, except the Mata provenance, were significantly greater than the population average.

On the good lowland site (site C) however, *A. crassicarpa* did not outperform *A. mangium*. Both of these species were comparable.

On the highland, *A. auriculiformis* was found to be generally poorer than average, indicating that it might be less suited to the highlands than the other *Acacia* species tested.

Across the four sites, *A. crassicarpa* was again (as with height) the most impressive species, with all the represented provenances outperforming the population average by 1 LSD at $P \leqslant 0.01$. The poorest species was *A. mearnsii*.

The combined analysis of variance indicated that dbh appeared to be under greater genetic control than height over the four test localities. In this case, species/provenance differences accounted for almost half of the total variance and were highly significant. Site differences and interaction effect were also significant at $P \leqslant 0.01$, with the latter contributing almost twice as much to the total variation as the former.

Table 5. Diameter at the four sites.

Species/Provenance	Mean dbh (mm)			
	Site A	Site B	Site C	Site D
Acacia mangium				
PNG	132	128	—	149
Tawau, Sabah	91	84	180	142
Tamparuli, Sabah	98	80	148	144
Acacia auriculiformis				
Balamuk, PNG	102	121	125	110
Iokwa, PNG	138	129	—	—
Bula, PNG	109	132	145	—
Yigo, Guam	104	97	102	93
Sepilok, Sabah	82	109	93	79
Acacia crassicarpa				
Wemenever, PNG	150	160	185	153
Mata, PNG	134	150	175	147
Oriomo, PNG	141	160	189	162
Woroi/Wipim PNG	131	167	164	142
Acacia aulacocarpa				
Keru, PNG	120	137	136	—
Oriomo, PNG	118	124	141	117
Iokwa, PNG	114	121	134	123
Acacia mearnsii	60	71	76	137
Overall mean	115	124	142	132
LSD ($P < 0.01$)	37.2	30.6	30.5	31.6

Wood density

The analysis of variance showed that wood density was greatly influenced by site. In fact, site effect accounted for more than 50% of the total variance. In this case, the wood density (PILODYN reading) tended to be correlated with diameter growth. For instance, at site C where the diameter growth was fastest, the PILODYN reading was smaller, indicating higher wood density.

Species/provenances contributed 25% to the total variance. Though in most cases not statistically significant, *A. auriculiformis* and *A. mearnsii* had a lower PILODYN penetration than the other species. On the other hand, *A. mangium* had a higher pilodyn penetration compared to all other species, although the differences were not statistically significant in most instances. Within species, there were indications that the PNG provenances of both *A. mangium* and *A. auriculiformis* had a lower wood density than the other provenances (see Table 6).

Species/provenance site interaction was not significant.

Table 6. PILODYN readings at the four sites.

Species/Provenance	Mean penetration (mm)			
	Site A	Site B	Site C	Site D
Acacia mangium				
PNG	18.1	20.8	—	20.2
Tawau, Sabah	15.9	17.9	11.6	17.8
Tamparuli, Sabah	14.6	15.9	11.7	17.7
Acacia auriculiformis				
Balamuk, PNG	11.9	14.1	11.5	13.0
Iokwa, PNG	13.0	14.5	—	—
Bula, PNG	12.5	14.9	12.2	—
Yigo, Guam	11.0	11.8	8.9	13.7
Sepilok, Sabah	11.9	12.7	9.2	12.4
Acacia crassicarpa				
Wemenever, PNG	13.8	15.7	10.9	15.8
Mata, PNG	13.8	16.3	9.8	16.1
Oriomo, PNG	14.0	16.5	9.6	15.7
Woroi/Wipim, PNG	14.8	15.3	10.3	16.2
Acacia aulacocarpa				
Keru, PNG	12.3	12.7	10.9	—
Oriomo, PNG	12.9	14.3	10.8	13.7
Iokwa, PNG	12.2	13.6	9.9	14.2
Acacia mearnsii	10.0	10.1	8.7	13.7
Overall mean	13.4	14.9	10.4	15.4
LSD ($P < 0.01$)	2.6	2.0	2.0	2.4

Stem borer

The Chi-square test showed that differences of the species/provenances with regards to stem (pinhole) borer attack were statistically significant at the probability level of 99%. Among the species treated, *A. crassicarpa* and *A. mearnsii* were the most susceptible with more than 80% (averaged over the four sites) of the trees affected by the borer (Table 7). The intensity of attack was also more severe in these two species than in the others.

The effect of the stem borer did not appear to be influenced by site. There was also no apparent evidence of variations in the susceptibility of provenances within each of the species.

Table 7. Stem borer attack at the four sites.

Species/Provenance	Trees attacked (%)			
	Site A	Site B	Site C	Site D
Acacia mangium				
PNG	40	40	—	52
Tawau, Sabah	9	17	63	30
Tamparuli, Sabah	13	36	37	40
Acacia auriculiformis				
Balamuk, PNG	18	50	31	72
Iokwa, PNG	26	53	—	—
Bula, PNG	22	48	18	—
Yigo, Guam	19	23	32	31
Sepilok, Sabah	32	30	36	22
Acacia crassicarpa				
Wemenever, PNG	84	86	100	77
Mata, PNG	84	79	98	82
Oriomo, PNG	69	81	100	94
Woroi/Wipim, PNG	76	92	92	84
Acacia aulacocarpa				
Keru, PNG	44	55	52	—
Oriomo, PNG	49	46	52	31
Iokwa, PNG	59	32	47	26
Acacia mearnsii	100	92	73	92
Overall mean	45	53	60	58

Adaptability and stability

Adaptability and stability estimates for height and diameter are given in Table 8. These estimates were not calculated for mortality and PILODYN as their spp/prov x site interaction effects were not significant.

The adaptability estimate indicated that *A. auriculiformis* and *A. aulacocarpa* were generally less well adapted than the other species. This was because their performance, both in height and diameter, did not change much in proportion to the site. They had regression coefficients (b) of less than 1. *A. crassicarpa* and *A. mangium* showed good adaptability since their regression coefficients (b) for height and/or dbh were greater than 1. However, *A. crassicarpa* had the highest mean height and dbh (Table 9) and would be considered well adapted to all four test sites. *A. mearnsii* showed average adaptability.

The stability estimate (using r^2) showed that height had a greater stability (i.e. predictability of performance of a genotype in various environments) than dbh. All species tended to appear stable over the four sites for height growth. However height is not a good indicator of stability for these acacias. But in terms of dbh, *A. crassicarpa*, *A. mangium* and *A. aulacocarpa* were found to be more outstanding than the others. All provenances of these three species showed higher than average r^2 values. But among them, only *A. crassicarpa* was considered to be both stable and well-adapted (high b, r^2, dbh/ht) while *A. mangium* and *A. aulacocarpa* were stable but not as well-adapted (high b, r^2, lower dbh/ht).

All provenances of *A. auriculiformis* and *A. mearnsii* exhibited poor stability.

Table 8. Adaptability (b) and stability (r^2) estimates for height and diameter at the four sites.

Species	Provenance	Height		Diameter	
		b	r^2	b	r^2
A. mangium	Tawau, Sabah	0.89	0.34	3.21	0.86
	Tamparuli, Sabah	1.97	0.88	2.06	0.64
A. auriculiformis	Balamuk, PNG	0.41	0.76	0.60	0.55
	Yigo, Guam	0.53	0.64	−0.05	0.02
	Sepilok, Sabah	0.60	0.82	0.04	0.002
A. crassicarpa	Wemenever, PNG	1.74	0.88	1.01	0.70
	Mata, PNG	0.85	0.91	1.22	0.88
	Oriomo, PNG	0.62	0.68	1.48	0.95
	Woroi/Wipim, PNG	1.03	0.87	0.77	0.34
A. aulacocarpa	Oriomo, PNG	0.29	0.36	0.64	0.58
	Iokwa, PNG	0.85	0.79	0.62	0.97
A. mearnsii	South Africa	2.08	0.99	0.96	0.13

Table 9. Provenance means across the four sites.

Species	Provenance	Mean across the four sites				
		Mortality (%)	Ht (m)	Dbh (mm)	Pilodyn (mm)	Borer (%)
A. mangium	Tawau, Sabah	32	13.1	124	15.8	30
	Tamparuli, Sabah	39	13.9	118	15.0	31
A. auriculiformis	Balamuk, Sabah	21	13.2	115	12.6	43
	Yigo, Guam	24	10.8	100	11.2	26
	Sepilok, Sabah	32	11.0	91	11.5	30
A. crassicarpa	Wemenever, PNG	32	17.8	162	14.0	87
	Mata, PNG	41	16.1	152	14.0	86
	Oriomo, PNG	27	16.6	163	14.0	86
	Woroi/Wipim, PNG	28	17.2	151	14.2	86
A. aulacocarpa	Oriomo, PNG	19	15.0	126	12.9	44
	Iokwa, PNG	24	13.6	123	12.5	41
A. mearnsii	South Africa	74	11.0	90	10.7	89
Overall mean		32	14.2	127	13.2	57
LSD ($P < 0.01$)		11	3.22	12.7	2.4	—

Conclusions

The results of the trial showed that the performance of the acacias varied considerably with the site conditions. All the species tested grew faster on weed-free sites with deep, well drained and loamy/clayey soil. Growth was slower on weedy sites and where the soil was shallow and sandy.

Among the species tested, *A. crassicarpa* appeared to be the most vigorous for both diameter and height growth. The estimates of adaptability and stability suggested that this species was best for all four test locations. Its superiority to the other species was most significant on shallow soil, where it outperformed *A. mangium*. However, the species did not outperform *A. mangium* on a site were the soil was deep and the ground was relatively weed-free. But compared to *A. mangium*, it appears to have a higher wood density.

Although *A. crassicarpa* was superior in growth, it had the disadvantage of being highly susceptible to stem (pinhole) borer attack. All other species, except *A. mearnsii*, were less prone and only lightly affected.

A. aulacocarpa, *A. auriculiformis* and *A. mearnsii* were generally slower growing and less well adapted. *A. aulacocarpa* and *A. auriculiformis* were particularly poor on the highland while the opposite was true for *A. mearnsii*. These three species, however, may have the virtue of relatively higher wood density.

Provenance differences within each of the species were mostly statistically insignificant. Exceptions were the superior vigour of the PNG provenances of *A. mangium* and *A. auriculiformis* as compared to the original Sabah source.

Apart from *A. mearnsii*, mortality rate did not vary a great deal among the species. But for all the species except *A. mearnsii* mortality was significantly higher on the highland site than on the three lowland localities. This higher mortality may be due to the presence of brown root disease at the highland site. *A. mearnsii* was the only species that showed better survival on the highland than the lowland.

References

Eberhart, S.A. and Russell, W.A. 1966. Stability parameters for comparing varieties, Crop. Sci., 6, 36–40.

Finlay, K.W. and Wilkinson, G.N. 1963. The analysis of adaptation in plant breeding programme, Aust. J. Agric. Res., 14, 742–754.

National Research Council 1983. *Mangium* and other fast-growing Acacias for the humid tropics, National Academy Press, Washington, D.C., 62 p.

Sim, B.L. and Gan, E. 1988. Comparative growth of five tropical Acacias on four different sites in Sabah, Commonw. For. Rev. 67 (2), 149–158.

Acacia Species and Provenance Trials in Uplands of Sri Lanka

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Abstract

Two trials were conducted in Badulla District of Sri Lanka which included *Acacia* and other Australian species. Trials were established in 1984 and 1985 and results obtained at 30 months and onwards are described in the paper. Of the species tested in these trials, *A. glaucocarpa, A. crassicarpa, A. parramattensis, A. mearnsii, A. melanoxylon, A. auriculiformis* and *A. mangium* had promising growth rates under prevailing climatic conditions.

Acacia species have been introduced to Sri Lanka as far back as the 1870s. The main species introduced during these times were *A. decurrens, A. melanoxylon, A. mearnsii,* which were planted in upland areas. Subsequently *A. mangium* and *A. auriculiformis* were introduced in the 1980s and presently these species are being used in reforestation and agroforestry programs. In recent years, several new *Acacia* species were tested in field trials under the Community Forestry Project which was started in 1982. Several species and provenance trials including *Acacia* species were established under the project in different climatic conditions. Some of the *Acacia* species tested were found to have fast growth rates and easy establishment. Their performance after field establishment is reported in this paper.

Trial Design and Establishment

The results of two trials are reported here and those trials included *Acacia* and other species as well. Only the performance of *Acacia* species is described here. A list of species tested is given in Table 1. The details of the trials are given below.

Trial 1 at Pitamaruwa

The elevation of the trial site was around 1160 m with a rainfall of about 1580 mm. The trial was planted in December 1985. Experimental design was RCB with four replicates. Each plot contained 25 plants at 2 × 2 m spacing.

Trial 2 at Meegahakiula

The elevation of the trial site was about 225 m with a rainfall of ca. 1600 mm. The trial was planted in December 1984. The experimental design was RCB with three replicates. Each plot consisted of a single row having 15 plants at 2 m spacing. The spacing between rows was 2 m.

In both trials, seeds of different species were pretreated with boiling water for about 1 minute and soaked in normal water overnight before planting in polythene tubes. NPK fertiliser was applied after field planting at the rate of 30 g per plant.

The trees in the plots were measured for height growth and diameter. It should be noted that apart from *Acacia* species other species were also present in the trial and statistical analysis was carried out with all these species in combination, and comparisons were done in relation to the performance of all species. Therefore statistical analysis is not presented here and instead, only the performance of species are given.

Results and Discussion

Tree height and diameter at breast height (dbh) are given in Table 2.

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Table 1. Details of seed sources of *Acacia* species and provenances tested.

CSIRO Seedlot number	Species	Locality	Latitude (°S)	Longitude (°E)	Altitude (m)
Pitamaruwa trial					
13854	*A. auriculiformis*	Oenpelli area, NT	12°20′	133°04′	50
13684	*A. auriculiformis*	Balamuk, PNG	8°54′	141°18′	18
13229	*A. mangium*	Claudie River, QLD	12°44′	143°13′	60
13846	*A. mangium*	Mossman, QLD	16°31′	145°24′	60
13683	*A. crassicarpa*	Woroi Wipim, PNG	8°49′	143°00′	20
13681	*A. crassicarpa*	Mata, PNG	8°40′	141°45′	30
13865	*A. aulacocarpa*	Buckley L.A., QLD	17°09′	145°37′	720
13871	*A. polystachya*	Bridle L.A., QLD	16°58′	145°37′	480
14766	*A. melanoxylon*	Samford, QLD	27°22′	152°47′	300
14176	*A. melanoxylon*	Atherton, QLD	17°17′	145°26′	1022
14749	*A. deanii*	Kogan, QLD	27°04′	150°50′	360
14726	*A. decurrens*	Goulburn, NSW	34°53′	149°17′	685
14763	*A. glaucocarpa*	Blackdown Tableland, QLD	23°51′	149°51′	840
14725	*A. mearnsii*	Bungendore, NSW	35°12′	149°32′	760
14416	*A. mearnsii*	Dargo, VIC	37°28′	147°15′	200
14770	*A. mearnsii*	Polacks Flat Ck, NSW	36°39′	149°35′	260
14395	*A. mearnsii*	Lake George, NSW	35°15′	149°20′	700
14723	*A. parramattensis*	Bungendore, NSW	35°19′	149°25′	730
14773	*A. silvestris*	Bombala, NSW	36°49′	149°00′	800
14741	*A. polybotrya*	Turalin, QLD	27°51′	151°13′	420
Meegahakiula trial					
13846	*A. mangium*	Mossman, QLD	16°31′	145°24′	60
13862	*A. auriculiformis*	Normanby River, QLD	15°50′	145°00′	500
13681	*A. crassicarpa*	Mata, PNG	8°40′	141°45′	30
13653	*A. leptocarpa*	Starcke Holding, QLD	14°16′	144°26′	2
13871	*A. polystachya*	Bridle L.A., QLD	16°58′	145°37′	480
13654	*A. oraria*	Starcke Holding, QLD	14°16′	144°26′	1
13957	*A. cincinnata*	Yungaburra, QLD	17°16′	145°35′	750
13959	*A. aulacocarpa*	Yungaburra, QLD	17°16′	145°35′	750
13870	*A. flavescens*	Brooklyn, QLD	16°36′	145°13′	360
13875	*A. rothii*	Jackey Jackey, QLD	10°56′	142°27′	20

NT — Northern Territory; QLD — Queensland; NSW — New South Wales; VIC — Victoria; PNG — Papua New Guinea

Trial 1 at Pitamaruwa

The trial was conducted on degraded land in the highland area which had a cover of mana grass (*Cymbopogan confertiflorus*) before planting. It was interesting to note that some newly introduced species performed extremely well compared to commonly used species. The best performance in terms of height and diameter was recorded in *A. glaucocarpa* from Blackdown, Qld which reached more than 5 m in height and about 4.5 cm in dbh at 2.5 years. This growth rate at this age was not achieved by other species such as eucalypts. At 5 years the species had reached 10 m height. The distribution of *A. glaucocarpa* in Australia is reported to be confined to warm subhumid climatic zone (Turnbull 1986) and the existing climate in the area seems to have been favourable for this species.

The other promising species recorded in the trial was *A. crassicarpa* which is also an uncommon species in Sri Lanka. Of the two provenances tested in this species Woroi Wipim provenance from Papua New Guinea was superior to the Mata provenance of the same country. In another plot which was planted as an arboretum of *Acacia* species (results are not presented in this paper) *A. crassicarpa* was recorded as the best species in height as well as diameter growth at breast height at the same age of 2.5 years. However, there were marked provenance differences in this species, and the provenance from Cooktown, Qld was the best in the arboretum plot, surpassing the growth of common *Acacia* species such as *A. mangium* and *A. auriculiformis*. Growth rate of *A. parramattensis* was similar to *A. crassicarpa* provenance tested in this trial, which is another species not commonly planted in uplands.

The other species which recorded better performance in this trial were *A. mearnsii*, *A. melanoxylon* and *A. mangium*. Moderate growth was shown by *A. auriculiformis* and *A. decurrens* and poor growth rates were recorded in *A. aulacocarpa, A. polystachya, A. deanii* and *A. silvestris*. *A. polybotrya* had very poor survival. Species such as *A. aulacocarpa* and *A. polystachya* are reported as some of the few *Acacia* species associated with rainforests (Turnbull 1986) and probably they did not tolerate the fairly dry and cold climate in the trial area. Between 2.5 and 5.0 years of age, most species in this trial doubled in height.

Table 2. Growth of *Acacia* species tested at age 2.5 years.

CSIRO Seedlot number	Species	Height (m)	Diameter at breast height (cm)
Pitamaruwa trial			
13854	*A. auriculiformis*	3.15	2.6
13684	*A. auriculiformis*	3.06	2.5
13229	*A. mangium*	3.58	4.5
13846	*A. mangium*	3.31	3.5
13683	*A. crassicarpa*	3.92	3.6
13681	*A. crassicarpa*	3.26	3.0
13865	*A. aulacocarpa*	2.21	(not measured)
13871	*A. polystachya*	1.91	(not measured)
14766	*A. melanoxylon*	3.51	3.4
14176	*A. melanoxylon*	2.53	2.4
14749	*A. deanii*	2.98	1.9
14726	*A. decurrens*	3.11	2.6
14763	*A. glaucocarpa*	5.23	4.5
14725	*A. mearnsii*	3.91	3.3
14416	*A. mearnsii*	3.70	2.9
14770	*A. mearnsii*	3.67	3.7
14395	*A. mearnsii*	3.38	3.0
14723	*A. parramattensis*	3.97	3.8
14773	*A. silvestris*	2.03	—
14741	*A. polybotrya*	(very poor survival)	
Meegahakiula trial			
13846	*A. mangium*	6.55	7.6
13862	*A. auriculiformis*	6.50	7.9
13681	*A. crassicarpa*	6.50	7.2
13653	*A. leptocarpa*	4.65	4.5
13871	*A. polystachya*	3.15	2.1
13654	*A. oraria*	2.55	2.7
13957	*A. cincinnata*	very poor survival and growth	
13959	*A. aulacocarpa*	very poor survival and growth	
13870	*A. flavescens*	very poor survival and growth	
13875	*A. rothii*	very poor survival and growth	

Trial 2 at Meegahakiula

Meegahakiula trial was conducted at low elevation and under warm climatic conditions compared to the previous trial at Pitamaruwa. The site was infested with Gini grass (*Panicum maximum*) which is a troublesome weed in reforestation areas. The growth rates were recorded at 2.5 and 3.5 years of age. Growth data in both trials were comparable at 2.5 years.

In this trial *A. mangium, A. auriculiformis* and *A. crassicarpa* performed equally well and they were superior among the species tested (Table 2). Only one provenance was tested from each of these species. Provenances of *A. mangium* (13846) and *A. crassicarpa* (13681) which were tested in this trial were recorded to be inferior among other respective provenances of same species in Pitamaruwa trial. However, their performance was superior in Meegahakiula trial compared to Pitamaruwa trial. There were marked differences in height and diameter in these three species at the two sites, with almost twice the growth rates recorded in Meegahakiula trial. Superior height and diameter growth rates at Meegahakiula site clearly indicates *A. mangium*, *A. auriculiformis* and *A. crassicarpa* are better adapted to the warm climate of this site. Midgley and Vivekanandan (1987) reported that *A. mangium* had an unexpected drought tolerance in this trial area, which experiences a long (7 months) dry season. *A. leptocarpa*, *A. polystachya* and *A. oraria* had moderate growth rates.

Very poor survival and growth rates were recorded in *A. cincinnata, A. aulacocarpa* and *A. flavescens*. Poor growth rates may be attributed to their inherent characteristics or to long dry periods existing in the area. *A. cincinnata* which is reported to be a rainforest species may need a well distributed rainfall which was not characteristic of the trial area.

Conclusions

Both trials indicate that certain species have promising growth rates at 2.5, 3.5 and 5.0 years age. These species can potentially be used for reforestation in degraded lands under appropriate climatic conditions. Accordingly *A. glaucocarpa, A. crassicarpa, A. parramattensis, A. mearnsii, A. melanoxylon* and *A. mangium* could be selected for elevations around 1100 m with a rainfall ca. 1500 mm. In Sri Lanka this climatic zone can be categorised as Dry Intermediate Zone of Mid Country. However, these species may perform even better under wetter conditions at the same elevations. *A. mangium, A. auriculiformis* and *A. crassicarpa* can be selected for elevations around 225 m with a rainfall ca. 1600 mm in the Dry Intermediate Zone of Low Country.

It is recommended that selected provenances be further tested at Wet Intermediate Zone (1750–2000 mm rainfall) or Wet Zone (above 2000 mm rainfall) in Mid or Low Country areas of Sri Lanka.

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References

Midgley, S.J. and Vivekanandan, K. 1987. Australian acacias in Sri Lanka. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, 132–135.

Turnbull, J.W. 1986. Multipurpose Australian Trees and Shrubs: lesser-known species for fuelwood and agroforestry. ACIAR Monograph No. 1, 361 p.

Results from a Four-year-old Tropical *Acacia* Species/Provenance Trial on Hainan Island, China

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Abstract

Four-year height and diameter growth for nine tropical *Acacia* species (25 provenances) on trial on Hainan Island, China, are presented. Significant differences between species for height and diameter growth were found with the best species in the trial growing more than 13 m in height. Provenance differences for *Acacia crassicarpa* and *A. aulacocarpa* were also highly significant with superior performance from Papua New Guinea provenances.

ACACIAS are not as commonly planted as eucalypts in the tropical regions of China but are found in plantations and as amenity plantings around houses, fields and along roads. These plantings are of *A. confusa* or *A. auriculiformis* and are typified by generally poor stem and slow growth. The *Acacia* wood is used for fuelwood and simple furniture. There is tremendous scope to improve the scale of planting of this genus and its utilisation in tropical China through the identification of the more productive genotypes for particular environments.

This paper reports growth results from one of the oldest tropical *Acacia* species/provenance trials in China. This was planted on Hainan Island in April 1985 and growth data from May 1989 measurements of the trial are presented.

Materials and Methods

Trial site

The trial site is located at Bai Shi Ling forest farm (19°00′N, 110°15′E, 20 m elevation) 30 km south of Qionghai on the east coast of Hainan Island, China.

Soil on the site is a red sandy latosol, derived from sedimentary parent rock. This soil has a high gravel content which increases with soil depth. The soil is very acidic (pH 3.5–4.5) and has low fertility. The site was highly disturbed as a result of preparation for the trial. This involved the complete removal of the *Eucalyptus exserta*, planted formerly on the site, and the understorey herbs and grasses such as *Lygodium microstachyum, Dicraopteris linearis* and *Imperata cylindrica* var. *major*.

The climate is monsoonal with typhoons occurring between August and October. The average annual rainfall is 2072 mm. The mean annual temperature is 24 °C with an average temperature of 15 °C for the coldest month. The lowest recorded temperature is 5 °C.

Trial establishment and design

Seed for this trial was provided by the CSIRO Australian Tree Seed Centre (Canberra) with the exception of the control species *A. confusa*. Origin details of the species and seedlots in trial are presented in Table 1.

The 25 *Acacia* provenances in the trial were arranged in a completely randomised block design with four replicates. The plot size was 25 trees (5 × 5) planted at 3 × 3 m spacing.

The site was fully cultivated by tractor after clearing and planting holes (40 × 40 × 40 cm) were then prepared. Superphosphate (150 g) was placed in each hole prior to planting.

Results

All the introductions grew more quickly than the locally grown *A. confusa*. This species grew to only

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Table 1. Provenance details and growth data of *Acacia* species in trial.

CSIRO Seed No.	Species	Collection locality	Lat (S)	Long (E)	Alt (m)	Growth at 4 years Height (m)	Dbh (cm)
13680	*A. crassicarpa*	Wemenever, PNG	8°51′	141°26′	30	12.7	12.5
13681	*A. crassicarpa*	Mata, PNG	8°40′	141°45′	30	14.3	15.3
13682	*A. crassicarpa*	Oriomo River, PNG	8°50′	143°41′	20	13.3	13.5
13683	*A. crassicarpa*	Woroi Wipim, PNG	8°49′	143°00′	20	13.2	13.9
13863	*A. crassicarpa*	Shoteel L.A., QLD	16°57′	145°38′	440	11.3	11.1
13686	*A. aulacocarpa*	Iokwa, PNG	8°41′	141°29′	35	8.4	8.5
13688	*A. aulacocarpa*	Keru, PNG	8°32′	141°45′	40	10.1	8.7
13689	*A. aulacocarpa*	Oriomo River, PNG	8°48′	143°09′	20	10.9	11.8
13865	*A. aulacocarpa*	Buckley L.A., QLD	17°09′	145°37′	720	5.1	4.1
13866	*A. aulacocarpa*	Garioch, QLD	16°40′	145°18′	400	5.9	4.0
13684	*A. auriculiformis*	Balamuk, PNG	8°54′	141°18′	18	10.6	10.0
13686	*A. auriculiformis*	Iokwa, PNG	8°41′	141°29′	35	11.0	10.8
13854	*A. auriculiformis*	Oenpelli Area, NT	12°20′	133°04′	50	10.4	9.0
13191	*A. auriculiformis*	Darwin, NT	12°27′	130°50′	30	10.5	9.0
13861	*A. auriculiformis*	Springvale, QLD	15°50′	144°55′	150	10.9	10.3
13691	*A. leptocarpa*	Woroi-Wipim, PNG	8°52′	143°03′	20	10.0	10.1
13653	*A. leptocarpa*	Starcke Holding, QLD	14°16′	144°26′	2	10.9	9.9
13361	*A. cincinnata*	Mossman, QLD	16°37′	145°20′	480	5.9	4.0
13864	*A. cincinnata*	Shoteel L.A., QLD	16°57′	145°38′	440	6.5	4.7
13871	*A. polystachya*	Shoteel L.A., QLD	16°58′	145°37′	48	4.5	2.9
13500	*A. polystachya*	Coen River, QLD	13°42′	143°18′	360	5.2	3.7
13654	*A. oraria*	Starcke Holding, QLD	14°16′	144°26′	1	3.3	1.3
13867	*A. oraria*	Springvale, QLD	15°48′	144°56′	150	4.7	2.5
13690	*A. simsii*	Morehead, PNG	8°42′	141°32′	30	7.6	6.8
85001	*A. confusa*	Lufeng, Guangdong, CHN	23°00′N	115°40′	100	2.1	1.0

Localities:
PNG = Papua New Guinea
QLD = Queensland, Australia
NT = Northern Territory, Australia
CHN = China

2.1 m in height on average while the four tallest species/provenances on trial, all PNG provenances of *A. crassicarpa*, grew to over 13 m. The four most vigorous species in trial were, in order of height, *A. crassicarpa, A. auriculiformis, A. leptocarpa* and *A. aulacocarpa* (see Table 1). There was significant variation (at the 0.01 level of significance) in height and diameter between species in trial. The four replicates were also significant (0.05 level of significance) sources of variation for species height in the trial (see Table 2).

A. crassicarpa, *A. auriculiformis* and *A. aulacocarpa* were examined for the significance of variation between the provenances. This was highly significant (0.01 level) for *A. crassicarpa* and *A. aulacocarpa* (see Table 3). In both species the provenances from Papua New Guinea grew faster than those from Queensland. The differences between these was most extreme for *A. aulacocarpa*.

Table 2. Analyses of variance for height, diameter of 9 species trial at 4 years.

Source of variation	DF	MS	F-ratio
Height			
Species	8	32.2975	90.13**
Replication	3	1.4867	4.15*
Error	24	0.3583	
Diameter at breast height			
Species	8	45.5650	72.37**
Replication	3	1.0130	1.61
Error	24	0.6296	

Note: * and ** indicate significance at the 5 and 1% levels respectively.

The PNG provenances were trees and grew twice as tall on average (10.1–10.9 m) as the shrubby-formed Qld provenances (5.1–5.9 m). Variation in height between *A. auriculiformis* provenances from PNG, Qld and NT was not significant (Table 2). Similarly there were no significant differences between *A. leptocarpa* provenances from PNG and Qld.

A. auriculiformis, *A. leptocarpa*, *A. simsii* and *A. oraria* were observed to have some drought tolerance in the trial and, with the exception of *A. auriculiformis*, were wind-firm.

Table 3. Results of analyses of variance for height, diameter of the provenances trial at 4 years.

Source of variance	DF	MS	F-ratio
A. crassicarpa — height			
Provenance	4	4.628	6.93**
Replication	3	9.157	13.71**
Error	12	0.668	
A. crassicarpa — diameter			
Provenance	4	9.968	6.68**
Replication	3	2.793	1.87
Error	12	1.492	
A. auriculiformis — height			
Provenance	4	0.258	1.46
Replication	3	1.243	7.02**
Error	12	0.177	
A. auriculiformis — diameter			
Provenance	4	2.188	5.04*
Replication	3	0.793	1.83
Error	12	0.434	
A. aulacocarpa — height			
Provenance	4	25.455	19.07**
Replication	3	1.903	1.43
Error	12	1.335	
A. aulacocarpa — diameter			
Provenance	4	45.313	55.13**
Replication	3	5.213	6.34**
Error	12	0.822	

Note: * and ** indicate significance at the 5 and 1% levels respectively.

Discussion

The results from this trial clearly demonstrate the increased productivity that can be gained through species testing. All introduced species grew better than the locally grown *A. confusa* which reached 2.1 m in height after four years. The growth of the best species and provenances in the trial is impressive. For example the five provenances of the best species in the trial, *A. crassicarpa*, grew to more than 11 m in height. The Mata (PNG) provenance was the tallest of these at 14.3 m.

This trial is also a clear demonstration of the importance of testing a range of provenances as part of the species selection process. In this trial variation between provenances was highly significant for *A. crassicarpa* and *A. aulacocarpa* but not for *A. auriculiformis* and *A. leptocarpa*. For both *A. crassicarpa* and *A. aulacocarpa* the Papua New Guinea provenances grew significantly larger in height and diameter than the Queensland provenances. The variation in form between the Australian and Papua New Guinea provenances of *A. aulacocarpa* is also significant from a utilisation viewpoint. The PNG provenances exhibit a tree form, and at this early stage appear suitable for timber production. The Australian provenances are shrubs and appear ideal for soil conservation, soil reclamation and improvement and fuelwood plantings.

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Growth of some *Acacia* Species in Vietnam

Le Dinh Kha and Nguyen Hoang Nghia*

Abstract

Trials of five different *Acacia* species were undertaken at sites in northern and southern Vietnam during the 1980s. Performances of different provenances of *Acacia mangium, A. aulacocarpa, A. cincinnata, A. auriculiformis* and *A. crassicarpa* are compared.

IN the 1960s, *Acacia auriculiformis* was the first *Acacia* species introduced into Vietnam for planting in southern provinces. In the first half of the 1980s four *Acacia* species originating from Queensland and Northern Territory, Australia, were also tested in some areas of northern and southern Vietnam. Those species were *A. aulacocarpa, A. crassicarpa* and *A. mangium*. In 1988, six provenances of *A. mangium* were provided by the project of the Swedish Agency for Research Cooperation with Developing Countries (SAREC). In 1989, a set of 39 provenances of five *Acacia* species was also imported through this project. According to the research program of the Research Centre for Forest Tree Improvement (RCFTI), these provenances are undergoing trials in some main areas of Vietnam. Some trials with *Acacia* species were also conducted by Phu Ninh Research Centre with the assistance of SIDA.

The first generation plantations of *A. auriculiformis* have now been harvested for utilisation. The trees of four *Acacia* species in trials flowered and set fruit.

In the first trials with four *Acacia* species, trees were planted without replication, but later, species and provenance trials were conducted with three replications undertaken both in southern and northern provinces.

Trials at Ba vi and Hoa thuong

Ba vi: 50 km northwest of Hanoi; lat. 21°13 'N, long. 105°26 'E; 1900 mm rainfall; 50 m elevation.

Hoa thuong: Bac thai Province of northeastern Vietnam; lat. 21°34 'N, long. 105°43 'E; 1500–2000 mm rainfall; 70 m elevation.

Species planted at Ba vi in 1982 were:

A. aulacocarpa	13380	Atherton area, Qld
A. auriculiformis	13191	Darwin, N.T.
A. crassicarpa	13367	Daintree, Qld
A. mangium	13279	Daintree, Qld

Species planted in 1984 in Hoa thuong (2 m × 2 m spacing) were:

A. auriculiformis	13854	Oenpelli area, N.T.
A. aulacocarpa	13865	Buckley L.A., Qld
A. crassicarpa	13863	Shoteel L.A., Qld
A. mangium	13846	Mossman, Qld

Data collected in 1990 (Table 1) showed that in Ba vi and Hoa thuong, even at different ages, *A. mangium* was the best in both height and diameter growth. The second best in Ba vi was *A. crassicarpa* and in Hoa thuong was *A. auriculiformis*. In both areas, *A. aulacocarpa* was ranked the lowest.

While *A. mangium* mostly produced only one main stem, *A. aulacocarpa* had from 2 to 6 main stems. In Hoa thuong, this species was very bushy and up to 97% of trees had more than two main stems. *A. auriculiformis* and *A. crassicarpa* were in the intermediate position in both height and number of main stems.

In Ba vi the coefficient of variation in diameter was only 18.2% for *A. mangium* while it was 32.5% for *A. auriculiformis*, and the two remaining species had intermediate values. Coefficient of variation in height was similar for the four species. In Hoa thuong, *A. aulacocarpa* showed the highest coefficient of variation in diameter (26.9%), while the

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remaining species had similar values (11.8–14.8%). Low coefficients of variation in height were found in *A. mangium* and *A. crassicarpa* (7.9 and 7.5% respectively) and higher coefficients of variation were found in the remaining species (11.2 and 11.4%).

Plantations of *A. mangium*

Provenance trials of *A. mangium* from Queensland were carried out in Bau Bang (lat. 11°17'N, long. 106°25'E, 2100 mm rainfall) and La Nga (lat. 11°13'N, long. 107°21'E, 2000 mm rainfall). At La Nga with good soil and drainage, the Kuranda, Bronte and Hawkins Creek provenances were the best, while seedlot No. 0407 (unknown provenance) was the worst among the provenances from Queensland. A provenance derived locally from seed of trees grown from seed collected near Mossman, Qld and planted in 1983 was the worst provenance (Table 2).

In Bau Bang where drainage is bad in the rainy season, the two best species were *A. mangium* (Kennedy, Qld) and *A. auriculiformis* (Oenpelli, N.T. — 2.5 m height, 3.6 cm diameter). Within *A. mangium* the Ingham provenance had the slowest growth rate, while in both areas the Mossman provenance was in the slow-growing group. The local (derived) provenance of *A. auriculiformis* was one of the worst provenances (2.4 m height, 2.2 cm diameter).

On the other hand, fast-growing provenances also showed high survival (81–96%) in plantation. The survival rate of the slow-growing Ingham provenance was only 48%. It is clear that on unsuitable sites growth of trees was slow and survival was low.

Table 1. Growth of the *Acacia* species tested in northern Vietnam (2 × 2 m spacing).

Species	Mean height (m)	Mean diam. (cm)	MAI height	MAI diam.	Av. number of stems per tree	Percentage trees with >2 stems
Planted in 1982 in Ba vi						
A. mangium	15.4	18.9	1.9	2.4	1.1	7.7
A. crassicarpa	13.2	13.8	1.7	1.7	1.2	16.7
A. auriculiformis	12.5	14.9	1.6	1.9	1.6	50.0
A. aulacocarpa	10.8	10.1	1.4	1.3	2.4	78.6
Planted in 1984 in Hoa thuong						
A. mangium	11.6	17.6	1.9	2.9	1.2	20.0
A. auriculiformis	10.4	13.8	1.7	2.3	1.0	3.3
A. crassicarpa	9.9	12.6	1.6	2.1	1.6	40.0
A. aulacocarpa	6.9	8.0	1.2	1.3	4.1	96.6

Table 2. Growth of *A. mangium* provenances in La Nga and Bau Bang.

Provenance		La Nga (16 months old)		Provenance		Bau Bang (15 months old)	
		Height (m)	Diameter (cm)			Height (m)	Diameter (cm)
27II	Kuranda, Qld	4.3	4.9	34I	Kennedy	2.5	3.7
33I	Bronte, Qld	4.2	5.3	27I	Kuranda	2.4	3.1
31I	Hawkins, Qld	4.1	5.0	27II	Kuranda	2.4	3.3
26	Cardwell, Qld	4.0	4.7	0407	unknown	2.3	3.0
0515	Mossman, Qld	3.9	4.7	33I	Bronte	2.3	3.4
34I	Kennedy, Qld	3.9	4.7	26	Cardwell	2.3	3.1
13846	Mossman, Qld	3.9	4.9	13846	Mossman	2.3	3.0
0407	Supplied by Dendros Seeds, Qld	3.7	4.1	31I	Hawkins	2.2	3.1
	Trang bom	3.6	3.9	30II	Ingham	2.0	2.6

Performance of *Acacia* Species in Ba vi

The trial started in June 1990. After 6 months in the field, the height and ground-level diameters of the trees were measured (Table 3).

The data showed that after 6 months *A. auriculiformis* was the fastest growing species, and similar in ranking to Bau bang. *A. crassicarpa, A. mangium, A. aulacocarpa* and *A. cincinnata* followed in order of declining vigour.

Table 3. Growth of the provenances of five *Acacia* species at Ba vi.

Seedlot No.	Provenance	Height (cm)		Diameter (cm)	
		$\overline{X}$ mean	CV (%)	$\overline{X}$ mean	CV (%)
A. auriculiformis					
16142	Coen, Qld	126.3	15.9	1.38	13.9
16151	Mary R., NT	122.7	17.5	1.40	17.0
16683	Morehead R., PNG	121.5	18.7	1.43	17.9
16106	Mibini, PNG	118.4	16.5	1.51	19.1
16152	E. Alligator R., NT	115.5	19.6	1.38	19.2
16484	Morehead R., Qld	114.5	22.9	1.15	22.6
16485	Kings Plains, Qld	113.7	25.7	1.30	21.1
16154	Goomadeer R., NT	112.9	15.2	1.35	15.3
16158	Gerowie Creek, NT	109.2	22.3	1.27	22.9
16107	Old Tonda Village, PNG	106.3	21.5	1.15	21.2
16684	Bensbach R., PNG	103.9	20.5	1.28	18.6
16163	Elizabeth R., NT	102.8	23.6	1.15	24.7
16148	Manton R., NT	96.9	25.0	1.08	27.5
A. crassicarpa					
13681	Mata, PNG	117.3	22.8	1.74	23.6
16598	Bimadebun Village, PNG	111.2	26.3	1.37	26.2
16599	Pongaki E. Morehead, PNG	110.3	22.3	1.35	29.6
16605	Derideri, PNG	100.8	21.8	1.28	22.2
13680	Wemenever, PNG	99.2	25.6	1.26	32.4
16602	Dimisisi Village, PNG	95.0	23.7	1.22	32.3
13682	Oriomo R., PNG	93.3	27.6	1.11	26.9
16597	Gubam Village, PNG	91.0	32.4	1.15	29.4
16128	Jardine R.-Bamaga, Qld	49.7	38.6	0.86	45.8
A. mangium					
16589	Pongaki N. Morehead, PNG	101.8	20.6	1.38	24.9
16586	Gubam-Boite Village, PNG	97.6	22.9	1.35	28.0
15678	Helenvale, Qld	90.8	21.9	1.21	27.7
15367	Mossman, Qld	89.3	20.9	1.17	26.9
16679	Bloomfield-Ayton, Qld	85.2	22.6	1.15	25.3
16681	Ingham, Qld	84.8	27.5	1.20	27.8
15694	66 km N. Townsville, Qld	80.3	21.8	1.28	28.6
15677	Iron Range, Qld	74.2	21.5	1.16	25.1
13621	Piru, Ceram, Indonesia	72.6	24.5	0.83	31.0
A. aulacocarpa					
16113	Keru to Mata, PNG	103.9	22.5	1.06	29.8
16112	Morehead, PNG	86.6	25.4	0.98	34.2
13865	Buckley L.A., Qld	74.8	33.5	0.76	37.1
13866	Garioch, Qld	70.7	37.4	0.65	40.1
16180	Maningrida, NT	46.8	39.2	0.57	49.3
A. cincinnata					
15961	Julatten, Qld	73.4	19.1	0.92	29.3
15365	Mossman, Qld	64.5	22.2	0.85	28.3
13864	Shoteel L.A., Qld	64.2	23.9	0.82	35.1

A. auriculiformis also had the most uniform growth, as indicated by the low coefficient of variation and *A. aulacocarpa* was the most variable. In each species, the tendency was that fast-growing provenances showed smaller coefficient of variation and the slower-growing provenances had a higher coefficient of variation.

Generally the provenances originating from Papua New Guinea grew faster than the provenances from Queensland and Northern Territory.

For particular species, it was shown that the fastest growing provenance of *A. auriculiformis* were Coen (Qld), Mary River (N.T.), Morehead River (PNG), Mibini (PNG) and East Alligator (N.T.). The best provenances of *A. crassicarpa* were Mata (PNG), Bimadebun (PNG) and Pongaki, East Morehead River (PNG). The best of *A. mangium* were the Pongaki, East Morehead River (PNG) and Gubam-Boite Village (PNG). The best of *A. aulacocarpa* was the Keru to Mata provenance (PNG). *A. cincinnata* grew slowly and proved unsuitable for the trial site in Ba vi.

The best provenances among the 39 of five species tested in Ba vi were the Coen (Qld), Mary River (N.T.), Morehead River (PNG) and Mibini (PNG) for *A. auriculiformis* and Mata (PNG) of *A. crassicarpa*.

In the case of *A. mangium*, relatively slow growth of the Mossman provenance was similar to the earlier trial.

Conclusions

In the first trial with one provenance from each of four species, *A. mangium* proved to be faster growing than the other three species when measured after 6–8 years. *A. mangium* planted in La Nga and Bau Bang showed different results. In La Nga, where water drainage was very good in the rainy season, the Kuranda and Bronte provenances were the best, but in Bau Bang with very bad drainage, the Kennedy provenance of *A. mangium* and the Oenpelli area provenance of *A. auriculiformis* grew faster.

A. mangium planted in the southern provinces showed better growth than in the northern provinces and growth was also better at wider spacing.

In the first 6 months of the provenance trial at Ba vi the best species was *A. auriculiformis* and the worst was *A. cincinnata*. Four provenances of *A. auriculiformis* and one of *A. crassicarpa* were the best among 39 provenances tested.

Responses by Six Acacias to Fertiliser Applications on Infertile Sandy Loam

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Abstract

Responses of six *Acacia* species to age 11 months to the effects of six fertiliser treatments (additive combinations of phosphorus [P], potassium [K], nitrogen [N] and trace elements [T]) are reported. Survival was depressed significantly by the addition of fertilisers, due primarily to P. This effect tended to be offset by the addition of K, while lower survival was associated with the addition of T to PKN. Differences in survival between species were significant also. There was a general trend towards increased height at 11 months in response to the addition of P, K and N while the addition of T has tended to result in depressed growth. Differences in height growth between species at all ages were significant, while statistically significant differences were detected in two measures of height variance and coefficient of variation. Height variance and coefficient of variation and the implications of this result for experimental design are discussed briefly.

A large percentage of the soils in the tropics have single and frequently multiple nutrient deficiencies. Growth responses to fertilising broadleaved trees are common, and effective N fixation by N-fixing trees requires adequate levels of nutrition. It is argued that the development of sound information on the relationships between tree nutrition (particularly of the N-fixers), fertiliser use and tree function in the tropics is essential.

A BASIC premise underlying the conduct of the ACIAR species evaluation trials in southeast Queensland was that constraints to productivity should be minimised to enable valid evaluation of potential performance (Ryan and Bell 1989). Consequently, trial management aimed at providing reasonably high levels of inputs, including the addition of fertilisers. An essential part of this strategy is that once genetic potential has been determined, it is then necessary to determine the types and levels of inputs needed to achieve desired levels of growth.

Many tropical soils are inherently low in fertility and most have very low levels of plant available P (Isbell 1978). This is especially so for the more acid soils which often have high levels of Al saturation, low cation exchange capacities and generally low levels of other nutrients. Jordan (1985) argued that nutrients are the factor most limiting production in the humid tropics, despite the frequent assumption of high fertility. Munns and Franco (1982) estimated that low nutrient levels were likely to limit agricultural production on a total of 91% of tropical soils while 35% of these were likely to have multiple deficiencies of P, S, Mo, K and Zn.

It is frequently assumed that problems of low soil fertility can be overcome by the use of trees, particularly those that fix nitrogen. Schonau (1984) concluded that applications of fertiliser can lead to improved productivity of fast-growing broadleaved tree species, including acacias, while Dommergues (1982) pointed out that the productivity of nitrogen fixing trees and their ability to fix nitrogen depend on a range of soil factors including nutrient status. Reddell et al. (1989) reported large growth responses by *Casuarina cunninghamiana* inoculated with *Frankia* on P deficient soils in southeast Queensland, but only when P had been applied as fertiliser. Sun (1991) found that the yield of *Acacia mangium* increased significantly after applying a small starter dose of nitrogen fertiliser to very young seedlings and that this was associated with increased nodule initiation and increased specific acetylene reduction activity. In Thailand, a high proportion of legume crops suffer from one or more deficiencies of the micronutrients B and Mo and the macronutrients P, K, S and N (Bell et al. 1990). It is highly likely that

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the productivity of N-fixing trees would be impaired by deficiencies of the same elements, although perhaps not to the same extent.

Despite the evidence of widespread soil nutrient deficiencies in the tropics and potential responses in productivity due to improved nutrition, fertilising to improve tree growth is considered frequently to be too costly, and research into fertiliser use and tree nutrition tends to be ignored as a consequence. The fertiliser trial described in this paper was established to begin evaluation of the role of tree nutrition in the productivity of acacias on a site chosen because of its very low fertility. The suggestion by Evans et al. (unpubl.), following their observation of considerable variation in the stem form of acacias, that the influence of nutrition on stem form be tested has been incorporated.

Materials and Methods

The site (25°26′S, 152°26′E, 60 m altitude) is relatively flat, and adjacent to two of the trials described by Ryan and Bell (1989) on Wongi State Forest, in southeast Queensland. Soil texture is a loamy sand in the A horizons (0–37 cm) grading to sandy clay texture in the lower B horizon (to 137 cm). Although reasonably well drained, the soil is subject to seasonal waterlogging and mottles are present below 37 cm, with concretionary nodules beginning to appear below 62 cm. The levels of nutrients, especially N, P and K, are low (Table 1). On a number of similar soils in the general region it has been found necessary to add various trace elements for optimal growth of pastures (Andrew and Bryan 1955) and *Casuarina cunninghamiana* (Reddell, pers. comm.).

The trial is designed to test the effects of six fertiliser treatments on both the form and growth of six acacia species at two stocking densities (Table 2) and is laid out as split-split plots in two randomised complete blocks. The spacing treatments are contained in the major plots, fertiliser treatments in the minor plots and species in the least plots of 7 rows by 7 trees. The fertiliser treatments test the additive effects of various nutrient combinations but have been designed to enable the effects of some individual elements and factorial combinations to be determined by the use of planned linear contrasts. Rates and timing of applications are shown in Table 3. The treatments, either in solid form or in solution for small quantities, were applied to two holes 30 cm on either side of each tree. Later applications of K and N were to be broadcast evenly across the plots. All the species selected had grown well in the evaluation trials but stem form had ranged from a very high proportion of single stemmed, relatively straight individuals (*A. neriifolia*) to a complete multistemmed habit (*A. plectocarpa*).

Table 1. Soil analytical data at 0–15 cm (means of four samples) and 15–30 cm (means of two samples).

	Sample depth (cm)		
	0–15	15–30	Comment
pH	5.3	5.5	satisfactory for plant growth
EC (mS/m)	2.4	2.4	good
N (%)	0.02	0.01	very low
OC (%)	0.53	0.41	very low
C/N	25.4	28.3	>20; slow mineralisation and release of organic N
Pt (ppm)	13	10	very low
Pa (ppm)	2	1	very low (except response where Pa<20 for most ag. crops)
Na (meq%)	0.04	0.04	
K (meq%)	0.03	0.04	very low (<0.2 considered low especially where K/Σbases<2)
Ca (meq%)	0.59	0.48	dominant cation but low (values <2 considered low in ag.)
Mg (meq%)	0.22	0.22	low
Mn (ppm)	4.14	2.89	medium
CEC (meq%)	2.78	2.34	very low
BS (%)	31.7	32.8	

pH — Determined on a 1:5 soil/water suspension after shaking for 1 hour using glass and Calomel electrodes and a direct reading pH meter; N (%) — Modified Kjeldahl method; OC (%) — Walkley-Black; Pt (ppm) — Constant boiling HCl extract; Pa (ppm) — 0.1M sulphuric acid extract; P determined from intensity of blue colour sulfomolybdic acid. Exchangeable cations (meq%) — extraction with 1.0M ammonium acetate at pH 7.0; determined by AAS; CEC (%) as for exch. Na following saturation of exchange sites with sodium (1.0M sodium acetate).

Plants were raised in Hawaiian Dibbling Tubes following the procedures described by Ryan et al. (1987). No rhizobial inoculum was applied but all seedlings had developed apparently functional nodules by the time of outplanting.

The site was disc ploughed twice to a depth of 25–30 cm prior to planting and fertilising in February 1989. Very wet conditions followed for several months, resulting in poor survival, and all plants were removed after 6 months. Mounds were built to improve drainage while ensuring that soil was retained within the original plots. Replanting and fertilising were carried out in December 1989, with the species and fertiliser treatments conforming to the original layout. Although temperatures were high and humidity low at the time of planting, the soil was moist due to 72 mm of rain prior to planting while a further 24 mm of rain fell four days later. However, conditions thereafter tended to be hot (mean maximum temperatures were above 30 °C until mid March) and dry with no further significant rain falling until late February. Dead plants were replaced at 2 and 3 months to maintain complete stocking. Very wet weather occurred again in late autumn and winter but did not increase mortality unduly. The experiment has been slightly damaged by cattle. Competing weeds have been controlled by spraying with glyphosate as needed to maintain relatively weed free conditions.

Table 2. Fertiliser, species and stocking density treatments being tested in the trial.

Fertiliser	Species	Stocking density (trees/ha)
Nil	*A. neriifolia*	2500 (2.0 × 2.0 m)
P	*A. cincinnata*	5100 (1.4 × 1.4 m)
PK	*A. leptocarpa*	
PKT	*A. mangium*	
PKN	*A. crassicarpa*	
PKNT	*A. plectocarpa*	

Height measures of the internal five rows by five trees were carried out at 1, 5 and 11 months after planting. Analysis of variance of data for survival (following arcsine square root transformation) and height were carried out. Only data for original stems were analysed, data for refill stems were excluded. In addition, because a high level of variation had been observed in the field, height variance and coefficients of variation (CV) were analysed following log transformation. Duncan's multiple range test and planned linear contrasts were used to evaluate differences between treatments. Where analyses were conducted on transformed data, results of statistical tests are for the transformed data, though means are presented in untransformed format. Stocking density has had no statistical effect on results to date and is not considered further.

Results

Survival

Survival was depressed significantly by the addition of fertilisers (Fig. 1). Linear contrasts (Table 4) showed that lower survival was due primarily to phosphorus. This effect tended to be offset by the addition of potassium while lower survival was associated with the addition of traces to the PKN treatment. These latter effects were not significant although the trend appears to be strengthening with age.

Differences in survival were significant for species also (Table 5) but these differences were not affected by fertiliser treatments, i.e., species x fertiliser interactions were not significant.

Table 3. Individual fertiliser types, rates and timing of applications.

Fertiliser Treatment	Fertiliser and element rate		Application rate (kg/ha) and schedule of application (months)				
			−10 mo.	Planting	9 mo.	15 mo.	21 mo.
P	triple superphosphate	19% P	100	100			
K	potassium chloride	50% K	33	33	67		
T	copper sulphate	25% Cu	5	5			
	zinc sulphate	23% Zn	5	5			
	sodium borate	11% B	5	5			
	ferrous sulphate	20% Fe	10	10			
	sodium molybdate	38% Mo	0.5	0.5			
	cobalt sulphate	20% Co	0.05	0.05			
N	ammonium nitrate	34% N	25	25	50	75	150

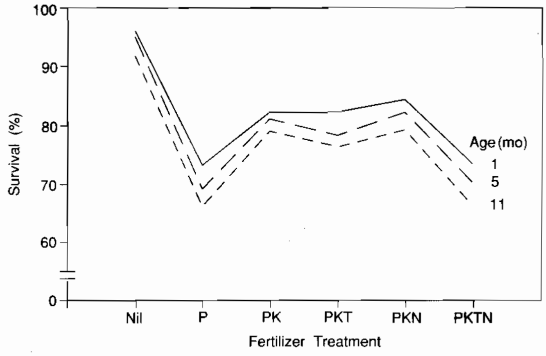

Fig. 1. Effect of fertiliser treatments on the survival of six acacias.

Table 4. Major relationships between fertiliser treatments and survival at 1, 5 and 11 months after planting.

Age (months)	Contrast	Probability
1	Nil (96.0) v P (73.3)	0.001
	Nil (96.0) v All Fert (78.8)	0.000
5	Nil (94.5) v P (68.8)	0.001
	Nil (94.5) v All Fert (75.8)	0.001
	P (68.8) v PK (80.7)	0.080
	PKN (81.8) v PKTN (69.7)	0.110
11	Nil (91.5) v P (66.0)	0.001
	Nil (91.5) v All Fert (73.3)	0.001
	P (66.0) v PK (79.2)	0.059
	PKN (79.3) v PKTN (66.2)	0.086

Table 5. Species survival at 1, 5 and 11 months after planting.

	Survival (%)		
	1 month	5 months	11 months
A. neriifolia	79 bc	75 c	74 bc
A. crassicarpa	87 ab	86 ab	85 a
A. plectocarpa	94 a	91 a	84 ab
A. cincinnata	80 bc	77 bc	76 abc
A. leptocarpa	76 c	74 c	72 c
A. mangium	75 c	71 c	67 c
Significance (AOV)	***	***	**

Significance levels based on analysis of arcsine square root transformed data; differences between species determined by Duncan's Multiple Range Test at the 5% level.

Height growth and variation

There is a general trend towards increased height at 11 months in response to the addition of P, K and N while the addition of traces has tended to result in depressed growth (Fig. 2). Although analysis of variance shows fertiliser effects to be nonsignificant at this stage, some linear contrasts are significant and support the emergence of this trend (Table 6).

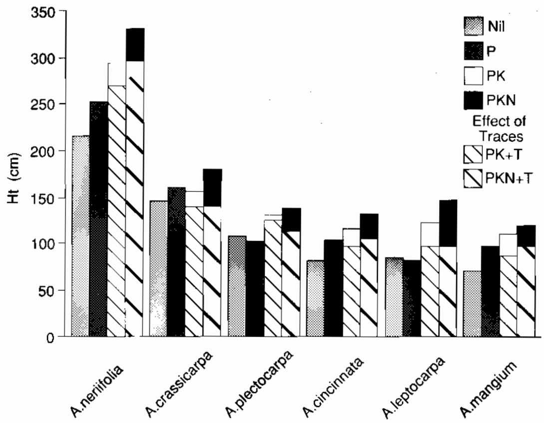

Fig. 2. The effects of fertiliser treatments on height of six *Acacia* species at age 11 months.

Table 6. Significant relationships between fertiliser treatments and height at age 11 months.

Contrast			Probability
Nil (117 cm)	v	All Fert (148 cm)	0.023
PK, PKN (164 cm)	v	PKT, PKNT (139 cm)	0.035

Differences in height growth between species at all ages were significant ($P < 0.001$) while statistically significant differences were detected in two measures of height variance and coefficient of variation. Height means, standard deviations and CVs at 11 months illustrate these results (Table 7). A significant fertiliser effect on CV and a significant species x fertiliser interaction were detected also at 5 months.

Discussion

While trends in treatment effects on both height and survival have become apparent, it is too early in the life of the trial to draw definitive conclusions. Interpretations of data at this stage are speculative and must be regarded cautiously especially given the high level of variation that is apparent across the trial and other limitations.

The increased mortality associated with the applications of P and traces can be attributed possibly to the high rates applied, which were double the levels originally planned. In the case of P, this may have been due to fertiliser burn or to increased stress and reduced vigour resulting from nutrient imbalance. The latter explanation appears to be the more likely given the improved survivals in the PK and PKN treatments. Similar imbalances may explain the effects of traces. Alternatively, the levels of one or more of the microelements may have been toxic. Simpson (pers. comm.) has noted B toxicity in *Pinus caribaea* var. *hondurensis* in glasshouse trials with podzols following the application of the equivalent of 10 kg/ha B.

While effects on survival by fertiliser treatments have been negative, the response in height growth has been positive. The general trend would appear to indicate that improved growth can be expected in response to the addition of all three macro-elements. This is not unexpected, since soil chemical analysis showed that the availability of these was very low. The depressed growth due to the addition of traces is unexpected and would appear to support the possibility that one or more of the elements has been applied in levels that are toxic. This may become clearer following foliar analysis.

Height variance tends to increase as average height increases. The implications for statistical analyses are that the comparisons of the taller species appear to be more sensitive than they should be while comparisons of the shorter species are not as sensitive as they could be. However, results were unaffected when data were reanalysed after omitting *A. neriifolia* and *A. crassicarpa*, the species with the highest variances. The analyses of the coefficient of variation revealed that two of the three shortest species had high relative variation. At this stage it appears that this is an inherent property of these particular species, since each species was represented by unimproved seed from a single seed source.

Although there are significant differences between species in both mortality and height growth, the lack of any interaction between species and fertiliser treatments would appear to suggest that it may be possible to use fewer species in future trials investigating the nutrition of acacias. This possibility is supported by Schonau (1984) who concluded, on reviewing literature on the fertilisation of fast-growing broadleaved species, that fertiliser types and rates depended more on site conditions than on the requirements of species, family or clone. However, this generalisation needs to be regarded cautiously and in context. Soil nutrient status is frequently the basis of selecting particular crop types and cultivars for particular sites in agriculture (e.g., Bell et al. 1990) because of genotypic differences in nutritional needs and in the capacity to utilise available nutrients. There is no biological reason to expect trees to be different. Cromer (1989) reported differential responses between species to the application of P although these differences were not tested statistically because of unequal variances in growth data. If future fertiliser trials were reduced to just two species, one would be tempted to select a fast and a slower growing species from those of interest. The problem of increasing variance with increasing mean would suggest that the species should be analysed separately. This could also simplify the experimental design.

Table 7. Species mean height, standard deviation and coefficient of variation at age 11 months.

Species	Av. ht. (cm)	Standard deviation	CV (%)
A. neriifolia	277 a	87.7 a	33 bc
A. crassicarpa	155 b	45.5 b	30 c
A. plectocarpa	120 c	38.1 c	33 bc
A. cincinnata	105 d	36.0 c	35 b
A. leptocarpa	104 d	44.9 b	47 a
A. mangium	96 d	38.5 c	41 a
Significance (AOV)	***	***	***

Significance levels and DMRT of SD based on analysis of ln variance and of CV on ln transformed data; differences between species determined by Duncan's Multiple Range Test at the 5% level.

It was pointed out in the introduction that a large percentage of the soils in the tropics have single and frequently multiple nutrient deficiencies, that growth responses to fertilising broadleaved trees are common, and that effective N fixation by N-fixing trees requires adequate levels of nutrition. Indeed, it is possible that small starter doses of nitrogen may be required to ensure infection of acacias by *Rhizobia*. The development of sound information on the relationships between tree nutrition, particularly the N fixers, and tree function in the tropics is essential. At the most basic level, data are required for evaluating the economics of applying fertilisers and to optimise the potential benefits of biological symbionts. This may enable the evaluation of potential benefits of developing other technologies also, e.g., the use of mycorrhizas to improve P nutrition on soils with low plant available P.

Ultimately, however, one needs to consider nutritional ecology and the capacity to sustain productivity. Raison (1984) warned of potentially adverse effects on soil fertility of short rotation forest crops with a high degree of biomass utilisation. While he was concerned primarily with the effects of intensive industrial forestry operations, his arguments can be applied equally to non-industrial forestry where trees may be harvested while still young, where all parts of the tree may be utilised and where there may be significant export of nutrients from the site.

An extensive data base on the performance of acacias in cultivation has been developed and this should enable improved capacity for selecting species appropriate to particular needs and sites. It is now necessary to develop the information base necessary to develop appropriate management prescriptions. This must include studies on nutrition and the use of fertilisers.

References

Andrew, C.S. and Bryan, W.W. 1955. Pasture studies on the coastal lowlands of subtropical Queensland. I. Introduction and initial plant nutrient studies. Aust. J. Agric. Res., 6, 265–290.

Bell, R.W., Rerkasem, B., Keerati-Kasikorn, P., Phetchawee, S., Hiranburana, N., Ratanarat, S., Pongsakul, P. and Loneragan, J.F. 1990. Mineral nutrition of food legumes in Thailand with particular reference to micronutrients. ACIAR Technical Report No. 16, 52 p.

Cromer, R.N. 1989. Response of Australian tree species to phosphorus in Thailand. In: Boland, D.J., ed., Trees for the Tropics: growing Australian multipurpose trees and shrubs in developing countries. ACIAR Monograph No. 10, 139–143.

Dommergues, Y. 1982. Ensuring effective symbiosis in nitrogen fixing trees. In: Graham, P.H. and Harris, S.C., ed., Biological Nitrogen Fixation Technology for Tropical Agriculture. Papers presented at a workshop held at CIAT, March 9-13, 1981. Cali, Colombia, Centro Internacional de Agricultural Tropical, 395–411.

Isbell, R.F. 1978. Soils of the tropics and sub-tropics: genesis and characteristics. In: Andrew, C.S. and Kamprath, E.J., ed., Mineral Nutrition of Legumes in Tropical and Subtropical Soils. Proceedings of a workshop held at CSIRO Cunningham Laboratory, Brisbane, Australia, 16–21 January, 1978, 1–20.

Jordan, C.F. 1985. Nutrient Cycling in Tropical Forest Ecosystems. John Wiley and Sons, Chichester, 190 p.

Munns, D.N. and Franco, A.A. 1982. Soil constraints to legume production. In: Graham, P.H. and Harris, S.C., ed., Biological Nitrogen Fixation Technology for Tropical Agriculture. Papers presented at a workshop held at CIAT, March 9–13, 1981. Cali, Colombia, Centro Internacional de Agricultural Tropical, 133–152.

Raison, R.J. 1984. Potential adverse effects of forest operations on the fertility of soils supporting fast growing plantations. In: IUFRO Symposium on Site and Productivity of Fast Growing Plantations held in Pretoria and Pietermaritzburg, South Africa, 30 April–11 May, 1984. South African Forest Research Institute, Pretoria, 457–472.

Reddell, P., Rosbrook, P.A. and Ryan, P.A. 1989. Managing nitrogen fixation in *Casuarina* species to increase productivity. In: Boland, D.J., ed., Trees for the Tropics: growing Australian multipurpose trees and shrubs in developing countries. ACIAR Monograph No. 10, 209–214.

Ryan, P.A. and Bell, R.E. 1989. Growth, coppicing and flowering of Australian tree species in trials in southeast Queensland, Australia. In: Boland, D.J., ed., Trees for the Tropics: growing Australian multipurpose trees and shrubs in developing countries. ACIAR Monograph No. 10, 49–68.

Ryan, P.A., Podberscek, M. Raddatz, C.G. and Taylor, D.W. 1987. Acacia species trials in southeast Queensland. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries, proceedings of an international workshop held at Gympie, Qld, Australia, 4–7 August, 1986. ACIAR Proceedings No. 16, 81–85.

Schonau, A.P.G. 1984. Fertilisation of fast-growing broadleaved species. In: IUFRO Symposium on Site and Productivity of Fast Growing Plantations held in Pretoria and Pietermaritzburg, South Africa, 30 April–11 May, 1984. South African Forest Research Institute, Pretoria, 253–268.

Sun, J. 1991. Studies on the nitrogen fixation by tree acacias. PhD thesis, University of Melbourne.

Testing *Acacia* Species on Alkaline Soils in West Timor

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Abstract

Tree species screening trials on five sites in West Timor were assessed 1.6 or 2.6 years after planting. The best *Acacia* species on highly alkaline soils were *A. ampliceps, A. holosericea, A. auriculiformis* and the native species of *A. leucophloia*. Some species, such as *A. torulosa* and *A. shirleyi*, appeared to be intolerant of alkaline soils. In *A. crassicarpa*, one provenance tolerated alkaline soils while another suffered severe nutrient deficiency. All the introduced species performed better on lowland sites than on highland sites.

THIS paper reports some results of a cooperative research project in West Timor, funded by ACIAR and the Government of Indonesia. Although a wide range of species has been used in the project field trials, this paper reports only the results of research on *Acacia* species used for the first two years' field trials in the project.

The ACIAR project in West Timor aims, inter alia, to introduce germplasm of tree species to West Timor for the production of fuelwood and fodder. The research is being undertaken by staff of the Balai Penelitian Kehutanan (Forest Research Station) in Kupang, with the technical collaboration of specialists from the Department of Conservation and Land Management in Western Australia.

West Timor has localised shortages of fuelwood, which are expected to become steadily more severe with time. It also has a cattle fodder resource problem caused by the combination of a large cattle population and virtual loss of one of the principal fodder sources, *Leucaena leucocephala* (Field and Yasin (1990) and Momuat et al. (in press)) as a result of the psyllid infestation.

Most people in the province subsist through shifting agriculture, and are unable to afford inputs, such as fertiliser, which would improve agricultural productivity and help them to stabilise their agricultural system. Greater use of legumes would benefit productivity if they could be made part of a more settled agricultural system and at the same time contribute to fodder and fuelwood needs.

With this background, the selection of species for trial in Timor concentrated on legumes which could tolerate the soil and climate factors, and produce both fuelwood and fodder. One complicating factor was the lack of good information on the fodder value of many legumes which might be of value in this environment. We selected a number of species from northern Australia on the basis that they were known to be taken by cattle (Turnbull 1986) and therefore there was not likely to be any obstacle to their use for livestock. However, whether they enable stock to gain weight or are of value merely to maintain the stock would require further study.

Less important tree uses considered in the choice of species for test were value for production of small logs for on-farm construction and material for fencing (either conventional post and rail or wire fencing or living fences). The possibility that a tree might also have some value for sawlog production was borne in mind as West Timor is an area of net deficit in sawn timber products.

Physical Environment

West Timor is one of the Outer Banda Arc of islands whose climate is greatly influenced by the proximity of the Australian land mass. As a consequence of the winds of the east monsoon being a hot dry outflow from the central Australian deserts, Timor has a long dry season of 8–9 months and a relatively short and unreliable wet season from December to

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March. Rainfall varies greatly from place to place due to topographic effects, but is generally in the range 800–1500 mm per annum. Dry season daily maximum temperatures average 33–36 °C. There is considerable topographic variation in Timor, so that the highlands are markedly cooler than the lowlands and receive more rainfall.

Timor is unique geomorphologically in that the island is built on clay, rather than rock, and this has profound consequences for its soils. The underlying parent material of the island is the Bobonaro Scaly Clay, which originated as volcanic ejecta laid down in a submarine environment. The clay so formed contains a high proportion of montmorillonite where the clay lattice is dominated by sodium ions. Timor occurs on the small Banda plate which is overriding the Australian continental plate. The island therefore contains the clay and fragments of the crustal plate, overlain around its edges by other formations laid down in sea (coral terraces) or lacustrine situations adjacent to the Bobonaro core. The geomorphology of the island has been described by Aldrick (1985).

The outcome of this history is a range of soils which are for the large part fragile, being subject to erosion and slumping, and often saline, sodic and alkaline. Most soils are alkaline to some extent. The vertisols formed on the Bobonaro Clay, which constitute about 30% of the land area of Timor, are particularly difficult to handle, as, in addition to poor fertility and sodicity, and a pH of 8–9, they are very prone to slumping when cleared of forest. Due to the high content of montmorillonite, the Bobonaro soils exhibit a high degree of contraction when they dry out. They wet up preferentially along the crack lines and tend to break away along those lines during wet periods, especially when there are earth tremors.

Large areas of this type have been cleared for cattle grazing in West Timor. They are maintained as grasslands by virtually annual burning. Indiscriminate use of fire in this way adds another dimension to tree species: fire sensitive species have poor prospects of success.

The red loam ultisol soils developed on the raised coral terraces (RCT) are well structured, have pH values closer to neutral (7.5) and are moderately fertile. They are frequently very shallow, although the limestone has many cavities which allow access to tree roots. Surprisingly large trees can often be seen on such sites. Although the most favoured soil for agricultural use, there are significant areas of shallow ultisol which could be used for reforestation.

The third main soil group is the entisols formed on the Viqueque formation. They are generally shallow soils, 30–60 cm in depth, calcareous and with pH values of 8–9. The Viqueque formation overlies the Bobonaro Clay and consists of white marls, grey claystones and chalky limestones. Soils formed here are generally quite well drained and of somewhat better fertility than those developed on Bobonaro Clay. They are extensively used for ladang and for livestock grazing.

Experimental Design

The approach taken was to establish field trial plots on each of the main soil types described above, and compare the growth and adaptability of the test species with local 'marker' species which had value for fuelwood and/or fodder. The theory was that unless an introduced species could perform better than a local species, there was no benefit to be gained from its introduction. In the data presented here, the local *A. leucophloia* (used for fodder) and the naturalised *A. auriculiformis* (used for fuel) were used as the markers.

Seedlings were raised in a central nursery at Sikumana, near Kupang, using unamended RCT red loam in 10 cm diameter polybags. All polybags were inoculated with *Rhizobium* brought dry from Australia. Although there are several species of *Acacia* growing in the area, it was considered a valuable insurance to inoculate the seedlings.

The standard field plot used was a 5 × 5 tree square plot, planted at 1 × 1 m spacing. Since the main objective was to screen species for further trial, this design made most efficient use of the limited land and staff resources available. The intention was to thin the plots after 3–4 years, depending on the rate of growth, to provide some preliminary information on early growth performance up to about age 5 years. For many purposes this age would be sufficient anyway. If a small farmer is to gain any useful benefit from a tree, he needs to realise at least some of that benefit in the first year or two.

Often, of course, nursery problems made it impossible to achieve the aim of 25-tree plots at all sites. This situation occurred in several species raised for the second year plots.

After a review of available information on the soils and climatic variation in Timor, it was decided to locate trial plots on each of the three main soil types — the raised coral terrace ultisols, the Viqueque entisols and the Bobonaro vertisols. One complete series was to be planted in the hotter, drier lowlands and another in the highlands around Soe, about 100 km from Kupang. Rainfall at the lowland sites was about 1200 mm, and in the highlands about 1500 mm (no accurate records for the trial sites are available).

For the first year's planting, in 1987, field trial sites were located in two of the three main soil types in the lowlands, the RCT red loam at Sikumana, near Kupang, and on a Viqueque at Besi Pae.

For the second year's planting, there were trials at the following sites:

Lowlands	Sikumana	RCT
	Besi Pae	Viqueque
	Besi Pae	Bobonaro
Highlands	Soe	RCT
	Soe	Bobonaro

Each plot site was cleared of all remaining woody vegetation, and the debris was removed from the plot area and burnt to avoid any ash-bed effects. Before planting took place, each plot site was sprayed with Roundup to control grass and herbaceous weed competition. All plots received two subsequent weed control treatments annually, so that they were kept essentially weed-free.

A study of this nature has some limitations, such as limited replication over sites, which are reflected in the results. It is difficult to determine survival and growth efficiently in the one trial. Survival data are not presented here as they are of less interest than the height growth data.

Plots were laid out in a split plot design, using the different plot sites as blocks, with two plots of each species at each site. The exception was the first year planting at Sikumana, where four blocks were planted, but one was later destroyed by fire. One plot of each species in each block was fertilised after planting with 50 g/tree of superphosphate, to evaluate the potential for productivity improvement by this means. For several species, two seedlots were used, to gain some feel for whether there was likely to be a significant amount of variation in performance from seed of different origins.

Results

First year plots

There were large differences between the height growth of many of the tested species from the first year. By the end of the second year after planting it had become necessary to thin the faster growing species. This was done by removing sufficient stems to leave the nine best stems in all plots. In a few plots the thinning was not completed by the time of measurement, so the heights of the nine best trees per plot were used to calculate the plot means in Table 1.

The data presented here are from a height measurement in July 1990, or 2.6 years after planting. Some qualifications have to be made, however. The height data in most cases represent the mean of four plots, each plot having nine trees in most cases. For species with poor survival some plots were complete failures and some have stocking as low as four stems. The data which are less reliable due to survival problems are indicated with an asterisk.

Table 1. Mean height (cm) of trees at Sikumana and Besi Pae at age 2.6 years.

Species	CSIRO Seedlot No.	Sikumana RCT	Besi Pae Viqueque
A. crassicarpa	15479	476	30
A. crassicarpa	13681	612	129
A. leptocarpa	15478	425	—
A. shirleyi	14622	239	—
A. ampliceps	17052	89*	451
A. auriculiformis	15477	577	550
A. holosericea	14660	318	337
A. leucophloia	local	51	188
A. stenophylla	14670	140*	204

N.B. We continue to refer to *A. holosericea* under that name as that was how the seed was supplied to us. It now appears that this seedlot should be known as *A. colei*.

Analysis of variance showed that there was no significant fertiliser effect overall, but some indication of a fertiliser x species interaction. However, there were highly significant ($P > 0.001$) differences in height growth between species. It is not possible to provide a single LSD figure for an unbalanced design of this kind. Specific comparisons can be made using the Tukey-Kramer test, but it is impractical to present data of that nature here.

Close examination of the data reveal very interesting differences in growth between different species on the same site, and between sites for some species. The outstanding example of the latter is the performance of *A. ampliceps*. At Sikumana it was virtually a failure, three of the four plots having zero survival, but at Besi Pae, on the more strongly alkaline soil, it was one of the best species, and one with real potential for use by farmers.

Similarly, both provenances of *A. crassicarpa* performed well at Sikumana, but much more poorly at Besi Pae. At the latter site, all plants of S/N 15479 suffered severely from a nutrient deficiency and were only about one quarter of the height of the other provenance.

Both *A. shirleyi* and *A. leptocarpa* were complete failures at Besi Pae, but survived well at Sikumana, although their growth was poor relative to *A. crassicarpa* and *A. auriculiformis*.

Of the marker species, *A. auriculiformis* was as good as the best of the introductions at Sikumana and better than all of them at Besi Pae, so none of the tested acacias had anything to offer in terms of growth rate. *A. leucophloia* grew very poorly at Sikumana but much better at Besi Pae, as might be expected as it occurs naturally around the plot site, but does not grow at Sikumana. The markedly better growth of *A. ampliceps* at Besi Pae, where it was the second best species after *A. auriculiformis*, indicated this species might have real promise for use by farmers, if its foliage was acceptable for fodder. Its relatively light canopy lends itself to use as an overstorey for other food crops.

The height growth of *A. holosericea* was much the same at both sites, although well below that of *A. auriculiformis*. However, this is a rather unfair comparison as it has a bushy habit of growth, whereas the *A. auriculiformis* and *A. crassicarpa* seedlots used have had strong apical dominance.

Second year plots

For the second year of field trials, the work was expanded to include highland (Soe) and lowland (Sikumana and Besi Pae) sites, as well as the first trials on the Bobonaro clay soils. Some difficulties were experienced in the nursery in the second year, making it necessary to use uneven numbers of trees in the plots at different sites. Where a species had been tried the previous year, and we could be confident of good survival, we used only nine trees per plot. But if we had not tested a soil type or climatic zone before, we tried to use the full 25 trees per plot.

The mean heights presented in Table 2 are the means of all surviving trees. The same species as the previous year were used, with some new species. For two of the new species, two seedlots were used, to explore the possibility of useful differences in performances of different provenances, following the differences displayed by the two *A. crassicarpa* provenances in the previous year. As in the first year results, analysis of variance showed highly significant differences ($P > .001$) in height growth between species, no significant overall fertiliser effect, but an indication that some species responded more to fertilisers than others.

Interpretation of the data in Table 2 is made difficult by the lack of plots in some species at some sites, nevertheless some general trends can be discerned. Species which had been planted the previous year generally performed the same way in the second year and the relative growth of the different species was about the same. *A. holosericea* height growth was as good as *A. auriculiformis* on all sites, and as it has a more bushy growth habit, its dry weight production was probably superior.

It was surprising that all species grew less well in the highland site near Soe, than in the lowlands, when growth is compared on similar soil types. This was completely contrary to expectation, as the cooler, moister climate there should have favoured

Table 2. Mean height (cm) of trees in second year plots, age 1.6 years.

Species	CSIRO Seedlot No.	Sikumana RCT	Besi Pae Bobo	Besi Pae Vique	Soe Bobo	Soe RCT
A. crassicarpa	15479	322	82	37	61	169
A. crassicarpa	13681	NP	NP	NP	204	134
A. leptocarpa	15478	285	178	110	41	186
A. shirleyi	14622	NP	NP	NP	—	—
A. ampliceps	17052	NP	NP	NP	199	89
A. auriculiformis	15477	313	215	386	90	164
A. holosericea	14660	289	218	275	60	131
A. leucophloia	local	54	34	48	71	86
A. stenophylla	14670	NP	NP	NP	110	NP
A. trachycarpa	15767	NP	NP	NP	71	—
A. polystachya	15860	282	162	57	40	144
A. polystachya	13871	226	44	158	31	121
A. torulosa	14888	314	—	—	—	230
A. plectocarpa	16182	NP	NP	NP	—	103
A. plectocarpa	17499	NP	NP	NP	NP	120

NB: — indicates plot failure
NP means no plot due to lack of sufficient seedlings
Bobo = Bobonaro clay
Vique = Viqueque
RCT = Raised coral terrace soil

better tree growth than in the lowlands at Sikumana and Besi Pae.

Of the new species, *A. plectocarpa* had too few plots to draw any useful conclusions, as did *A. stenophylla* and *A. trachycarpa*. There were marked differences in the performance of the two provenances of *A. polystachya*. One performed well on the Raised Coral Terrace soil at Sikumana and the Bobonaro clay at Besi Pae, but poorly on the Viqueque and both sites at Soe. The other did moderately well at Sikumana, poorly on the Besi Pae Bobonaro, but quite well on the Viqueque, and badly again at Soe. *A. torulosa* did best of all on the RCT at Sikumana and on the same soil type at Soe, but failed at all other sites, indicating little tolerance to high soil alkalinity. Its good performance (better than the marker) on the ultisols indicates it is worthy of further study on those soils.

The sources of the seed used in these trials are shown in Table 3. It is of interest that the best performing provenance of *A. crassicarpa* was the more northerly one, which confirms the findings of Pinyopusarerk (1989) in Thailand, Ryan and Bell (1989) in Queensland and in Sabah (Sabah Forest Industries 1990). The seedlot serial numbers quoted are those allocated by the CSIRO Tree Seed Centre, who provided all the seed used in the trials, apart from the local Timor collections.

At this stage there appear to be no significant pest problems with any of the *Acacia* species included in these trials. All have suffered to some degree from leaf-eating insects (beetles, grasshoppers) but none seems particularly susceptible to damage. Termite damage has also been only slight.

Discussion

The results indicate that there are several species of *Acacia* from Australia which have real potential for use in West Timor for a number of purposes. On the highly erodible vertisols formed on the Bobonaro Clay, several species are capable of growing much faster than the native *A. leucophloia* and the previously introduced *A. auriculiformis*. *A. holosericea, A. ampliceps* and *A. crassicarpa* would be quite suitable for rehabilitation of landslides on those soils and would provide much more rapid cover than *A. leucophloia* or *Casuarina junghuhniana* which naturally gradually colonise such sites.

A. holosericea and *A. ampliceps* could also supplement *A. auriculiformis* in the integrated farming systems being developed in the entisols typical of the Viqueque formation. If the potential of the seed of *A. holosericea* (*A. colei*) for human consumption is realised (Rinaudo, pers. comm.), then it should be easily assimilated into NTT farming systems. The seeds ripen just at a time when other sources of food are very limited. However, a great deal of work remains to be done to select high seed-yielding strains of this species and develop suitable management techniques.

Another interesting outcome of the field trials was the consistent differences in performance on different soils of different provenances of *A. crassicarpa*. There is an indication of similar differences between two provenances of *A. polystachya*. These results indicate the need for extensive provenance testing, once a species has been identified as showing some promise. Furthermore, they indicate that species

Table 3. Source of seed used in Timor screening trials.

Species	CSIRO Seedlot No.	Locality
A. crassicarpa	15479	Coen, Queensland
A. crassicarpa	13681	Mata, Papua New Guinea
A. leptocarpa	15478	Musgrave, Queensland
A. shirleyi	14622	Daly Waters, Northern Territory
A. ampliceps	17052	Roebuck Plain, Western Australia
A. auriculiformis	15477	Morehead River, Queensland
A. holosericea	14660	Turkey Creek, Western Australia
A. leucophloia	—	Ikan Foti, West Timor
A. stenophylla	14670	Cow Creek, Western Australia
A. trachycarpa	15767	DeGrey River, Western Australia
A. polystachya	15860	Lockerbie, Queensland
A. polystachya	13871	Bridle, Queensland
A. torulosa	14888	Laura, Queensland
A. plectocarpa	16182	Mann River, Northern Territory
A. plectocarpa	17499	Spillway Creek, Western Australia

screening trials, at least in this region, should always test more than one provenance of a species. If we had tested only *A. crassicarpa* S/N 15479, we would probably not have bothered to persist with this species.

Although the field trials are only 3 years old, some species can be rated for their tolerance to alkaline soils and, to a lesser extent, for their suitability for highland or lowland sites. The following species appear to have a poor tolerance for soils of pH8 and above:

A. shirleyi	
A. torulosa	
A. crassicarpa	(S/N 15479)
A. polystachya	(S/N 13871)
A. leptocarpa	

Species which tolerate a high level of soil alkalinity in these trials are:

A. ampliceps	
A. leucophloia	
A. auriculiformis	
A. holosericea	
A. polystachya	(S/N 15860)
A. crassicarpa	(S/N 13861)

Both *A. ampliceps* and *A. leucophloia* appear to grow better on alkaline soils than on near-neutral soils. *A. auriculiformis* and *A. holosericea* appear to be insensitive to soil pH, within the limits sampled in our trials.

The unexpected finding that all species grew less well at the higher, cooler sites at Soe needs further testing, as it might have been an artifact of seasonal conditions in that year.

There is an indication that *A. torulosa* is less severely affected by the highland climatic conditions than the other species. Finding a group of species suited to the highland conditions is clearly an avenue for future research.

We plan to continue the species screening trials, but at a lower level than in the first two years, and concentrate on defining the best provenances of the most promising species: *A. crassicarpa, A. auriculiformis, A. ampliceps* and *A. holosericea.* This was, in fact, the thrust of the third year trials. In that year we also established 'production areas' of these species to provide material for further silvicultural research and fodder value trials. Once we know which are the best species/provenances for each soil type, the next step is to develop a way of managing the trees to produce something useful to the smaller farmer.

Acknowledgments

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References

Aldrick, J.M. 1985. Volume III, Land Resource. In: NTT Livestock Development Project Feasibility and Design Study, ACIL Australia Ltd, Melbourne.

Field, S.P. and Yasin, M. 1990. Improving the effectiveness of multipurpose tree research in Nusa Tenggara Timur, Indonesia. Proc. Symp. Multipurpose Tree Species Research for Small Farms: Strategies and Methods, Jakarta, November 1989. Winrock Institute for Agricultural Development and IDRC, 125–132.

Momuat, E.O., Field, S.P. and Bamualin, A. Forage Production Systems in Nusa Tenggara Timur. Proc. Seminar 'Production and Utilisation of Shrub Legumes in the Tropics', Denpasar, 31 July–1 August 1990. In press.

Pinyopusarerk, K. 1989. Growth and survival of Australian tree species in field trials in Thailand. In: Boland, D.J., ed., Trees for the Tropics: growing Australian multipurpose trees in developing countries. ACIAR Monograph No. 10, 109–127.

Ryan, P.A. and Bell, R.E. 1989. Growth, coppicing and flowering of Australian tree species in trials in southeast Queensland, Australia. In: Boland, D.J., ed., Trees for the Tropics: growing Australian multipurpose trees in developing countries. ACIAR Monograph No. 10, 247 p.

Sabah Forest Industries. 1990. 1988/89 Research Report, Vol. III.

Turnbull, J.W. 1986. Multipurpose Australian Trees and Shrubs: lesser known species for fuelwood and agroforestry. ACIAR Monograph No. 1, 316 p.

Performance of *Acacia auriculiformis* in India

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Abstract

Acacia auriculiformis (Benth) A. Cunn., introduced into India in 1946 for lateritic soils in West Bengal, grows successfully in all types of soil and climate, especially for afforestation of grasslands, reforestation of degraded forests and roadside planting. It has also been planted as a mixed crop along with *Eucalyptus* hybrid, *Leucaena leucocephala, Casuarina equisetifolia, Acacia nilotica* and *Dalbergia sissoo.*

The present technique is to sow seeds treated with boiling water in polybags and to plant out in the field after 4–6 months. The rotation is 10 years when it attains a height of about 12 m and a girth of about 60 cm (at bh) in best areas. In 8 years, it has produced a total fresh biomass of 243 t/ha in Madikeri, the wood biomass alone (64 t/ha) forming 63% of total biomass.

Experiments have shown that *Acacia auriculiformis* plantations have enriched the soil through litter, and the soil pH has increased from 4.98 to 5.37 over a period of 8 years. The species has grown faster than *Casuarina equisetifolia*, but not as well as *Eucalyptus* hybrid and *Leucaena leucocephala*. It is an excellent species to suppress grass and weeds and its wood is used widely as fuelwood, pulpwood, in toy making and furniture.

ACACIA *auriculiformis* (Benth) A. Cunn. was first introduced to India on plantation scale in West Bengal in 1946 for laterite areas (Banerjee 1973). Its introduction has been extended all over India from coastal sands to high altitude laterite soils and from areas having 500 mm to over 7000 mm of rainfall per annum. It is now one of the main species in reforestation of degraded forests and grasslands, used as a cover crop and also a source of fuelwood. The species is also used as a nurse crop with an ultimate aim of introducing shade tolerant and more valuable evergreen species under it. Being an evergreen species, *A. auriculiformis* keeps the barren hill slopes characteristically green all through the year and improves the soil with leaf litter and through its nitrogen fixing roots. It has now been widely accepted as an indispensable species for various locations. It has also been mixed in plantations with *Eucalyptus* hybrid, *Cassia siamea, Casuarina equisetifolia, Dalbergia sissoo* and *Acacia nilotica.* The strong objections of environmentalists against raising eucalypts have given further impetus to this species in India's plantation program.

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Establishment Techniques

When it was first introduced in southern India in the 1970s, the technique was to sow the pretreated seeds on the mounds formed out of trenches along the contour. The pretreatment consisted of pouring boiling water over the seeds and allowing them to soak for 3–4 minutes, then keeping them in cold water for 24 hours. When the cost of establishment per ha was increased, the technique was improved and now the pretreated seeds are sown directly into polybags and nursed for 4–6 months before planting in the field. The planting is normally done in 45–50 cm cube pits or in trenches (4 m long, 0.50 m wide and 0.50 m deep) at 5 m contour intervals. In each trench one seedling of *A. auriculiformis* will be planted with two other valuable species as a mix.

In a few places the degraded areas were ripped by bulldozer and seedlings were planted in manually formed furrows. The spacing is normally 2 × 2 m in square planting or 4 × 5 m if in trenches. In fertile, well worked soils the 2 × 2 m spacing enables intermediate thinning out 3 or 4 years after planting and the thinnings can be used as fuelwood. Rotation time is 10 years, when the plantation will be clearfelled and replanted.

Table 1. Growth data of *A. auriculiformis* from various localities.

Location (State)	Annual rainfall (mm)	Soil	Age (yr)	Gbh (cm)	Ht (m)	Source
Tyrandur (Karnataka)	2000	Laterite	7	29.0	8.8	Sugur 1989
Kunchenahally (Karnataka)	800	Red loam	5	17.0	6.2	Silviculturist
	1000		6	19.0	7.2	Dharwad (pers. comm.)
			7	21.0	8.4	
Arabari (West Bengal)	1000	Red soil	16	35.9	10.2	Banerjee 1973
Garbeta (West Bengal)	1200	Deep red soil	10	28.0	8.5	Banerjee 1973
			6	21.2	7.0	Banerjee 1973
Madikeri (Karnataka)	2000	Red soil	11	70.0	13.7	Silviculturist
			8	46.0	9.7	Madikeri (pers. comm.)
Badami (Karnataka)	750	Sandy loam	10	36.2	11.3	Silviculturist Dharwad (pers. comm.)

Growth

The growth measurements of *A. auriculiformis* in plantations raised at 2 × 2 m spacing at different localities are given in Table 1. Girth and height vary considerably with locality. The growth recorded at Madikeri, Karnataka was by far the best; trees attained a girth of 70 cm and a height of 13.7 m in 11 years. Madikeri receives an average annual rainfall of 2000 mm. Growth was poorer in areas with less rainfall. At Badami, also in Karnataka, trees reached a girth of 36 cm and a height of 11 m in 10 years. The area's rainfall averages 750 mm, less than half that at Madikeri. Soils in these areas differ, and this has shown up in tree growth. Trees were growing better on red soil at Madikeri than on lateritic soil at Tyrandur.

A. auriculiformis and *Eucalyptus* hybrid have been tried in the same locality and therefore a comparison of growth is possible. Data on growth in height and diameter for 10 years are given in Table 2 for these two species. The height and diameter growth are better in *Eucalyptus* hybrid right through to the 10th year (rotation age) in sandy soils of Badami where the annual average rainfall is around 750 mm (temperatures 16 °C (Jan.) mean minimum and 39 °C (April) mean maximum).

Biomass Studies

Biomass studies were carried out in 7–8-year-old plantations at Madikeri, Talacauvery and Tyrandur. Table 3 shows dry weight of various tree components as well as total growing stock and mean annual increment. The spacing was 2 × 2 m at all localities. The biomass studies in Madikeri and Talacauvery were carried out in September 1990, which was the period of decreasing southwest monsoon rains. Moisture content was generally higher in all tree components tested from the higher rainfall area (Talacauvery) except in leaf and root material. The average moisture content for whole trees is 43.26 and 45.95% respectively for plantations at Madikeri and Talacauvery. The total biomass was more (by 13.8%) in the lower rainfall area (Madikeri). Compared to the figures available for Malaysia, Indonesia and West Bengal (India), the mean annual increment is better in the plantations under study. In Tyrandur the growth was poor as indicated by mean annual increment of 12.66 t/ha (Sugur 1989). The wood including bark formed 92% of total above ground biomass. Root biomass was however not assessed at Tyrandur.

Litter Studies

Litter studies were carried out in 1977 Sakleshpur plantations of *A. auriculiformis* in 1986 to determine monthly litter production. Table 4 gives litter production in tonnes per ha of fresh (green) weight. Litter production was higher in the rainy season. The annual litter production is 10.7 t/ha in 8-year-old plantations at 2 × 2 m spacing. The average moisture content in leaf litter was 32.0%, compared to 28.0% in twig litter and 27.0% in bark litter. Therefore, the total dry litter production was 7.4 t/ha.

The trees have not shown any indication of flowering even after 15 years in these areas. This is the case in all plantations of *A. auriculiformis* located at altitudes over 1000 m where the summer rainfall exceeds 2000 mm per annum. The reasons for this phenology are still under investigation. The litter production in *Casuarina equisetifolia* plantations of the same age and spacing and in the same locality was 11.6 t/ha of fresh weight, of which the fruit litter was 1.6 t/ha.

The average percentage concentration of N in leaf litter was 1.22 and the maximum percentage concentration of P was 0.296, Mg was 0.669 and Ca was 2.44. Comparatively the percentage concentration of nutrients in leaf litter of *Casuarina equisetifolia* was N: 1.135, P: 0.059, Mg: 0.416 and Ca: 1.7. The non-leaf litter of *A. auriculiformis* has shown comparatively less concentration of nutrients.

Table 2. Comparative average growth rates of two species over 10 years in Badami, Karnataka.

Age (yr)	*A. auriculiformis* Height (m)	*A. auriculiformis* Diameter (cm)	*Eucalyptus* hybrid Height (m)	*Eucalyptus* hybrid Diameter (cm)
1	—	—	—	—
2	—	—	—	—
3	7.25 ± 1.70	5.31 ± 0.60	—	—
4	8.23 ± 1.80	6.85 ± 0.72	9.67 ± 1.02	7.99 ± 1.02
5	8.46 ± 1.80	7.59 ± 0.80	12.30 ± 3.28	9.66 ± 1.21
6	8.78 ± 1.88	8.42 ± 0.81	12.88 ± 3.43	10.69 ± 1.51
7	9.18 ± 1.82	9.02 ± 1.00	13.03 ± 3.46	11.24 ± 1.64
8	9.80 ± 2.13	10.00 ± 1.31	13.33 ± 3.50	11.25 ± 1.90
9	10.41 ± 2.10	10.88 ± 1.52	14.11 ± 4.22	12.51 ± 1.98
10	11.27 ± 2.70	11.53 ± 1.80	14.59 ± 3.63	13.45 ± 2.11

± indicates standard deviation

Table 3. Mean weights of various components of *Acacia auriculiformis* from three contrasting localities.

Details	Locality		
	Madikeri (8 yr)	Talacauvery (8 yr)	Tyrandur (7 yr)
Altitude (m)	1100	1400	600
Rainfall (mm)	2000	6000	2000
Soil	Clayey loam	lateritic	lateritic
Mean min. temp (°C)	16.0	14.0	16.5
Mean max. temp (°C)	24.0	23.0	27.0
Girth at BH (cm)	38.0	36.0	29.0
Bole length (m)	6.80	6.26	6.00
Oven dry weight (kg)			
Wood	64.25(63)	57.50(65)	36.17(92) (with bark)
Bark	11.30(11)	9.35(11)	
Twig	6.85(7)	4.75(5)	1.58(4)
Leaf	7.10(7)	6.50(7)	1.65(4)
Above-ground biomass	89.50	78.10	39.40
Root	13.00(12)	10.25(12)	—
Total biomass	102.50	88.35	
Total growing stock (t/ha)	243.44	198.79	88.66
Mean annual increment (t/ha)	30.43	24.85	12.66

Note: The percentage of each component to total biomass is given in parenthesis

Table 4. Mean litter production (green weight, t/ha) in an 8-year-old *A. auriculiformis* plantation at Sakleshpur.

Component	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Leaf	1.06	0.96	0.68	0.64	0.56	0.68	1.20	0.50	0.48	0.64	0.43	0.86
Twig	—	—	0.12	0.04	0.04	0.10	—	—	—	0.70	0.60	—
Bark	—	—	—	—	—	—	0.25	0.06	0.08	—	—	0.06
Total	1.06	0.96	0.80	0.68	0.60	0.78	1.45	0.56	0.56	1.34	1.03	0.92
Rainfall (mm)	5.6	5.1	5.9	51.8	113.5	397.3	859.0	452.1	170.2	186.4	81.5	20.3

Nutrient Release

Taking into consideration the average nutrient concentration percentage in leaf and non-leaf litter and the average annual production (t/ha) of litter, the annual nutrient release (kg/ha) from litter is calculated and given in Table 5.

Maximum release of nutrient from litter was 170.6 kg/ha/yr of Ca, followed by 81.17 kg/ha/yr of N. The phosphorus release from litter was only 4.20 kg/ha/yr.

Table 5. Nutrient release (kg/ha/yr) from litter in an 8-year-old *A. auriculiformis* plantation at Sakleshpur.

Nutrients	Leaf	Non leaf	Total
N	72.15	9.02	81.17
P	3.16	0.59	4.20
K	17.49	2.69	20.18
Mg	39.53	4.98	44.51
Ca	144.20	26.45	170.65

Soil Improvement

A study was also undertaken in Madikeri to determine the extent of enrichment of soil nutrients by *A. auriculiformis* over a period of 8 years, compared to the nutrient content of soil at the beginning of the plantation (at zero age). The soil samples at two different depths (0–15 cm and 15–30 cm) were analysed and increases, due to litter decomposition in the plantations, were recorded for most nutrients measured (Table 6).

Table 6. Nutrient content (kg/ha) at various soil depths in *Acacia auriculiformis* plantations at Madikeri.

	At zero year		At 8 years	
Nutrient	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Ammonia	24.66	13.45	103.10	82.93
Nitrate	22.41	13.45	100.86	77.33
Phosphorus	4.48	4.48	4.48	4.48
Potash	33.62	24.66	58.28	38.10
Calcium	358.62	358.62	896.55	896.55
pH	4.98	4.86	5.37	5.21

Discussion

Acacia auriculiformis is now one of the most successful species in India and has been planted in all kinds of soils, altitude and climate. Plantations of *A. auriculiformis* are seen side by side with other species like *Eucalyptus* hybrid, *Casuarina equisetifolia* and *Leucaena leucocephala*. Keeping the quality in view, the most ideal spacing is 2 × 2 m, but 1 × 1 m spacing has given higher biomass production per ha due to increased population (Kushalapa 1987). The closer spacing produces inferior stems and causes early crowding thus retarding growth. The height and diameter growth are better than those of *Casuarina equisetifolia* (Kushalapa 1988) but *Eucalyptus* hybrid and *Leucaena leucocephala* are found to grow faster than *A. auriculiformis*. In red soils the growth response to irrigation was comparatively poor and the increase of biomass was only 22.86% by dry weight, whereas *Eucalyptus camaldulensis* and *Leucaena leucocephala* have shown an increase of 143 and 285% respectively (Swaminath et al. 1989).

A. auriculiformis species has adapted well in soils with pH from 4.98 to 8.12. For afforestation of high altitude grasslands, this species is better than *Casuarina equisetifolia*, as it casts heavy shade within a year of planting and thus suppresses grass considerably. The annual litter production is also quite high and when decomposed will add substantial quantity of nutrients to the soil. The trees are not ordinarily browsed and hence the survival percentage is also good. This species is not as drought tolerant as *Eucalyptus* hybrid and in times of severe drought it wilts and dies much earlier. However it thrives well in infertile soils and low rainfall areas and is suitable for semi-arid regions of India.

Experiments have shown that the wood is suitable for paper pulp and is also being used as fuelwood due to its high calorific value. The wood is also good for carving and lacquer work and is an alternative now to the traditional wood of *Wrightia tinctoria* in toy-making (Rajan et al. 1979). It also makes excellent but cheap furniture. The present target of planting is roughly about 10 000 ha in India both as a pure and mixed crop. Therefore there is an urgent need for tree improvement programs to evolve fast-growing, drought-tolerant and high-yielding varieties.

References

Banerjee, A.K. 1973. Plantations of *Acacia auriculiformis* (Benth) A. cunn. in West Bengal. Indian Forester, 99, 533–540.

Kushalapa, K.A. 1987. Comparative biomass of *Acacia auriculiformis* and *Casuarina equisetifolia* under different spacings. Van Vigyan, 25, 51–55.

1988. Comparative productivity of *Acacia auriculiformis* and *Casuarina equisetifolia* in high rainfall areas. NFTRR, 6, 12.

Rajan, B.K.C., Kushalapa, K.A. and Khan, K.A.R. 1979. Wood of *Acacia auriculiformis* for turnery and lacquer coating. Myforest, 15, 83–86.

Sugur, G.V. 1989. Biomass production of different density stands of *Acacia auriculiformis* and *Casuarina equisetifolia*. Myforest, 25, 84–88.

Swaminath, M.H. and Vadiraj, B.A. 1989. Studies on the N, P and K uptake by forestry species under irrigated and unirrigated conditions. Myforest, 25, 135–143.

Species Trials of Some Acacias in Tropical Dryland Queensland, Australia

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Abstract

The paper presents some early results from trials involving Australian tree species planted in semi-arid environments in the tropics of north Queensland, Australia. Results after the first season indicated that as site difficulty increased (decreasing annual rainfall and increasing temperature) survival and growth rate decreased for a number of acacia species. *Acacia holosericea*, *A. glaucocarpa* and *A. salicina* have been indentified as species potentially suitable for planting in dryland areas, but growth rate and survival will depend on available moisture. Further monitoring of the trials is required.

A NETWORK of species trials was established from 1984 to 1987 in Australia, Thailand, Kenya and Zimbabwe with the sponsorship of ACIAR. The major aim of these trials was to evaluate the potential of a wide range of lesser known Australian species for purposes such as fuelwood, fodder and agroforestry.

A large number of species that may be useful for testing outside of Australia has been identified from these trials. Data on growth and biology are being assembled to enable analysis of the climatic requirements of a species (Booth 1987) but this information has been limited by the range of climatic and soil variation covered by the trial sites. To develop information on the environmental limitations of the species, trials on a greater range of sites is necessary. Due to the problems associated with growing trees in semi-arid/arid areas, identifying species suitable for planting in these areas is of considerable importance.

The establishment of trees in dryland areas is limited predominantly by low annual precipitation. It is essential therefore that planting is timed to coincide with rain, which can be difficult when rainfall occurs infrequently and irregularly. Nursery stock must be healthy and well drought-conditioned also. Termites, browsing by insects and animals and extremes of soil and air temperatures pose additional problems.

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In 1989 and 1990 a series of species trials was established in the drier part of tropical Queensland, Australia. These trials aimed to complement trials established in dryland areas in Kenya and were selected to cover a gradient of climatic conditions. This paper discusses the establishment and early performance of acacias and some comparative species in the dryland trials established in 1989.

Methods

Site details

Two sites are in northern Queensland at Mareeba and Charters Towers and the remaining sites are in central Queensland at Longreach. Details of the sites are provided in Table 1. The soils at three of the sites are coarse-textured and mildly acidic red earths while an alkaline cracking clay was included at Longreach. At Longreach two different locations were covered for each soil type. Using interpolation surfaces for climatic estimates three of the Longreach sites were found to be comparable — the cracking clays and one of the coarse-textured sites. Data were therefore combined for these sites (see Table 1). The other coarse-textured site was very different in climate, therefore estimates are presented separately.

The original vegetation at the north Queensland sites was open forest dominated by eucalypt species (Specht et al. 1974). At Mareeba, the main eucalypt species were *Eucalyptus leptophleba* and *E. polycarpa*. At Charters Towers they were *E. crebra* and *E. papuana*. The coarse-textured earths at Longreach carried low open woodland dominated by *E. papuana*. The cracking clay soils are naturally treeless and notoriously difficult for the establishment of trees.

Nursery

All planting stock was raised at the Queensland Forest Service coastal nursery at Toolara. Fertilisers, potting mixes and watering regimes followed those outlined by Ryan et al. (1987), but all stock was grown in the larger Queensland Forestry tube (volume 170 cc).

In the latter part of the 1989 nursery phase unseasonally high rainfall and associated humidity resulted in severe declines in seedling health. To compound the problems associated with the adverse weather conditions, routine nursery management, which involves high density stand-out bays, caused poor air circulation. Resultant fungal diseases caused further dieback to some species. Subsequently, a large number of species failed in the nursery and had to be excluded from outplanting. These species originated from a range of environments but those most severely affected were from areas where annual rainfall is less than 500 mm.

Nursery procedures were modified for the 1990 planting, and these resulted in considerable improvements in the health and quality of the stock available for outplanting. The potting medium was changed to a mix of one part each of peat, vermiculite and perlite following laboratory tests on moisture-holding capacity and air filled porosity of a range of mixes.

At the onset of high humidity and rainfall, plants showing signs of dieback were covered to exclude rain and watering of all plants was reduced. In addition, all species were sorted into different height categories and each category watered only as required. Species observed to have excessive leaf shed or symptoms of dieback were double spaced within trays to improve air circulation.

Field establishment

Site preparation over all sites involved clearing and the removal of all existing vegetation from the experimental area. In north Queensland both sites were strip-ploughed along the planting lines and planting holes augered using a tractor-mounted tree planting auger. At Longreach all sites were cross cultivated with offset disc harrows while the red earth sites were also cross ripped to 25 cm in two directions. All trees were then hand planted using mattocks. Planting conditions were ideal over all sites, with heavy rains falling both pre- and post-planting.

All trees were fertilised with a complete NPK fertiliser, one-third applied at planting and two-thirds at age one year, delivering a total of 70 kg/ha N, 75 kg/ha P and 62 kg/ha K.

Where termites were a potential risk, carbosulfan (Marshal suscon) controlled release insecticide granules were mixed with the backfill from the planting hole. This is an experimental formulation developed by Incitec and has been successful in controlling termites in field trials in Africa.

After planting, all trees were mulched with hay for water conservation and weed control.

Table 1. Details of trial sites.

Site	Mareeba	Charters Towers	Longreach		
			Coarse-textured soils		Cracking clays
Latitude (°S)	16.98	19.62	27.12	23.42	23.42
Longitude (°E)	145.33	145.8	143.18	144.19	144.19
Altitude (m)	530	295	175	195	195
MAT (°C)	22.2	24	21.8	23.4	23.4
MMTCM (°C)	11.1	10.1	5.1	6.7	6.7
MMTHM (°C)	31.8	35.5	37.6	37.1	37.1
MAR (mm)	894	609	266	399	399

Sites in order of increasing level of harshness
Note: Sites are combined and data averaged where individual sites are comparable
MAT: Mean Annual Temperature
MMTCM: Mean minimum temperature of the coldest month
MMTHM: Mean maximum temperature of the hottest month
MAR: Mean Annual Rainfall
Estimates provided by T.H. Booth following the procedure described by Hutchinson (1988)

Experimental design

The design was a randomised incomplete block with four replications. Each replication consisted of a line plot of seven trees with 2 m between trees within plots and 3 m between plots.

At Longreach, irrigation was laid out over the red earth sites and two replications of the cracking clay sites. Irrigation was discontinued on two of the red earth replications 7 months after establishment. There was no irrigation at the Mareeba or Charters Towers sites.

Details of seedlot number, species, provenance and trial planting sites are contained in Appendix 1.

Results and Discussion

Survival, mean height and diameter at ground level for each species at ages 13, 14 and 11 months for the Mareeba, Charters Towers and Longreach sites respectively, are presented in Appendix 2. Table 2 presents the results for species common to at least the acid soil sites.

Acacia salicina has the best survival for the acacia species over all sites. However, growth has been relatively slow when compared with *A. holosericea* and *A. glaucocarpa*.

A. brassii, A. cincinnata and *A. plectocarpa* (Spillway Creek) showed good growth and survival at Mareeba, the site receiving the highest annual rainfall. But growth and survival declined steadily as the level of site stress increased. This trend was obvious for a number of the acacia species. In particular *A. brassii, A. cincinnata, A. difficilis* and *A. glaucocarpa* had lower survival (Fig. 1) and height growth (Fig. 2) on the harsher sites.

Survival of *A. ampliceps* and *A. tumida* over all planting sites was poor while the growth and survival of *Casuarina cunninghamiana* and the eucalypt species over all planting sites were generally good.

Mareeba

Species with over 90% survival at Mareeba included *A. brassii, A. cincinnata, A. glaucocarpa, A. leptocarpa, A. storyi, A. concurrens, A. holosericea* (Carranya) and *A. salicina*.

Table 2. Results for species common to most sites.

CSIRO Seedlot No.	Species	Survival (%) Trial site and age (months)						Height (cm) Trial site and age (months)						Diameter, ground level (cm) Trial site and age (months)					
		M	C	LE +I	LE −I	LC +I	LC −I	M	C	LE +I	LE −I	LC +I	LC −I	M	C	LE +I	LE −I	LC +I	LC −I
		13	14	11	11	11	11	13	14	11	11	11	11	13	14	11	11	11	11
15734	*A. ampliceps*	21	18	0	0	21	0	181	165	f	f	132	f	2.3	3.5	f	f	4.2	f
16134	*A. brassii*	100	75	21	14	—	—	364	189	113	71	—	—	5.6	2.5	2.1	1.3	—	—
15961	*A. cincinnata*	100	71	43	21	—	—	308	121	102	34	—	—	6.0	1.9	2.2	1.1	—	—
15949	*A. crassicarpa*	86	71	43	29	—	—	237	66	116	70	—	—	4.2	1.4	3.2	2.1	—	—
16173	*A. difficilis*	68	46	21	0	—	—	163	90	78	f	—	—	4.9	1.6	2.3	f	—	—
15473	*A. glaucocarpa*	100	89	64	21	—	—	407	257	192	106	—	—	5.8	3.3	3.7	2.2	—	—
16389	*A. holosericea*	82	71	29	50	43	0	431	261	315	281	164	f	6.2	3.0	4.6	4.1	2.3	f
16182	*A. plectocarpa*	71	64	57	50	21	0	183	77	131	52	26	f	4.2	1.5	3.6	1.6	0.9	f
17499	*A. plectocarpa*	86	82	21	43	0	0	327	165	161	189	f	f	5.5	2.5	3.8	4.3	f	f
15465	*A. salicina*	93	68	93	79	86	57	162	111	92	47	98	39	3.0	2.2	2.3	1.2	2.8	1.1
14576	*A. simsii*	68	54	50	36	—	—	226	118	99	91	—	—	4.0	1.5	2.0	2.0	—	—
17046	*A. tumida*	14	32	0	14	—	—	177	107	f	79	—	—	2.4	1.2	f	2.9	—	—
13508	*C. cunninghamiana*	93	96	100	86	—	—	208	240	187	207	—	—	3.1	3.5	3.3	3.8	—	—
15504	*E. argophloia*	100	93	100	79	100	50	120	163	176	156	175	80	2.3	2.8	4.3	3.6	3.9	1.4
14338	*E. camaldulensis*	100	100	100	100	100	57	336	233	323	255	199	141	5.4	3.1	5.5	4.5	3.4	1.8
12937	*E. cambageana*	93	89	100	71	100	57	100	114	150	120	121	69	1.2	1.5	3.4	2.8	2.2	1.1
15944	*E. microtheca*	93	100	93	86	93	71	138	170	183	124	166	91	2.8	3.0	4.4	3.0	3.2	1.5

f: fail

Trial Sites

M Mareeba (4 reps, no irrigation); C Charters Towers (4 reps, no irrigation); LE Longreach, earth (2 reps, continuing irrigation, 2 reps irrigation for first 6 months); LC Longreach, clay (2 reps, continuing irrigation, 2 reps no irrigation)

+I Continuing irrigation; −I Irrigation for the first six months only

— not planted

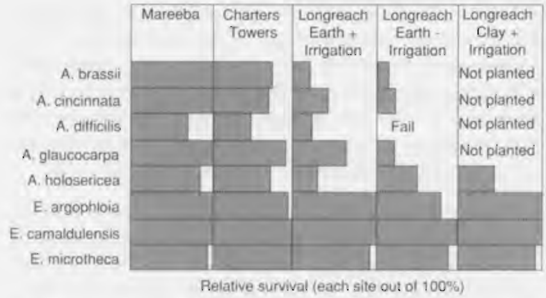

Fig. 1. Effect of site on the survival of some *Acacia* and *Eucalyptus* species at about one year of age.

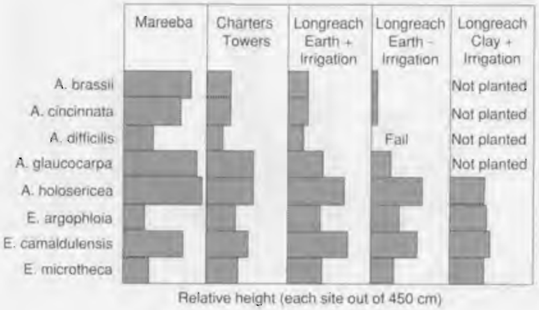

Fig. 2. Effect of site on height of some *Acacia* and *Eucalyptus* species at about one year of age.

All the above species showed good height growth on this site, having attained greater than 300 cm by 14 months of age. However, the best performer was *Acacia holosericea* (Coopers Creek) with an average height of 431 cm. This was closely followed by *A. glaucocarpa* (407 cm), *A. crassa* (365 cm), *A. brassii* (364 cm) and *A. concurrens* (357 cm).

While acacia species were generally the top performers on this site, good growth and survival were demonstrated by the other species. *Eucalyptus argophloia* and *E. camaldulensis* had 100% survival, while average heights of *E. camaldulensis* and *Casuarina cunninghamiana* were 336 and 208 cm respectively.

Charters Towers

Survival at Charters Towers was generally lower than at Mareeba. Acacias with good survival were *A. glaucocarpa, A. holosericea* (Carranya) and *A. leptocarpa*.

Height growth was best for *Acacia crassa* (268 cm), *A. holosericea* from Coopers Creek (261 cm) and *A. glaucocarpa* (257 cm). *A. brassii, A. holosericea* (Carranya), *A. plectocarpa* (Spillway Creek) and *A. storyi* all had greater than 75% survival and average heights of over 150 cm by 14 months of age.

Survival of both *A. stenophylla* and *A. tumida* (Fitzroy Crossing) was very poor.

Survival by *Casuarina cunninghamiana* and *E. microtheca* was greater at Charters Towers than at Mareeba. *E. argophloia* and *E. cambageana* along with these species also had greater average height and diameter growth at Charters Towers. *E. camaldulensis* and *E. microtheca* were the only species with 100% survival.

Longreach

Performance by a large number of *Acacia* species established in the 1989 planting has been poor at all Longreach sites (Appendix 2). Many species naturally derived from arid areas had performed poorly or completely failed by 11 months of age. These include *Acacia ampliceps* (WA and NT provenances), *A. tumida, A. umbellata* and *A. victoriae*.

Cracking clays

A. harpophylla (with 64%) and the Coopers Creek provenance of *A. holosericea, A. concurrens* and *A. ramulosa* (each with 43%) had the best survival on the irrigated clay site after *A. salicina* (86%). *A. holosericea* (Coopers Creek) with an average height of 164 cm was the tallest species. *A. ampliceps* (NT), *A. holosericea* (Carranya) and *A. leptocarpa* (NT) all attained heights greater than 100 cm by 11 months but survival was less than 30% for all three species.

A. salicina (57%) and *A. georginae* (14%) were the only surviving acacias at 13 months on the unirrigated clay site.

Of the four eucalypts in the irrigated trial, *E. argophloia, E. camaldulensis* and *E. cambageana* had 100% survival and all were greater than 100 cm in height. Where there had been no irrigation, *E. microtheca* had the best survival (71%) while only *E. camaldulensis* had an average height greater than 100 cm.

Coarse-textured red earths

Under the continuing irrigation treatment, the only acacias showing 50% or greater survival were *A. bancroftii, A. glaucocarpa, A. plectocarpa* (NT), *A. torulosa* (Qld) and *A. simsii*. Survival of *A. holosericea* (Coopers Creek) was very poor (only 29%) under continuing irrigation but was 50% where irrigation had been removed. Survival of *A. bancroftii* (71%), *A. harpophylla* (50%) and *A. plectocarpa* (NT) (50%) was fair also when irrigated during establishment only.

A. bancroftii, A. holosericea and *A. glaucocarpa* had the best height growth in both irrigated and unirrigated treatments.

Some differences between irrigation treatments were apparent four months after removal of irrigation (Fig. 3 and 4). Survival of some species was affected after the removal of irrigation (Fig. 3). When compared with continual irrigation *A. aneura* (Qld), *A. brassii, A. cincinnata, A. harpophylla* and *A. torulosa* have all shown greater mortality in the unirrigated treatments. Survival with *A. crassicarpa* had been unaffected by removal of irrigation by 11 months of age.

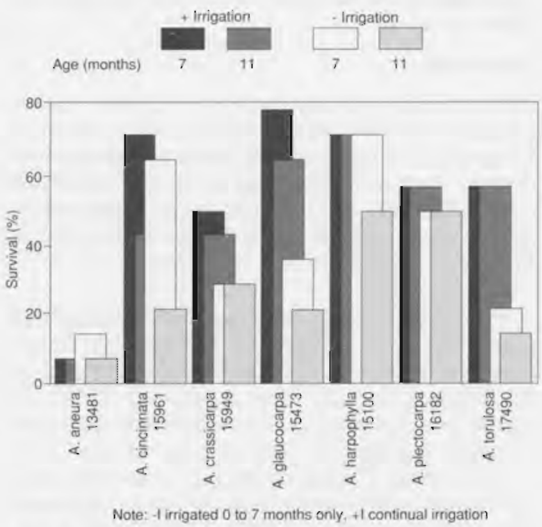

Fig. 3. Survival patterns of acacias in ± irrigation treatments to age 11 months (seedlot numbers in parentheses).

Height increment was greater with continual irrigation with *A. brassii, A. cincinnata, A. crassicarpa, A. glaucocarpa* and *A. plectocarpa* (NT) (Fig. 4). However, height growth increment was greater without irrigation for *A. aneura* (Qld), *A. bancroftii* and *A. torulosa*.

Eucalypt species have been the best performers on the Longreach sites. In particular, *E. camaldulensis* had 100% survival on the coarse-textured red earth and the irrigated clay site at 11 months of age. Other species with high survival over all sites are *Casuarina cunninghamiana, E. argophloia* and *E. microtheca*.

Conclusions

The results are only early at this stage, but there has been a general tendency for the survival and growth rates of acacia species to decrease with increasing harshness of planting site. Poor condition of the nursery stock for the 1989 planting may have been a factor contributing to the poor performance of a number of the acacia species, particularly on the harsher sites. Further monitoring of species planted in both years will provide further information.

A. holosericea and *A. glaucocarpa* grew best on the non-alkaline sites, but survival was far better with *A. salicina. A. salicina* was also one of the very few acacias to survive on the alkaline soil where there had been no irrigation.

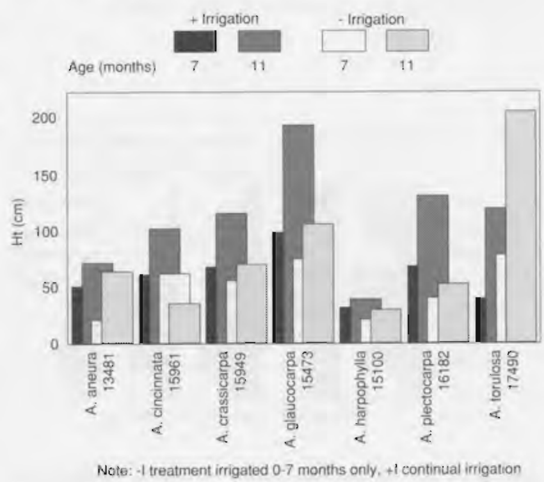

Fig. 4. Height growth patterns of acacias in ± irrigation treatments to age 11 months (seedlot numbers in parentheses).

Acknowledgments

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Much of this work would not have been possible without the collaboration of private landholders at Charters Towers and Longreach. In particular the considerable time and effort by the Clarks at 'Leander', the Emmotts at 'Noonbah' and the Manns at 'Hillview' have ensured the success of these trials. Our thanks also to the staff of the Department of Primary Industries at Longreach and Mareeba.

References

Booth, T.H. 1987. Selecting Acacia species for testing outside Australia. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16. ACIAR, Canberra, Australia, 74–76.

Hutchinson, M.F. 1988. A new objective method for spatial interpolation of meteorological variables. In: E.A. Fitzpatrick, ed., Proceedings of United Nations Workshop on the need for climatic and hydrologic data in agriculture of South-East Asia. Tokyo, United Nations University.

Ryan, P.A., Podberscek, M., Raddatz, C.G. and Taylor, D.W. 1987. Acacia species trials in southeast Queensland, Australia. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16. ACIAR, Canberra, Australia, 81–85.

Specht, R.L., Roe, E.M. and Boughton, V.H. 1974. Conservation of major plant communities in Australia and Papua New Guinea. Australian Journal of Botany, Supplementary Series No. 7. East Melbourne, Victoria, CSIRO. 667 p.

Appendix 1. Species, seedlot numbers, origins and trial planting sites.

Seedlot Number	Gen	Species	Origin: Locality	Latitude	Longitude	Alt (m)	Trial Plot Locations: M	C	LE +I	LE -I	LC +I	LC -I
15702	Aca	ampliceps	Yilyarra, Punmu 2 WA	22 02	123 07	350					X	X
15734	Aca	ampliceps	70 km N Wave Hill NT	17 00	130 34	250	X	X	X	X	X	X
13481	Aca	aneura	Charleville QLD	26 25	146 17	300			X	X		
13720	Aca	aneura	Floodout NT	21 47	131 09	580			X	X		
16147	Aca	auriculiformis	King Ck NT	12 23	131 00	28	X					
15589	Aca	bancroftii	Moranbah QLD	21 30	148 05	310			X	X		
16134	Aca	brassii	Heathlands QLD	11 36	142 35	120	X	X	X	X		
15961	Aca	cincinnata	Julatten QLD	16 35	145 25	410	X	X	X	X		
17141	Aca	concurrens	Fernvale QLD	27 33	152 41	50	X				X	
17153	Aca	crassa ssp crassa	Barakula SF QLD	26 27	150 40	350	X	X				
15949	Aca	crassicarpa	Laura - Musgrave QLD	15 23	144 08	90	X	X	X	X		
16173	Aca	difficilis	Donydji Airport NT	12 55	135 18	70	X	X	X	X		
17093	Aca	georginae	Urandangi NT	21 57	137 59	600					X	X
15473	Aca	glaucocarpa	Gayndah QLD	25 32	151 29	390	X	X	X	X		
15100	Aca	harpophylla	70 km N Moranbah QLD	21 44	147 36	300			X	X	X	X
14657	Aca	hemignosta	98 km N Halls Ck WA	17 30	127 56	395					X	
14651	Aca	holosericea	Carranya WA	19 14	127 46	340	X	X			X	X
16389	Aca	holosericea	Coopers Ck NT	12 19	133 19	60	X	X	X	X	X	X
16171	Aca	latescens	Lake Evella NT	12 24	135 44	55					X	X
14139	Aca	leptocarpa	Mt Molloy QLD	16 40	145 18	400	X	X				
16176	Aca	leptocarpa	Annie Ck NT	13 14	134 45	60					X	X
17029	*Aca*	*penninervis*	*Gayndah QLD*	*25 32*	*151 30*	350	X					
17182	Aca	platycarpa	Fitzroy Crossing WA	17 58	125 15	210					X	
16182	Aca	plectocarpa	Mann River NT	12 13	134 03	30	X	X	X	X	X	X
17499	Aca	plectocarpa	Spillway Ck WA	16 02	128 47	500	X	X	X	X	X	X
13795	Aca	ramulosa	Uluru NP NT	25 20	131 15	580					X	
15465	Aca	salicina	Mitchell QLD	26 29	148 02	325	X	X	X	X	X	X
14625	Aca	shirleyi	Hidden Valley NT	16 38	133 01	260				X		
14576	Aca	simsii	Mareeba QLD	16 52	145 35	355	X	X	X	X		
17497	Aca	stenophylla	Sturt Ck WA	18 40	128 33	500		X	X	X		
17540	Aca	storyi	Blackdown Tableland QLD	23 49	149 02	800	X	X				
14183	Aca	torulosa	NW Chillagoe QLD	16 36	144 07	275		X	X	X		
17490	Aca	torulosa	Elliot NT	17 33	133 30	500		X	X	X		
17046	Aca	tumida	57 km ENE Broome WA	17 49	122 45	30	X	X	X	X		
17181	Aca	tumida	Fitzroy Crossing WA	18 18	125 37	130		X	X	X		
16181	Aca	umbellata	Mt Molloy - Mareeba QLD	16 49	145 23	380		X			X	X
17209	Aca	victoriae	Georgetown QLD	18 17	143 14	220		X			X	X
13508	Cas	cunninghamiana	Augathella QLD	25 47	146 36	370	X	X	X	X		
15504	Euc	argophloia	NW Chinchilla QLD	26 31	151 02	330	X	X	X	X	X	X
14338	Euc	camaldulensis	Petford QLD	17 17	145 03	500	X	X	X	X	X	X
12937	Euc	cambageana	Augathella QLD	25 53	146 30	400	X	X	X	X	X	X
15944	Euc	microtheca	Rockhampton QLD	33 22	150 31	4	X	X	X	X	X	X

M: Mareeba (4 reps, no irrigation); C: Charters Towers (4 reps, no irrigation)
LE: Longreach, earth (2 reps, continuing irrigation, 2 reps irrigation for first 6 months)
LC Longreach, clay (2 reps, continuing irrigation, 2 reps no irrigation)
+I: Continuing irrigation; -I: Irrigation for the first six months only
■ : not planted; x: planted
Genus Codes: Aca - Acacia, Cas - Casuarina, Euc - Eucalyptus

Appendix 2. Survival, mean height and diameter at ground level at each trial planting site.

		Survival (%) Trial site and age (months)						Height (cm) Trial site and age (months)						Diameter, ground level (cm) Trial site and age (months)					
		M	C	LE	LE	LC	LC	M	C	LE	LE	LC	LC	M	C	LE	LE	LC	LC
Seedlot	Gen Species			+I	-I	+I	-I			+I	-I	+I	-I			+I	-I	+I	-I
No		13	14	11	11	11	11	13	14	11	11	11	11	13	14	11	11	11	11
15702	Aca ampliceps					0	0					f	f					f	f
15734	Aca ampliceps	21	18	0	0	21	0	181	165	f	f	132	f	2.3	3.5	f	f	4.2	f
13481	Aca aneura			7	7					71	63					2.5	2.1		
13720	Aca aneura			36	36					79	83					1.9	1.9		
16147	Aca auriculiformis	89						238						6.1					
15589	Aca bancroftii			71	71					208	188					3.4	2.7		
16134	Aca brassii	100	75	21	14			364	189	113	71			5.6	2.5	2.1	1.3		
15961	Aca cincinnata	100	71	43	21			308	121	102	34			6.0	1.9	2.2	1.1		
17141	Aca concurrens	96				43		357				64		6.4				1.3	
17153	Aca crassa ssp crassa	82	68					365	268					4.5	2.9				
15949	Aca crassicarpa	86	71	43	29			237	66	116	70			4.2	1.4	3.2	2.1		
16173	Aca difficilis	68	46	21	0			163	90	78	f			4.9	1.6	2.3	f		
17093	Aca georginae					14	14					35	54					1.5	1.1
15473	Aca glaucocarpa	100	89	64	21			407	257	192	106			5.8	3.3	3.7	2.2		
15100	Aca harpophylla			71	50	64	0			39	29	53	f			0.8	0.6	0.9	f
14657	Aca hemignosta					0						f						f	
14651	Aca holosericea	95	93			7	0	232	172			139	f	3.5	2.5			2.1	f
16389	Aca holosericea	82	71	29	50	43	0	431	261	315	281	164	f	6.2	3.0	4.6	4.1	2.3	f
16171	Aca latescens					0	0					f	f					f	f
14139	Aca leptocarpa	100	93					352	165					5.2	2.4				
16176	Aca leptocarpa					29	0					125	f					1.8	f
17029	Aca penninervis	79						333						4.0					
17182	Aca platycarpa					0						f						f	
16182	Aca plectocarpa	71	64	57	50	21	0	183	77	131	52	26	f	4.2	1.5	3.6	1.6	0.9	f
17499	Aca plectocarpa	86	82	21	43	0	0	327	165	161	189	f	f	5.5	2.5	3.8	4.3	f	f
13795	Aca ramulosa					43						54						1.3	
15465	Aca salicina	93	68	93	79	86	57	162	111	92	47	98	39	3.0	2.2	2.3	1.2	2.8	1.1
14625	Aca shirleyi				14						25						0.9		
14576	Aca simsii	68	54	50	36			226	118	99	91			4.0	1.5	2.0	2.0		
17497	Aca stenophylla		21	7	0				110	63	f				1.9	1.0	f		
17540	Aca storyi	100	82					293	180					4.4	3.0				
14183	Aca torulosa		64	21	0				124	64	f				1.3	1.4	f		
17490	Aca torulosa		32	57	14				67	120	205				0.7	2.1	3.2		
17046	Aca tumida	14	32	0	14			177	107	f	79			2.4	1.2	f	2.9		
17181	Aca tumida		7	0	7				103	f	f				0.8	f	f		
16181	Aca umbellata		75			0	0		49			f	f		0.5			f	f
17209	Aca victoriae		71			0	0		32			f	f		0.4			f	f
13508	Cas cunninghamiana	93	96	100	86			208	240	187	207			3.1	3.5	3.3	3.8		
15504	Euc argophloia	100	93	100	79	100	50	120	163	176	156	175	80	2.3	2.8	4.3	3.6	3.9	1.4
14338	Euc camaldulensis	100	100	100	100	100	57	336	233	323	255	199	141	5.4	3.1	5.5	4.5	3.4	1.8
12937	Euc cambageana	93	89	100	71	100	57	100	114	150	120	121	69	1.2	1.5	3.4	2.8	2.2	1.1
15944	Euc microtheca	93	100	93	86	93	71	138	170	183	124	166	91	2.8	3.0	4.4	3.0	3.2	1.5

f: fail

M: Mareeba (4 reps, no irrigation); C: Charters Towers (4 reps, no irrigation)

LE: Longreach, earth (2 reps, continuing irrigation, 2 reps irrigation for first 6 months)

LC Longreach, clay (2 reps, continuing irrigation, 2 reps no irrigation)

+I: Continuing irrigation; -I: Irrigation for the first six months only

[shaded box] : not planted

Early Results from Trials of Australian Acacias in Semi-arid Kenya

F. Chege and M. Stewart*

Abstract

A number of collaborative trials have been established in the drylands of Kenya by the Kenyan government with assistance from the British and Australian governments. This paper reports on the progress of Australian acacias in two of the oldest trials. The trials were established in April 1989 and assessed after 18 months.

The relationship between species and rates of survival and growth in the trials was highly significant at both sites. Tables detailing the analysis of the trials are presented. Species are ranked on the basis of their height growth and subjected to a least significant difference Multiple Range Test.

A subset of the data was analysed to compare performance at the two sites. There were no significant site/species interactions relating to either survival or height growth. There were, however, significant differences in both survival and height between the two sites.

Acacia holosericea performed significantly better than all other species on both sites with regard to height growth.

AT least two-thirds of Kenya is arid and semi-arid. These dry areas currently support around 20% of the population. As a result of a rapidly increasing population, people are now moving into these areas and pressure on the limited resource base is increasing rapidly. Trees are being cleared for utilisation and to enable cultivation. There is concern that this may lead to a shortage of tree products and to environmental degradation.

Agroforestry techniques provide possible countermeasures to the above problems. There is, however, a shortage of suitable species for use by small farmers in arid and semi-arid lands (ASAL). Suitable species are required to satisfy the need for a range of tree products in the minimum time. At present the majority of farmers want to plant fast-growing species for poles and general utility. The average farmer wants to plant trees on his smallholding (< 5 ha) around the boundaries, along terraces and in the living compound. There is little interest in growing trees for fodder, fuel or soil improvement at present in ASAL of Meru.

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The Kenya Forest Research Institute (KEFRI) is conducting trials on many exotic and indigenous species with a view to addressing the problems of agroforestry in ASAL. As part of this effort a number of collaborative trials have been established between KEFRI, CSIRO Division of Forestry, ACIAR and the Overseas Development Administration (ODA) of the British Government. These trials look particularly — though not exclusively — at Australian acacias.

This paper reports early findings from two of the earliest collaborative trials, which were established at Marimanti and Lanchiathurio in April 1989.

Experimental Sites and Plot Layouts

The trial sites are semi-arid characterised by a mean annual rainfall of approximately 450–900 mm, with a bimodal distribution. The average potential evaporation is 1650–2300 mm. The indigenous vegetation on both sites is thorn bush dominated by indigenous *Acacia* species, and typical of lowland (ca 600 m) semi-arid sites in Kenya.

Marimanti

The soil is an infertile red sandy-clay with a pH 6.5. Site preparation involved clearance of existing secondary vegetation and bush. The site was ripped along the contour to a depth of around 20 cm at a 2.5 m interval by a single tine mounted on a two-wheel-drive tractor. Seedlings grown in 17 × 10 cm (layflat) poly tubes were planted along the rip lines at a 1.5 m spacing during the rains of April 1989.

The trees were planted in line plots of 8 trees with 1.5 m spacing between trees in the plot and 2.5 m between parallel plots. There were no guard rows. The trial was planted as a replicated block with 4 replicates. Unfortunately germination and growth in the nursery was not sufficient to enable complete replication of all species. The growth of 31 species is reported here (Table 1) for the purpose of this paper, but only the performance of Australian acacias has been presented and analysed.

Lanchiathurio

This is a lowland site between Meru and Isiola. Soils are moderately fertile red clay-loams with pH 6. The site was already cleared for agriculture but has never been cropped. It was disc ploughed. Seedlings were grown in 17 × 10 cm poly tubes and planted at a spacing of 2 × 3 m during the April 1989 rains.

The trees were planted in 10 tree line plots with 2 m between trees in a plot and 3 m between parallel plots. The trial was a replicated block with 4 replicates. The trees were intercropped by maize and beans in the first season, however the maize produced no yield due to the poor rains in the area.

Table 1. Origin of species planted at Marimanti.

CSIRO Seedlot No.	Species name	Location	Lat (°S)	Lon (°E)	Alt (m)
16389	*A. holosericea*	Coopers Creek, NT	12°19′	133°19′	60
17069	*A. holosericea*	Beagle Bay, WA	16°59′	122°24′	10
14634	*A. cowleana*	Hooker Creek, NT	18°48′	131°13′	300
14139	*A. leptocarpa*	Mt. Molloy, QLD	16°40′	145°18′	400
17499	*A. plectocarpa*	Spillway Creek, WA	16°02′	128°47′	500
17490	*A. torulosa*	Elliot, NT	17°33′	133°30′	500
14651	*A. colei* ms	Carranya, WA	19°14′	127°46′	340
17181	*A. tumida*	Fitzroy Crossing, WA	18°18′	125°37′	130
14183	*A. torulosa*	Chillagoe, QLD	16°36′	144°07′	275
17046	*A. tumida*	Broome, WA	17°49′	122°45′	30
16134	*A. brassii*	Heathlands, QLD	11°36′	142°35′	120
16147	*A. auriculiformis*	Noogoo Swamp, NT	12°23′	131°00′	28
15702	*A. ampliceps*	Yilyarra, WA	22°02′	123°07′	350
14974	*A. julifera* ssp *julifera*	Balfes Ck, QLD	20°13′	145°53′	330
17333	*A. monticola*	Pt. Smith, WA	18°31′	121°51′	25
14625	*A. shirleyi*	Hidden Valley, NT	16°38′	133°01′	260
15066	*A. ligulata*	Sthn NT, NT	22°00′	131°00′	500
17164	*A. eriopoda*	Broome, WA	17°57′	122°14′	10
15767	*A. trachycarpa*	De Grey River, WA	20°12′	119°10′	50
16173	*A. difficilis*	Donydji, NT	12°55′	135°18′	70
16182	*A. plectocarpa*	Mann River, NT	12°13′	134°03′	30
15559	*A. victoriae*	Clermont, QLD	22°57′	147°07′	300
17490	*A. torulosa*	Elliot, NT	17°33′	133°30′	500
15465	*A. salicina*	Mitchell, QLD	26°29′	148°02′	325
17182	*A. platycarpa*	Fitzroy Crossing, WA	17°58′	125°15′	210
13481	*A. aneura*	Charleville, QLD	26°25′	146°17′	300
15774	*A. sclerosperma*	67 km S of Barradale, WA	23°11′	114°28′	70
15749	*A. pachycarpa*	Sturt Creek, WA	19°35′	127°42′	350
15473	*A. glaucocarpa*	Gayndah, QLD	25°32′	151°29′	390
17497	*A. stenophylla*	Sturt Creek, WA	18°40′	128°33′	500
15747	*A. maconochieana*	Tanami Downs, NT	20°25′	129°12′	350

Table 2. Analysis of variance, Site 1 (Marimanti).

1. Effect of species and block on mean height growth at age 18 months

Source of variation	Sum of squares	d.f.	Mean square	F-ratio	Sig. level
Main effects	844834	34	24848	6.761	.000 ***
Species	824756	31	26605	7.239	.000 ***
Block	21062	3	7021	1.910	.1358
Residual	257262	70	3675		
Total (corr.)	1102095	104			

The species effect on height growth is highly significant.
The blocking effect on height growth is not significant at the 90% level of probability.

2. Effect of species and block on the Arc Sin of survival at age 18 months

Source of variation	Sum of squares	d.f.	Mean square	F-ratio	Sig. level
Main effects	13.802	34	.4059	4.041	.0000 ***
Species	10.715	31	.3456	3.441	.0000 ***
Block	2.344	3	.7815	7.779	.0001 **
Residual	7.031	70	.1005		
Total (corr.)	20.834	104			

The effect of species on survival rates is highly significant.
The effect of blocking on survival is highly significant.

Results

Marimanti

Survival and height growth were best at Marimanti. The relationship between species and height growth and survival was significant at the .01% level of confidence (Table 2). The effect of the blocks was not significant on height growth but did influence survival.

Growth was very good with 14 species achieving over 3.0 m height in 18 months. *Acacia holosericea* (16389) was significantly taller than all other species with a mean height of 5.11 m and 91% survival. This contrasts with the performance of the closely-related *A. colei* (14651) with a mean height of only 3.69 m and survival of 81%. The latter species, which grows in more arid conditions in Australia, is of noticeably poorer form and has consistently grown more slowly than *A. holosericea*, even in later trials.

Other species showing good growth, survival and form are *A. cowleana, A. leptocarpa, A. plectocarpa* and *A. brassii* (Table 3).

Lanchiathurio

Survival and growth were much poorer than at Marimanti. This was probably because of lower rainfall and strong, warm winds following planting. Due to local geography the area in which Marimanti lies rarely gets strong wind. There are other differences in treatment between the two sites but on balance it is likely that Lanchiathurio received a higher standard of care than Marimanti.

Species correlated strongly with height attained and rate of survival, as at Marimanti. There was no significant effect of blocking on height growth (Table 4).

Combined sites

Although there are important differences in treatment between the two sites it is interesting to compare the performance of the same species and provenances on the two sites. For this purpose nine of the best performers (height) were selected from the two sites. When the data are combined (Table 5) it is apparent that species and site both have a highly significant impact on both height and survival. There is still no effect on either parameter from the experimental blocking. Interestingly there is also no significant species/site interaction with respect to either height growth or survival. This implies that the ranking of species will not change significantly between the two sites under consideration.

Table 3. Summary of survival and height growth at Marimanti of Australian acacias at 18 months (planted April 1989, assessed October 1990).

CSIRO Seedlot No.	Species	Mean ht (cm)	Survival %	Homogeneous groups mean ht (LSD 95% level)
16389	*A. holosericea*	511	91	*
17069	*A. holosericea*	414	81	*
14634	*A. cowleana*	408	75	**
14139	*A. leptocarpa*	384	75	***
17499	*A. plectocarpa*	380	78	***
17490	*A. torulosa*	373	37	****
14651	*A. colei* ms	369	81	****
17181	*A. tumida*	369	100	****
14183	*A. torulosa*	368	69	****
17046	*A. tumida*	350	67	*****
16134	*A. brassii*	344	87	*****
16147	*A. auriculiformis*	342	94	*****
15702	*A. ampliceps*	327	72	*****
14974	*A. julifera*	304	91	*****
17333	*A. monticola*	298	50	* ******
14625	*A. shirleyi*	287	44	** *****
15066	*A. ligulata*	278	58	** ****
17164	*A. eriopoda*	276	62	** ****
15767	*A. trachycarpa*	275	62	** ****
16173	*A. difficilis*	273	81	** ****
16182	*A. plectocarpa*	249	67	*** ***
15559	*A. victoriae*	248	69	*** ***
17490	*A. torulosa*	240	94	**** **
15465	*A. salicina*	239	84	**** **
17182	*A. platycarpa*	239	33	**** **
13481	*A. aneura*	216	34	***** *
15774	*A. sclerosperma*	210	72	****
15749	*A. pachycarpa*	179	78	****
15473	*A. glaucocarpa*	157	12	***
17497	*A. stenophylla*	130	37	**
15747	*A. maconochieana*	99	37	*

Note
Fishers Protected Least Significant Difference multiple range test gives a least significant difference of 88 cm at the 95% level of confidence.

Table 4. Analysis of variance, Site 2 (Lanchiathurio).

Effect of species and block on mean height growth at age 18 months

Source of variation	Sum of squares	d.f.	Mean square	F-ratio	Sig. level
Main effects	315198	35	9005.656	2.578	.0005 **
Species	297874	32	9308.588	2.665	.0004 **
Block	16458	3	5486.000	1.570	.2050
Residual	227062	65	3493.2672		
Total (corr.)	542260	100			

The species effect on height growth is significant at the 95% level
The blocking effect on height growth is not significant at the 90% level of probability

The top nine species and their mean heights over the two sites are listed in Table 6 where they are ranked by means of the LSD multiple range test. Again *A. holosericea* (16389) is significantly taller than all other species.

Discussion

The primary object of farmers planting trees in ASAL of Meru at present is to provide utility poles for domestic consumption. These poles are small by most standards and are generally considered in two categories i.e. 3 m × 3 cm and 2.5 m × 20 cm. The larger category is required in smaller numbers but is required to be durable in contact with the ground. The smaller category is used for roof supports (thatch and corrugated iron) and cross members in a wattle and daub house; durability is not of vital importance. It is for the smaller category that fast-growing Australian species appear best suited.

Other tree products may be required in large quantities in future, although at present they are not obtained from planted trees. Through studies of the characteristics of Australian acacias their suitability for products such as fuel, charcoal, fodder and amenity may be assessed.

The next steps are to identify the most promising species from the screening trials and conduct further more detailed studies of management, provenance, drought resistance and other characteristics. Collaborative trials such as those reported in this paper are important avenues for identifying potentially valuable species.

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Table 5. Analysis of variance for tallest nine species.

1. Effect of species, site and block on mean height of the tallest 9 species at age 18 months. Sites 1 and 2 (Marimanti and Lanchiathurio).

Source of variation	Sum of squares	d.f.	Mean square	F-ratio	Sig. level
Main effects	536238	12	44686.52	14.331	.0000
Species	129762	8	16220.28	5.202	.0001
Site	356248	1	356248.20	114.248	.0000
Block	9978	3	3325.91	1.067	.3730
2-factor interactions	11324	8	1415.51	.454	.8813
Species v. site	11324	8	1415.51	.454	.8813
Residual	137201	44	3118.21		
Total (corr.)	684763	64			

2. Effect of species, site and block on arcsin survival (%) of the tallest 9 species at age 18 months. Sites 1 and 2 (Marimanti and Lanchiathurio).

Source of variation	Sum of squares	d.f.	Mean square	F-ratio	Sig. level
Main effects	3.0967	12	.258	2.643	.0094 ns
Species	1.4502	8	.181	1.856	.0919 ns
Site	1.4516	1	1.452	14.865	.0004 **
Block	.3314	3	.110	1.131	.3468 ns
2-factor interactions	1.045	8	.131	1.338	.2508
Species–site	1.044	8	.131	1.338	.2508
Residual	4.297	44	.098		
Total (corr.)	8.439	64			

Table 6. Multiple range analysis (LSD) of top nine species.

Ranking of tallest 9 species using LSD multiple range test applied to plot means (height cm) of sites 1 and 2 (Marimanti and Lanchiathurio) at 95% level of probability.

CSIRO Seedlot No.	Species No.	No. of reps.	Mean height (cm)	Homogeneous groups (LSD 95%)
15702	*A. ampliceps*	8	265	*
16147	*A. auriculiformis*	8	273	*
14651	*A. colei* ms	8	286	**
16134	*A. brassii*	6	290	***
17499	*A. plectocarpa*	7	304	***
14139	*A. leptocarpa*	6	317	***
17069	*A. holosericea*	8	337	**
14634	*A. cowleana*	8	344	*
16389	*A. holosericea*	6	448	*

Early Growth of Lesser-known Australian Acacias at Loruk, Kenya

J.M. Kimondo*

Abstract

Four trials of lesser-known Australian and African tree and shrub species were established at Loruk, Kenya in 1988 and 1989. These were assessed for growth and survival at 1 and 2 years of age. *Acacia holosericea, A. salicina, A. nilotica* and *Cordia sinensis* had the best growth and survival.

THE arid and semi-arid lands (ASAL) of Kenya cover some 473 000 km² (KEFRI 1990). This vast area supports 20–25% of the population and more than half of the livestock (KEFRI, unpubl.). ASAL's natural vegetation is extremely important to livestock and people. As populations have grown, pressure on the natural vegetation has also increased. As a result, opportunities for supplementing the natural vegetation by planting multipurpose trees are being considered. To complement these efforts, lesser-known Australian and African tree and shrub species have been incorporated in a series of nationwide screening experiments.

This paper reports only results of two-year-old trials at one of these centres, Loruk (ACIAR Project 8808). Loruk (1° 02 'N and 36° 03 'E) lies at an elevation of 1100 m above sea level and receives about 600 mm of rainfall annually. Annual temperature and potential evaporation ranges are 18–28 °C and 1650–2300 mm, respectively. The experimental site was previously bushland (Milimo 1989).

Materials and Methods

Two separate experiments were established in 1988 and 1989 (Table 1). On each occasion one experiment comprised species indigenous to Australia and the other those indigenous to Africa. These were laid-out in plots of 16 trees each, replicated four times.

The plots were assessed for mean height and percentage survival. Since the plots are only 1 and 2 years old, statistical analysis has not been carried out.

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Table 1. Multipurpose tree and shrub species planted at Loruk in 1988 and 1989.

Planting year	Country of origin	Number of species established
1988	Australia	16
	Kenya	12
1989	Australia	35
	Kenya	17
	Zimbabwe	5
	Malawi	1

Results and Discussions

Mean height and percentage survival for the 1988 planting are presented in Table 2 for the Australian and Table 3 for the African species. For 1989 planting Table 4 is for Australian species. Most Australian species other than *Acacia raddiana* and *A. trachycarpa* (15767) attained a height of 2 m at age 2 years. Survival rate ranged from 15 to 93%. Six species out of the 13 tested in 1988 had a lower than 50% survival. These are: *A. brassii* (15480), *A. shirleyi* (14622), two provenances of *A. cowleana* (14885 and 14683), *A. torulosa* (14888), *A. julifera* (14656) and *A. trachycarpa* (15767); with survival of 15, 26, 35 and 32, 33, 44 and 18% respectively (Table 2). The overall best seed lots in order of increasing performance are: *A. plectocarpa* (17207), *A. nilotica* var. *India, A. holosericea* (14660) and *A. holosericea* (14632).

Table 2. Mean height and survival rates of Australian acacias at 2 years.

Species	CSIRO Seedlot No.	Mean height (m)	Survival rate (%)
Acacia holosericea	14660	2.8	85
A. holosericea	14632	2.8	93
A. nilotica var. India	—	2.8	78
A. farnesiana	—	2.6	55
A. torulosa	14888	2.6	33
A. plectocarpa	17207	2.5	74
A. brassii	15480	2.4	15
A. difficilis	14623	2.4	51
A. ampliceps	14668	2.4	74
A. ampliceps	14631	2.3	55
A. shirleyi	14622	2.2	26
A. cowleana	14885	2.1	35
A. julifera	14656	2.1	44
A. cowleana	14683	2.1	32
A. raddiana	—	1.7	82
A. trachycarpa	15767	1.6	18

Table 3. Mean height and survival rate of indigenous species at 2 years.

Species	Mean height (m)	Survival rate (%)
Sesbania sesban	3.2	25
Acacia nilotica	2.9	97
Acacia tortilis	1.9	82
Cordia sinensis	1.6	99
Dalbergia melanoxylon	1.6	91
Terminalia brownii	1.5	97
Tamarindus indica	1.3	95
Acacia mellifera	1.1	98
Croton megalocarpus	1.1	94
Berchamia discolor	1.1	74
Acacia nubica	1.0	23
Balanites aegyptiaca	0.9	68

Only *Sesbania sesban* (3.2 m) and *A. nilotica* (2.9 m) in the experiment on indigenous species attained height growth greater than two metres in two years. However, percentage survival was overall good, with all species other than *S. sesban* (25%) and *A. nubica* (23%) having a survival rate higher than 50% (Table 3). The growth performance of *A. nilotica* (2.9 m height and 97% survival) compares favourably with that of the best among the Australian acacias, i.e. *A. holosericea* (Table 2 and 3). The high survival percentage among African species and lack of it in those from Australia could be a reflection of adaptability to the local physical conditions and ecology.

Table 4. Performance of acacias and other species at 1 year.

Species	CSIRO Seedlot No.	Mean height (m)	Survival (%)
Acacia auriculiformis	16147	1.3	65
A. glaucocarpa	15473	1.1	18
A. brassii	16134	0.9	55
A. platycarpa	17182	0.4	8[c]
A. stenophylla	17497	1.2	53
A. salicina	16293	1.9	95[a]
A. auriculiformis	16484	1.4	40
A. maconochieana	15747	0.6	33
A. sclerosperma	15774	0.9	58
A. leptocarpa	14139	1.3	58
A. monticola	17333	1.1	18
A. trachycarpa	15767	1.1	45
A. holosericea	16389	1.2	58
A. ampliceps	15702	1.5	85
A. maconochieana	15737	1.0	60
A. tumida	17046	0.6	30
A. plectocarpa	17499	0.9	48
A. salicina	15465	1.4	83
A. holosericea	14651	1.4	93
A. shirleyi	14625	0.5	8[c]
A. julifera	14974	0.7	23
A. tumida	17187	0.6	33
A. difficilis	16173	0.4	5[c]
A. torulosa	14183	0.6	23
A. cowleana	14634	0.7	20
A. victoriae	15559	1.2	33
A. eriopoda	17164	0.9	35
A. torulosa	17490	0.7	33
A. pellita	17069	1.0	78
A. plectocarpa	16182	0.6	8
A. ligulata	15066	0.9	33
A. pachycarpa	15749	0.8	50
Sesbania formosa	15752	2.4	45[b]
Grevillea striata	17254	0.5	43
Ventilago viminalis	15468	0.5	15[c]
A. sieberiana	Zimbabwe	0.8	64
A. albida	Malawi	0.9	88
A. tortilis var. *heteracantha*	Zimbabwe	1.1	80
A. nilotica	Baringo (Kenya)	1.3	73[a]
A. albida	Zimbabwe	0.7	63
Prosopis chilensis	Baringo	1.9	95[a]
Bekea plurujuga	Zimbabwe	1.7	32
Haemanoxylon brabitella	Pents	1.5	100[a]
Sesbania sesban	Muguga (Kenya)	2.4	38

[a] Some of the most suited species
[b] Species with high growth rate but low survival
[c] Species least adapted to Loruk site

Within the 1989 establishment (Table 4), height and survival percentage after one year is very variable among species. *Sesbania formosa* (15752) had the best height growth while *A. difficilis* (16173) had the poorest. This ranged from only 0.4 m in the latter to 2.4 m in the former. *Bekea plurujuga*, Zambezi teak, had the poorest survival of only 3%. The highest survival of 100% was observed in *Haemanoxylon brabitella*. For those species that were planted in both 1988 and 1989, the performance ranking was comparable. Among these are *A. holosericea* and *A. nilotica*. Others that performed well after one year and had not been included in the 1988 planting are: *A. salicina* (15465 and 16293), *A. ampliceps* (15702), *A. auriculiformis* (16484) and *A. holosericea* (14651) (Table 4).

Height growth among Kenyan seed sources established in 1989 ranged from only 0.3 m for *Boscia coriacea* and *Diospyros scabra* to 2 m for *Albizia lebbek*. Survival on the other hand ranged from 9% for *B. coriacea* to 92 and 93% for *A. nilotica* and *A. seyal*, respectively. On average, performance was encouraging for *A. tortilis, A. karoo, A. nilotica, A. seyal, Albizia lebbek, Cordia sinensis* and *Melia volkensii*.

Conclusion

At this early stage of the trials, results indicate that *Acacia holosericea* (14623, 14660 and 14651) and *A. salicina* (16293 and 15465) may grow well in Baringo. Others that have so far shown promising performance are *A. ampliceps, A. auriculiformis, A. nilotica, A. plectocarpa, A. tortilis, Cordia sinensis, Dalbergia melanoxylon* and *Terminalia brownii*. The plots need to be kept for about five more years, however, before making final recommendations on the suitable species for the area.

References

Kenya Forestry Research Institute (KEFRI) 1990. A Strategic Plan for Research and Development, 1989-2000. Nairobi, AMREF. 113 p.

Milimo, P.B. 1989. Growth and survival of Australian tree species in field trials in Kenya. In: Boland, D.J. ed., Trees for the Tropics. ACIAR Monograph No. 10, 103–107.

Acacia mearnsii Provenance Trials in Southern China

Gao Chuan Bi and Li Ji Yuan*

Abstract

Acacia mearnsii provenances from Australia, China, South Africa and Brazil are compared for growth performance, form and tannin production in a series of provenance trials at four years of age on three sites in southern China. Variation between the provenances on each site was significant as was variation between the provenances on different sites. The introduced provenances have potential to improve *A. mearnsii* tannin and wood production in China.

For more than a century the Australian species *A. mearnsii* has been grown around the world for its bark, which is a high-yielding source of vegetable tannin for leather and adhesive manufacture. The species has been grown in China since about 1950 and current plantings in southern China are estimated to cover an area of 10 400 ha (Hillis 1989).

There are plans to extend the plantation areas of *A. mearnsii* to meet China's unsatisfied demand for tannin. Collaborative research between scientists from Australia (CSIRO) and China (Chinese Academy of Forestry) was initiated in 1985 to improve the growth, stem form and tannin production of the species. The origin of the first introductions of *A. mearnsii* to China is unknown and thus the first step toward improvement of the species has been the collection, introduction and testing of a large number of Australian provenances. These have been planted across six sites in four provinces in China. Results from the three oldest of these trials at 4–4.5 years of age are reported. This paper extends the earlier results for these trials (Gao 1989).

Materials and Methods

This series of trials was based on 25 seedlots. The composition of the trials changed from site to site due to the availability of seed but there was a core of 14 Australian, two South African, one Brazilian and five Chinese provenances across all sites. Provenance details for these seedlots are given in Table 1. The Australian provenances did not represent the species distribution in South Australia and Tasmania, due to the unavailability of seed.

The three trial sites in Fujian (Nanping), Jiangxi (Ganzhou) and Guangxi Autonomous Region (Nandan) were selected to represent potential major *A. mearnsii* plantation areas. The latitude, longitude, altitude, mean annual temperature and precipitation of these sites are presented in Table 2. Details of site preparation, trial design and layout were given by Gao (1989). The trials were planted during 1986; Nanping (March 1986) Ganzhou (July 1986) and Nandan (October 1986).

Height, diameter at breast height and insect damage were assessed annually in December. Stem form and bole length were evaluated three years after planting and bark thickness and tannin production for the Ganzhou and Nandan sites were estimated from measurements taken in December 1990 when the trials were 4.25 and 4.0 years old respectively.

Duncan's Multiple Range Tests were conducted for the provenances at the three trial sites. These are presented in Table 3.

Individual tree volumes were derived from an *Acacia mearnsii* volume table (Linjin et al. 1987) based on the following formula:

$$V = 0.035 \times (D + 0.7)^{2.1487} \times H^{0.8752}$$

For the tannin analysis, bark was sampled and bulked from six trees selected from the trial to represent each provenance. Mean diameter (dbh) and height estimates were used to locate a representative tree in each of the six replicates of each provenance. Each tree was then sampled for bark using a wad punch with a 1 cm diameter. Bark discs from each tree were removed in a vertical line centred at 1.3 m dbh on the southern aspect of the tree. The 25 bulked provenance samples were oven dried and analysed for tannin content by the Ganzhou Forestry Research Institute using the International Standard hide powder method. Results from Guangzhou and Nandan trial sites are presented in Table 4.

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Table 1. Seed sources of *Acacia mearnsii* used in the provenance trials.

Seedlot No.	Location	No. of parent trees	Lat. S*	Long. E	Alt. (m)
14394	Candelo, NSW	13	36°45′	149°40′	80
14395	Lake George, NSW	7	35°15′	149°20′	700
14397	Bodalla, NSW	11	36°08′	150°05′	75
14398	N Batemans Bay, NSW	10	35°42′	147°15′	40
14416	Dargo, VIC	3	37°28′	147°15′	200
14725	NE of Bungendore, NSW	12	35°12′	149°32′	760
14769	Googong Rsvr, NSW	12	35°29′	149°16′	670
14770	Polacks Flat Ck, NSW	6	36°39′	149°35′	260
14771	S of Cooma, NSW	9	36°28′	149°01′	940
14922	NW of Braidwood, NSW	12	35°15′	149°38′	720
14923	S of Bombala, NSW	13	37°09′	149°20′	500
14924	Merimbula, NSW	7	36°55′	149°54′	20
14925	Blackhill Reserve, VIC	6	37°12′	144°28′	500
14926	Omeo Highway, VIC	9	37°10′	147°45′	300
14927	Sth. Gippsland, VIC	7	37°44′	146°51′	100
14928	Cann R & Orbost, VIC	5	37°34′	148°28′	100
15087	Harding, Natal, S. Africa	Unknown	30°35′	29°51′	932
15088	Natal, S. Africa	Unknown	29°32′	30°28′	838
C20	Brazil	Unknown	—	—	—
C21	Wenzhou, Zheijiang, China	Unknown	28°01′	120°40′	50
C22	Guangnan, Yunnan, China	Unknown	24°02′	105°02′	1540
C23	Xingfeng, Jiangxi, China	Unknown	25°24′	114°50′	200
C24	Tongjiang, Sichuan, China	Unknown	31°56′	107°14′	690
C25	Jiangbian, Yunnan, China	Unknown	24°20′	103°20′	1600

* Latitude N for Chinese seedlots

Table 2. Trial site data.

Planting site	Lat. (N)	Long. (E)	Alt. (m)	Ann. Temp (°C)	Ann. Rain (mm)	Design
Ganzhou	25°51′	114°50′	124	19.4	1434	25 Seedlots, 6 Replic. BIB
Nanping	26°39′	119°10′	92	19.6	1679	25 Seedlots, 6 Replic. RCB
Nandan	24°59′	107°32′	698	18.0	1559	25 Seedlots, 5 Replic. BIB

Bark production (kg/tree) was also estimated using a table (Lin et al. 1987). Tannin production was calculated using the tannin content and bark production estimates for the provenances in the trial at Ganzhou at 4.5 years of age (see Table 5). Stem form for each provenance was expressed as the percentage of trees with single straight stems compared to the total number of trees assessed for the provenance.

Selection of superior provenances at each site was based on a weighted assessment of economic characters, as follows:

Character	*Weighting*
Wood volume	40
Tannin production	30
Stem form	20
Gummosis incidence	10

Provenance means for each character were calculated as a ratio of the best measurement for each character, and then all character means were added for each provenance to give a total which was used to select the superior Australian provenances (see Table 6).

Table 3. Duncan's Multiple Range Test ($P < 0.05$) for mean seedlot growth 3.5 years after planting.

Seedlot No.	Height (m)	Seedlot No.	Dbh (cm)	Seedlot No.	Volume (dm³)
Ganzhou					
14771	5.48	14925	5.00	14925	7.09
14925	5.43	15088	4.62	14771	6.32
14397	5.24	14771	4.48	14725	5.89
14725	5.19	14725	4.40	15088	5.78
14928	5.08	15087	4.38	14922	5.32
14922	5.01	14922	4.33	14397	5.22
15088	4.94	14926	4.10	15087	5.19
14926	4.92	14397	4.03	14416	4.85
14416	4.87	14928	3.97	14926	4.83
14398	5.75	14416	3.83	14928	4.55
14394	4.74	14927	3.67	14395	4.23
15087	4.72	14395	3.65	No. 22	4.09
14395	4.63	14769	3.59	14769	3.85
14927	4.62	14924	3.55	14927	3.72
No. 22	4.56	14398	3.55	14398	3.67
14924	4.40	No. 22	3.45	14924	3.48
14923	4.37	14394	3.43	14394	3.47
14769	4.36	14923	3.42	14923	3.36
14770	4.22	14770	3.36	14770	2.99
Nandan					
14397	7.54	14397	6.12	14397	14.01
14926	7.26	14926	5.92	14926	12.51
14416	6.94	14416	5.80	14416	11.11
14771	6.90	14471	5.78	14771	10.93
14924	6.84	14924	5.48	14924	10.26
14927	6.64	14927	5.44	14927	9.31
14398	6.44	14922	5.40	14398	8.66
14925	6.36	14928	5.36	14922	8.54
14923	6.20	14398	5.24	14928	8.45
14928	6.14	14923	5.20	14923	8.17
14394	6.06	14925	5.16	14925	8.01
14770	6.04	14770	5.06	14770	7.38
14922	6.04	14769	4.50	14394	5.94
14769	5.32	No. 22	4.50	No. 22	5.77
No. 22	5.08	14394	4.48	14769	5.33
Nanping					
14398	8.06	14398	6.95	14398	18.20
14925	7.82	14395	6.77	14925	16.19
14926	7.48	14925	6.76	14395	15.75
14395	7.37	14771	6.73	14922	15.63
14770	7.36	14926	6.69	14771	15.63
14923	7.34	14770	6.62	14926	15.30
14927	7.32	14922	6.54	14770	14.73
14397	7.23	14923	6.51	14928	14.57
14928	7.27	14928	6.50	14923	14.25
14725	7.19	14725	6.11	14725	13.06
14771	7.07	14397	6.05	14397	12.51
14922	7.03	14416	5.87	15088	12.35
14924	6.65	15087	5.86	14927	11.94
15088	6.63	14927	5.84	No. 22	11.47
No. 22	6.22	No. 22	5.82	14416	11.16
14416	6.07	15088	5.72	15087	10.83
15087	5.94	14769	5.21	14924	9.34
14394	5.73	14924	5.15	14394	7.35
14769	5.22	14394	4.80	14769	7.26

Table 4. *Acacia mearnsii* bark characteristics at 4.5 years.

Ganzhou trial				Nandan trial		
Seedlot No.	Thickness of bark (mm)	Production of Bark (kg/tree)	Tannin (%)	Seedlot No.	Thickness of bark (mm)	Tannin (%)
14394	2.9	1.60	35.48	14394	3.3	38.38
14927	3.8	2.08	44.70	14927	3.0	44.07
14725	3.6	1.99	38.52	14770	2.8	43.57
14770	2.8	1.64	41.19	14769	2.8	36.40
15087	4.5	2.40	44.36	14397	2.9	41.47
Ganzhou	4.2	1.78	44.57	14925	3.4	34.33
14769	3.1	1.57	36.98	14922	3.4	46.67
14397	3.2	2.18	41.56	14416	3.3	39.96
14925	4.2	2.69	43.13	14398	2.8	41.27
14922	4.1	2.39	40.70	14926	3.4	43.87
14416	3.7	1.71	42.45	14924	3.4	37.94
14393	3.0	1.47	43.24	14771	2.9	39.26
14926	4.1	1.96	45.33	14923	3.0	37.04
14924	3.2	1.61	43.36	14928	3.1	39.78
15088	4.4	2.60	45.89	Brazil	4.1	44.87
14395	3.8	2.29	42.43	Wenzhou	3.5	49.01
14771	4.0	2.57	38.72	Guangnan	3.7	46.64
14923	3.5	1.66	40.78	Xingfeng	3.7	46.38
14928	3.2	1.90	41.68	Tongjiang	3.6	44.00
Brazil	4.1	2.52	47.70	Jiangbian	3.4	43.48
Wenzhou	4.3	2.93	48.11	Nandan	4.1	41.33
Guangnan	4.2	1.72	44.18			
Xingfeng	4.4	2.49	47.22			
Tongjiang	4.1	2.83	44.90			
Jiangbian	4.1	2.44	48.16			

Table 5. Tannin production (kg/tree) for *A. mearnsii* provenances at Ganzhou at 4.5 years of age.

Seedlot No.	Tannin production (kg/tree)	Ratio (%)
14925	1.53	153
15088	1.46	146
15087	1.39	139
14771	1.31	131
14395	1.28	128
14922	1.25	125
14927	1.22	122
14926	1.14	114
14928	1.02	102
14725	1.01	101
C22	1.00	100
14410	0.95	95
14923	0.93	93
14924	0.90	90
14770	0.88	88
14398	0.83	83
14394	0.76	76

Table 6. Superior Australian *A. mearnsii* provenances at three trial sites.

Site	Rank	Seedlot No.	Greater than control (%)	Greater than lowest ranked seedlot (%)
Ganzhou	1	14771	56.6	94.7
	2	14925	54.8	
	3	14922	34.3	
	4	14307	30.7	
	5	14395	26.6	
Nandan	1	14922	106.5	106.5
	2	14771	101.0	
	3	14926	91.5	
	4	14397	92.7	
	5	14395	68.1	
Nanping	1	14398	93.6	125.5
	2	14925	76.8	
	3	14770	64.3	
	4	14926	42.1	
	5	14395	39.1	

Results

Height, diameter and volume growth

There were highly significant (0.01%) differences in height, diameter and volume growth between provenances for each site and between the sites. Means for diameter, height and volume growth at 3.5 years for provenances in trials at Ganzhou, Nandan and Nanping are presented in Table 3. Height growth for provenances varied between 5.5 m and 8.1 m, with the best growth at Nanping and the slowest at the relatively drier Ganzhou site.

Volume growth varied between 3.0–7.1 dm^3 for Ganzhou, 5.3–14.1 dm^3 for Nandan and 7.3–18.2 dm^3 for Nanping. The ranking of provenances for height, diameter and volume growth also varied significantly from site to site (see Table 3).

In terms of wood volume, the best three Australian provenances at Ganzhou were S14925 (Blackhill Reserve, Vic.), S14771 (S Cooma, NSW), and S14725 (NE Bungendore, NSW); at Nandan S14397 (Bodalla, NSW), S14926 (Omeo Hwy, Vic.) S14416 (Dargo, Vic.) and at Nanping S14398 (N Batemans Bay, NSW), S14925 (Blackhill Reserve, Vic.) and S14395 (Lake George, NSW).

No pattern of variation emerged to link growth performance with the geographic origin of the provenances.

Bark thickness, tannin content and bark production

Significant differences were found between the provenances for bark thickness and tannin content when they were assessed at 4–4.5 years of age at Ganzhou and Nandan trial sites. At Ganzhou the South African seedlots had the thickest bark — S15087 and S15088 with 4.5 mm and 4.4 mm respectively. Among the Australian provenances at both sites S14925 (Blackhill Reserve, Vic.) had the thickest bark — 4.2 mm at Ganzhou and 3.4 mm at Nandan. S14770 (Polacks Flat Creek, NSW) had the thinnest bark — 2.8 mm at both Ganzhou and Nandan.

Tannin content, expressed as a percentage of the oven-dry weight of the bark, was high for all the provenances tested at the two sites. It was highest at Ganzhou for Chinese seedlots C25 (Jiangbian, Yunnan, 48.2%) and C23 (Xingfeng, Jiangxi, 47.2%) and C20 (Brazil, 47.7%). Among the Australian seedlots, S14926 (Omeo Hwy, Vic., 45.3%) and S14927 (Sth Gippsland, Vic., 44.7%) were the highest. At Nandan a Chinese seedlot once again had the highest tannin content with C21 (Wenzhou, Zhejiang, 49.0%), closely followed by S14922 (NW Braidwood, NSW, 46.7%), C22 (Guangnan, Yunnan, 46.6%) and C23 (Xingfeng, Jiangxi, 46.4%). The lowest tannin contents were 35.5% (S14394 Candelo, NSW) at Ganzhou and 34.3% at Nandan (S14925 Blackhill Reserve, Vic.).

Bark production (kg/tree) was assessed for provenances at Ganzhou and ranged between 1.5 and 2.9 kg/tree. Chinese seedlots C21 (Wenzhou, Zhejiang) and C24 (Tongjiang, Sichuan) were estimated to produce the most bark with 2.9 kg/tree and 2.8 kg/tree respectively. These were followed by S14925 (Blackhill Reserve, Vic., 2.7 kg/tree), S15088 (Natal, South Africa, 2.6 kg/tree), S14771 (S. Cooma, NSW, 2.6 kg/tree), S15087 (Harding, Natal, South Africa, 2.4 kg/tree), S14922 (NW Braidwood, NSW, 2.4 kg/tree) and S14395 (Lake George, NSW, 2.3 kg/tree).

Tannin production

Tannin production for all provenances in trial at Ganzhou at 4.5 years of age was assessed on the basis of tannin content and bark production (Table 5). Blackhill Reserve (S14925), the two South African provenances (S15088 and S15087), S of Cooma (S14771) and Lake George (S14395) ranged from 53 to 28% higher than the Chinese control (C22).

Stem form

Stem form of the provenances was assessed at Ganzhou, Nandan and Nanping three years after planting. There was significant variation in form between the trial sites, with all provenances having poorer form at Ganzhou. At each site there were significant differences between the provenances with the new introductions having straighter stems, longer bole lengths and lighter branching than the Chinese provenances.

Disease incidence

No significant differences for gummosis or disease susceptibility were found between the new introductions and Chinese provenances. However there was a trend in the incidence of dieback disease at Ganzhou after autumn drought, with the new introductions more severely affected.

Age of first flowering and seeding

Chinese provenances flowered 1–2 years after planting, while flowering of the Australian provenances did not commence until the third summer after planting. At 4 years of age all the Chinese provenances and two of the Australian provenances had produced seed. Two Australian provenances had yet to flower.

Superior provenances

On the basis of a weighted evaluation of characters of economic importance (timber volume, tannin production, stem form and gummosis incidence) the five superior Australian provenances at each of five trial sites have been determined (see Table 6). These differ between the trial sites but include S14771 (S of Cooma, NSW), S14925 (Blackhill Reserve, Vic.), S14922 (NW Braidwood, NSW), S14397 (Bodalla, NSW), S14395 (Lake George, NSW), S14926 (Omeo Hwy, Vic.), S14398 (N Batemans Bay, NSW) and S14770 (Polacks Flat Creek, NSW).

Discussion

After 3–4.5 years these results indicate superior performance of particular *A. mearnsii* provenances from China, Australia, South Africa and Brazil in terms of height, diameter and volume growth, stem form and tannin production.

Variation between the provenances is highly significant and provenance performance varies significantly between the three trial sites. These preliminary results will be used to guide more extensive seed collections in Australia from the most productive provenances. These superior provenances will form the basis of seed production areas to supply improved seed for the major *A. mearnsii* growing areas in China.

The difference in flowering ages between the Australian provenances will have to be taken into account in the design of seed production areas and seed orchards.

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References

Gao, C. 1989. *Acacia mearnsii* provenance trials in the People's Republic of China. In: Boland, D.J., ed., Trees for the Tropics: growing Australian multipurpose trees and shrubs in developing countries. ACIAR Monograph No. 10, 97–101.

Hillis, W.E. 1989. *Acacia mearnsii*: Its past and potential use with reference to the development of plantations in the People's Republic of China. In: Boland, D.J., ed., Trees for the Tropics: growing Australian multipurpose trees and shrubs in developing countries. ACIAR Monograph No. 10, 21–25.

Lin, J., Chen, P., Hang, J. and Fang, Y. 1987. The study of constructing the management table in mathematical models of *Acacia mearnsii*. I. Construction of standing trees' volume table. Journal of Fujian College of Forestry, 7 (2), 41–48.

Performance of *Acacia mearnsii* Provenance/Progeny in Southern China

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Abstract

Sites in Fujian and Jiangxi provinces of China were used to test 171 families within 19 black wattle provenances from Australia. The trial results at two years old showed that the Australian mainland provenances were superior to the Tasmanian provenances. At the Ganzhou site (Jiangxi) the best provenance (from South Gippsland, Victoria) was 25% greater in height and 60% in dbh than the worst provenance from Avoca, Tasmania. At the Meipen site (Changtai county, Fujian) the South Gippsland provenance was better in height and dbh than the local control by 40 and 42% respectively. The performance of the provenances differed between the two sites. In particular the Tasmanian provenances performed a great deal worse at Meipen than at Ganzhou. Heritability for height was 0.30 and 0.38 at Meipen and Ganzhou respectively; corresponding figures for dbh were 0.29 and 0.37.

ACACIA *mearnsii* De Willd was first introduced to China in the early 1950s (Hillis 1989), and an estimated 10 400 ha of the species are now in plantations in South China. However there has been no genetic improvement of the species, and better lines are needed to realise the growth potential and utilisation values reported in other countries. The Chinese Academy of Forestry signed a cooperative program 'Black wattle silviculture and pulping studies' (ACIAR project 8849) with ACIAR in July 1988 (Hillis 1989). As part of this program, 171 families within 19 black wattle provenances were supplied by CSIRO. Two planting sites were established for experimentation, one being at Meipen and the other at Ganzhou. The trials are expected to be converted into seed orchards to produce genetically improved seeds in future (Raymond unpubl.). This paper records results gathered at age two years.

Materials and Methods

Site details

The Ganzhou site is located in Jiangxi province (lat. 25°51′, long. 114°50′ and altitude 124 m). The Meipen site is in Changtai county near Zhangzhou in Fujian province (lat. 24°49′, long. 117°52′ and altitude 1109 m).

Provenances/families

Details of the origin and numbers of families used at each site are shown in Table 1. In addition to the families supplied by CSIRO, a local seedlot, Wenzhou No. 5 was included as a trial control at Meipen.

Trial design and field layout

Although the number of provenances and numbers of families within each provenance varied from site to site, the trials were both planted at 2 × 2 m spacing in single tree plot incomplete block designs for 169 families and 20 replicates. In addition, two guard rows were planted around both experiments to avoid edge effects and damage by larger animals.

Stocks, site preparation and planting

Stocks Seeds were treated in warm (90 °C) water, and were germinated in flat plates at room temperature. They were transplanted at radicle stage in polythene containers of 10 cm diameter and 16 cm depth.

Site preparation Previous crops consisted of *Camellia oleifera* and several weed species. Following site clearance, planting holes of 60 cm width and 40 cm depth were dug by hand.

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Planting Seedlings were outplanted in March 1988 and 100 grams of N-P mixed fertiliser (ratio 1:2) were applied at the bottom of each hole. Mie Chao bait was applied at the base of the seedlings to control termites.

Tending First weeding was done by hoe in May, when 50 grams of nitrogen fertiliser (urea) was applied to individual trees. Second weeding was in August in the planting year, but no fertilisers were applied. The third took place in August 1989.

Data collection and analysis

Height (ht) and diameter at breast height (dbh) of individual trees in each replication were measured after two years; crown width, stem straightness and clear bole height were investigated. Drought resistance and flowering characteristics were observed at the end of each year. Statistical analyses were carried out on height and dbh using the PC-based software package, GENSTAT version 4.03e.

Results and Analysis

Provenance and family variation

The statistical analysis of the data necessitated some procedural decisions which are summarised as follows:

(a) The tree survival at each site was quite low (74% at Meipen and 66% at Ganzhou). For a single tree plot experiment this means a large number of missing plots. Therefore even though the experiments had been designed as incomplete block designs, it was decided to use randomised complete block analysis.

(b) The size of the experiments at each site were too big to be analysed using GENSTAT 4.03e on the PC. Therefore for each site the data were divided up and 10 replicates analysed at a time.

(c) At each site the residual mean squares from the analysis of each set of 10 replicates were compared for homogeneity and then pooled. The estimated family means from each set of 10 replicates were combined by forming a weighted mean according to the family survival in each set.

(d) The estimated family means from each site were then analysed using the family replications as weights to partition the family variation into between-provenances and between-families, within-provenances components.

The results of this multistage procedure for analysis are given in Table 2. The *A. mearnsii* families were collected across the natural distribution of the species and thus have been treated as a random factor. The family-within-provenance mean squares have been used in Table 2 to test provenance

Table 1. Origin of provenances.

Provenance No.	Location	Origin			No. of families	
		Lat (S)*	Long (E)	Alt (m)	Meipen	Ganzhou
14394	Candelo, NSW	36°45′	149°40′	80	13	13
14769	Goongong Rsvr, NSW	35°29′	149°16′	670	12	12
14922	NW of Braidwood, NSW	35°15′	149°38′	0	10	12
14923	Sth. of Bombala, NSW	37°09′	149°20′	500	12	13
14924	Merimbula, NSW	36°55′	149°54′	0	4	4
14925	Blackhill Reserve, VIC	37°12′	144°26′	500	6	6
14926	Omeo Highway, VIC	37°20′	147°45′	300	9	9
14927	Sth. Gippsland, VIC	38°00′	147°00′	100	7	7
14928	Cann R & Orbost, VIC	37°40′	149°00′	100	6	6
17233	Studley Park, VIC	37°48′	145°01′	20	11	11
17234	Watsonia, VIC	37°42′	145°15′	60	9	9
17235	Dandenong, VIC	37°53′	145°14′	40	10	10
17236	Minammite, VIC	37°57′	141°51′	0	7	5
15326	George Town, TAS	41°07′	146°52′	60	10	10
15328	Avoca, TAS	41°49′	147°35′	220	10	10
15329	Apsley River, TAS	41°56′	148°14′	10	10	10
15330	Boyer, TAS	42°46′	147°08′	60	6	6
15331	Hobart Airport, TAS	42°50′	147°31′	10	10	10
15858	St. Leonards, TAS	36°15′	149°05′	950	6	6
No. 5	Wenzhou, China	28°01′	120°40′	50	1	0

* Chinese seedlot from north latitude

differences (all $P < 0.001$). Estimated provenance means in rank order are given in Table 3. Mean heights of provenances at two years ranged from 2.7 to 3.9 m across sites, whilst dbh ranged from 1.8 to 3.2 cm. The best provenance at Ganzhou (provenance No. 14927) was 25% and 48% better than the worst for height and dbh respectively. At Meipen the best provenance (again provenance No. 14927) was 40% and 42% better than the local control for height and dbh.

Provenance and site interaction

The estimated provenance means in Table 3 were combined across the two sites to investigate the consistency of the rankings. The provenances were grouped according to their Australian state of origin (New South Wales, Victoria or Tasmania) as given in Table 1. The analysis of variance of the provenance means with weights according to the provenance replication (on a per tree basis) is

Table 2. Analyses of tree data for height and dbh at each site.

Source	Meipen			Ganzhou		
	df	ms	var.	df	ms	var.
Provenance	19	[a]17.95 16.63	6.87*** 4.95***	18	8.54 16.33	10.39*** 8.69***
Family	149	2.61 3.35		150	0.82 1.88	
Residual	2513	1.18 1.53		2240	0.35 0.80	

*** = P(<0.001)
a: upper figure for ht
lower figure for dbh

Table 3. Ranking of provenance means for height (m) and dbh (cm) at Meipen and Ganzhou.

Meipen				Ganzhou			
seedlot	ht	seedlot	dbh	seedlot	ht	seedlot	dbh
14927	3.86	14927	2.92	14927	3.74	14925	3.20
14923	3.73	17235	2.78	14923	3.69	14922	2.98
14394	3.65	14928	2.78	14394	3.68	14927	2.96
14926	3.63	14923	2.70	14922	3.68	17235	2.83
14928	3.63	14922	2.69	14925	3.65	14926	2.82
17235	3.61	14926	2.68	14926	3.57	17234	2.77
17233	3.58	17233	2.67	17235	3.57	14923	2.73
14922	3.54	14394	2.60	14924	3.56	14924	2.70
14769	3.46	14769	2.50	17233	3.52	14394	2.67
14924	3.43	17236	2.50	17234	3.46	17233	2.64
14925	3.36	14924	2.46	14928	3.43	14928	2.52
17234	3.33	17234	2.47	15236	3.27	15858	2.31
17236	3.18	14925	2.45	14769	3.24	17236	2.29
15331	2.95	15858	2.09	17236	3.16	15326	2.29
15858	2.85	No. 5	2.06	15858	3.14	15330	2.25
15330	2.86	15331	2.04	15330	3.13	15329	2.25
15328	2.84	15330	1.99	15329	3.05	15331	2.08
No. 5	2.75	15328	1.86	15331	3.01	14769	2.03
15329	2.73	15329	1.83	15328	3.00	15328	2.00
15236	2.70	15326	1.80				
average LSD (.05)	0.30		0.38		0.09		0.20

presented in Table 4. In this analysis we have excluded the single Chinese seedlot present at Meipen but not at Ganzhou. Also in Table 4 the between-family, within-provenance mean squares from Table 2 have been pooled over sites and used as the residual term. The analyses show large differences between states. The site-by-state means are presented in Table 5 and it can be seen that the Tasmanian provenances have not performed as well as those from the Australian mainland; the significant interaction for height ($P < 0.01$) is largely due to the poor growth of the Tasmanian provenances at Meipen.

Table 4. Provenance by site analyses of variance for ht and dbh.

Source	df	ms	var.
Site	1	[a]4.53 14.29	2.7 5.5
State	2	167.59 180.96	98.0 69.3
Site.State	2	9.77 6.36	5.7 2.4
State.Provenance	16	4.89 7.07	2.9 2.7
Site.State.Provenance	16	1.51 4.67	0.9 1.8
Residual	299	1.71 2.61	

a: upper figure for ht
lower figure for dbh

Table 5. Site by state interaction table of estimated means for ht (m) and dbh (cm).

Site		State		
		NSW	Vic	Tas
Meipen	ht	3.59	3.54	2.81
	dbh	2.61	2.67	1.91
Ganzhou	ht	3.58	3.53	3.09
	dbh	2.61	2.77	2.18

LSD (.05): ht 0.14
dbh 0.18

Selection parameters of *A. mearnsii* families

Looking at each site separately, the expectation of the unweighted family-within-provenance mean square has the form $\sigma^2 + r\sigma^2_f$, where σ^2 is the variance, σ^2_f is the family variance component and r is the harmonic mean of the family replication numbers (Cochran and Cox 1952). Using the residuals for each site in Table 2 as estimates for σ^2 allows a solution for σ^2_f. Hence the heritability can be derived assuming half sib families as $h^2 = 4\sigma^2_f/\sigma^2_p$, where $\sigma^2_p = \sigma^2 + \sigma^2_f$ (Falconer 1981). Heritabilities were similar at both sites (0.30 and 0.38 for height and 0.29 and 0.37 for dbh at Meipen and Ganzhou). Genetic gain from selection is estimated from $R = ih^2\sigma_p$, where i is the selection intensity (here one unit). Results are included in Table 6.

Table 6. Selection parameters for height and dbh at both sites.

Parameters	Meipen		Ganzhou	
	ht	dbh	ht	dbh
σ^2_f	0.095	0.120	0.036	0.082
σ^2_p	1.275	1.65	0.386	0.882
h^2	0.30	0.29	0.38	0.37
R	0.34	0.37	0.24	0.35

Conclusions

The variation between 2-year-old *A. mearnsii* showed that Australian mainland provenances were superior to Tasmanian provenances. The best provenance came from South Gippsland. The Tasmanian seedlots performed particularly badly at Meipen, possibly due to climate.

There was family variation within provenances. These differences can be used as a basis for selection for the improvement of *A. mearnsii* within Australian mainland provenances in future.

References

Cochran, W.G. and Cox, G.M. 1957. Experimental Designs. 2nd ed. New York, Wiley, Section 14.3.

Falconer, D.S. 1981. Introduction to quantitative genetics. 2nd ed. New York, Longman, Chapter 10.

Hillis, W.E. 1989. *Acacia mearnsii*: Its past and potential use with reference to the development of plantations in the People's Republic of China. In: Boland, D.J., ed., Trees for the Tropics: growing Australian multipurpose trees and shrubs in developing countries. ACIAR Monograph No. 10, 21–25.

Growth of Australian Acacias in Species/Provenance Trials in Subtropical Guangdong, China

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Abstract

Plantations in northern Guangdong province, China, are losing productivity as the result of soil degradation, and insect and disease problems. A species/provenance trial of 20 Australian acacias was established to identify nitrogen-fixing species that will grow well on these degraded sites and provide the wood products required. This trial included relatively unknown bipinnate *Acacia* species in the taxonomic section *Botrycephalae*. These are closely related to Australian acacias (*A. mearnsii, A. dealbata, A. decurrens* and *A. elata*) already introduced to China.

Results from 18-month growth data show that new *Acacia* introductions are growing significantly better than the locally used *A. confusa*. Between-provenance variation for *A. melanoxylon* was found to be significant. These early results indicate the great potential for Australian *Acacia* species (particularly those from the *Botrycephalae* taxonomic section) for plantation establishment in subtropical China.

SUBTROPICAL mountainous areas of Guangdong province are important sources of timber. *Pinus massoniana* and *Cunninghamia lanceolata* plantations have been established in these areas for generations but are now suffering the effects of overcutting, subsequent land degradation and tree pests and diseases. Reforestation on the degraded soils is proving difficult, with frequent species failures. A trial was established to identify nitrogen-fixing *Acacia* species/provenances suitable for planting to improve wood production and to assist in restoring degraded soils.

This trial was also established to examine the growth and utilisation potential of species closely related to the industrially-important and widely-planted *Acacia mearnsii*. This Australian species is a high-yielding source of vegetable tannins (36–44% tannin content of bark dry weight) and for this reason has been an important plantation species in a number of countries — most notably South Africa and Brazil (Turnbull 1986). The limited work that has been done on the tannin quality and yields of species in the same taxonomic grouping as *A. mearnsii* has not identified comparable tannin sources, and this may to some extent explain why genetic research with these species has not proceeded.

A. mearnsii is one of approximately 44 species and subspecies in the *Acacia* section *Botrycephalae*. All have bipinnate adult foliage and they vary in form from short-lived (10–15 years) shrubs to large longer-lived trees (more than 20 years). They occur in cooler, moister areas of south-eastern Australia across a range of soils (Boland 1987). A few *Botrycephalae* species other than *A. mearnsii*, such as *A. dealbata, A. decurrens, A. irrorata* and *A. elata* are well-known and noted for early rapid growth. They have been used for fuelwood, pulping and poles, and have ornamental value. However there are a number of tree species in this group about which very little is known (Boland 1987).

Provenance trials of *A. mearnsii* have been established in four provinces in China since 1986 as part of an ACIAR-funded project managed by the Chinese Academy of Forestry (Gao 1989). The best performing provenances from these were included in trial at Longdouxie for comparison.

Exploration of the potential of these bipinnate acacias began in 1985 when the CSIRO Australian Tree Seed Centre started to collect seed from

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Botrycephalae species. Despite difficulties locating populations and the lack of seed crops from year to year for many of the species, seed collections have been made from 25 species and subspecies. Some of these species have been included in the ACIAR trials near Gympie, southeast Queensland (Ryan and Bell 1989). Fifteen *Botrycephalae* species were included in this trial.

Materials and Methods

Trial site

The trial site is located at Longdouxie forest farm, around 80 km southwest of Shixing county and 52 km northeast of Shaoguan city (24°57′N, 115°05′E, 480 m asl) in northern Guangdong province, China. The site is on a very steep slope on deep, degraded yellow earth soils derived from granite. These acid (pH 5–6) soils are infertile, with little organic matter and total nitrogen. The area is subject to a humid subtropical climate that is influenced by strong winds during the monsoon. The mean annual temperature is 19.6 °C and the absolute minimum recorded is −5.5 °C. The mean annual rainfall is 1831 mm.

The trial site was formerly planted with *Cunninghamia lanceolata* and carried an understorey of shrub, fern and grass species.

Seed source and trial establishment

Origin data for the 21 species and 44 provenances including the Chinese control species *A. confusa* are presented in Table 1.

The six phyllodinous species in trial are *A. binervata, A. falciformis, A. implexa, A. melanoxylon, A. pycnantha* and the control *A. confusa*. The other fifteen species belong to the *Botrycephalae* section of *Acacia* (Pedley 1987). With the exception of *A. mearnsii, A. dealbata, A. decurrens, A. irrorata* and *A. elata*, the other *Botrycephalae* species in the trial have been rarely tested for plantation forestry. All available *Botrycephalae* species were included in the trial, where possible represented by a number of provenances. However, 11 of the species are represented by one provenance as these were the only seedlots available. Where a number of provenances were available, selections were made to represent the geographic range of the species and to match a provenance as closely as possible to the latitude and altitude of the trial site.

Acacia confusa, a native of Taiwan, was used as a control species in the trial because it is commonly planted in mainland China for fuelwood and soil conservation (Wang and Fang, these proceedings).

The seed was sown in November 1988 after pretreatment with boiling water. The uninoculated seedlings were planted out at the commencement of the rainy season in April 1989. The trial was not fertilised and plots were weeded in the first year.

Trial design and layout

The 44 treatments in trial were planted in a completely randomised block design with four replicates. The plot size was 25 trees (5 × 5) at 2 × 2 m spacing. The total number of trees in trial was 4400. The trial was surrounded by a buffer of two rows of *Acacia* species.

Measurement and data analysis

Percentage germination of the seedlots in the nursery was calculated from assessments made 1 month after sowing. Survival, height and root-collar diameter of the seedlings were measured in the nursery 1 and 6 months after sowing. Plot means for these measurements were calculated. Survival and height were measured 1 and 3 months after planting in the field, and height and diameter (dbh) were measured at 18 months. Duncan's multiple range tests for height and an analysis of variance for height and diameter were used to examine the 18-month data.

Results

Germination

Germination for 75% of the seedlots was high (80–90%) with 86% of the seedlots having germination equal to or greater than 70%. The poorest germination percentage of 50% was recorded for the *Acacia decurrens* No. S14768 seedlot.

Height and diameter at six months

After six months the tallest species (*A. fulva, A. pruinosa, A. filicifolia, A. parvipinnula* and *A. implexa* respectively, in terms of decreasing height) had exceeded 1.9 m. At this age *A. fulva* was the tallest species in the trial at 2.6 m and the local *A. confusa* was the smallest, growing to 0.65 m. Diameter at ground level varied between 0.5 and 2.0 cm with *A. fulva* also having the largest diameter.

Height and diameter at 18 months

After 18 months the trees in the best treatments in the trial had reached an average height of 5.6 m with *A. confusa* still the smallest at 1.5 m. *A. fulva, A. pruinosa* and *A. filicifolia* had continued to grow rapidly. Ranking for height growth in the trial had changed with the tallest being *A. filicifolia*

Table 1. Origin data for species and provenances in trial.

CSIRO Seedlot No.	Species	No. of parent trees	Origin: Locality	Lat. (S)*	Long. (E)	Altitude (m)
Bipinnate species (Botrycephalae)						
6611	*A. cardiophylla*	50	Coonoo State Forest, NSW	31°00′	149°00′	300
15538	*A. dealbata* ssp *dealbata*	8	SE of Melbourne, VIC	37°48′	146°16′	900
16267	*A. dealbata* ssp *dealbata*	7	32 Mile Road, VIC	37°25′	148°37′	350
16269	*A. dealbata* ssp *dealbata*	5	Cooma, NSW	36°28′	149°07′	910
16271	*A. dealbata* ssp *dealbata*	6	Errinundra Plateau, VIC	37°11′	148°52′	960
16376	*A. dealbata* ssp *dealbata*	11	WNW Bemboka, NSW	36°37′	149°26′	1035
16383	*A. dealbata* ssp *dealbata*	12	NW Swansea, TAS	41°55′	147°56′	615
16384	*A. dealbata* ssp *dealbata*	9	S Orford, TAS	42°41′	147°52′	120
16385	*A. dealbata* ssp *dealbata*	9	S Orford, TAS	43°41′	147°52′	120
17123	*A. dealbata* ssp *dealbata*	13	Pierces Ck, ACT	35°22′	148°57′	600
5933	*A. deanei*	Unknown	Warialda, NSW	29°30′	150°36′	300
9697	*A. deanei*	15	Gilgandra, NSW	31°00′	148°00′	300
17538	*A. deanei*	100	Durikai scrub, QLD	28°12′	151°37′	500
14768	*A. decurrens*	5	Goulburn, NSW	34°38′	150°09′	660
14726	*A. decurrens*	10	Goulburn, NSW	34°53′	149°17′	685
15848	*A. elata*	9	Buxton — Hill Top, NSW	34°17′	151°31′	410
15841	*A. filicifolia*	15	Singleton, NSW	32°41′	151°01′	150
15843	*A. fulva*	25	Howes Valley, NSW	32°52′	150°52′	240
17152	*A. glaucocarpa*	10	Bains Gully, QLD	26°48′	151°51′	400
17145	*A. irrorata*	10	Mt. Mee, QLD	27°07′	152°45′	250
14725	*A. mearnsii*	12	Bungendore, NSW	35°12′	149°32′	760
14771	*A. mearnsii*	9	Cooma, NSW	36°28′	149°01′	940
14922	*A. mearnsii*	12	Braidwood, NSW	35°15′	149°38′	720
16378	*A. mearnsii*	5	Merimbula, NSW	36°55′	149°54′	30
14925	*A. mearnsii*	6	Blackhill Reserve, VIC	37°12′	144°28′	500
15850	*A. mearnsii*	20	Araluen, NSW	35°42′	149°51′	160
14723	*A. parramattensis*	19	Bungendore, NSW	35°19′	149°25′	730
14767	*A. parramattensis*	5	Marulan, NSW	34°42′	150°02′	550
15842	*A. parvipinnula*	35	Howes Valley, NSW	32°52′	150°52′	240
6879	*A. pruinosa*	Unknown	Pilliga Scrub, NSW	31°00′	150°00′	360
16260	*A. silvestris*	10	Narooma, NSW	36°14′	149°48′	570
14229	*A. trachyphloia*	15	Monga State Forest, NSW	35°36′	149°55′	710
Phyllodinous species						
89003	*A. confusa*	Unknown	Lufeng Guangdong, CHN*	23°00′	115°40′	100
9973	*A. binervata*	5	Robertson, NSW	34°36′	150°36′	550
17260	*A. binervata*	10	Springbrook, QLD	28°12′	153°16′	500
15502	*A. falciformis*	15	S of Warwick, QLD	28°32′	151°58′	900
14740	*A. implexa*	1	Cooyar, QLD	27°05′	151°46′	600
17198	*A. implexa*	20	Maldon, VIC	36°59′	144°04′	440
15832	*A. implexa*	15	Swansea, NSW	33°05′	151°37′	10
15863	*A. melanoxylon*	10	Blackwood Park, TAS	40°57′	145°10′	250
16358	*A. melanoxylon*	10	Bli Bli, QLD	26°37′	153°02′	95
17288	*A. melanoxylon*	28	Captains Flat, NSW	35°37′	149°32′	700
17317	*A. pycnantha*	40	Toolernvale, VIC	37°37′	144°37′	50
17071	*A. pycnantha*	Unknown	Bacchus Marsh, VIC	37°40′	144°27′	180

* Chinese seedlot from north latitude

Table 2. Duncan's Multiple Range Tests for height and diameter at breast height (18 months). Values under the same bar are not significantly different at the 5% level.

Species/provenance		Height (m)	Species/provenance		Dbh (cm)
15841	*A. filicifolia*	5.6	16384	*A. dealbata*	3.7
15843	*A. fulva*	5.5	16267	*A. dealbata*	3.7
16384	*A. dealbata*	5.4	14925	*A. mearnsii*	3.7
16385	*A. dealbata*	5.3	16385	*A. dealbata*	3.6
6879	*A. pruinosa*	5.3	14922	*A. mearnsii*	3.6
16269	*A. dealbata*	5.0	15850	*A. mearnsii*	3.6
16376	*A. dealbata*	5.0	15841	*A. filicifolia*	3.5
14925	*A. mearnsii*	5.0	16383	*A. dealbata*	3.5
17152	*A. glaucocarpa*	5.0	16269	*A. dealbata*	3.4
16267	*A. dealbata*	4.9	14726	*A. decurrens*	3.4
16271	*A. dealbata*	4.9	14771	*A. mearnsii*	3.4
16383	*A. dealbata*	4.7	6879	*A. pruinosa*	3.4
16260	*A. silvestris*	4.7	16271	*A. dealbata*	3.3
15502	*A. falciformis*	4.6	14725	*A. mearnsii*	3.3
17198	*A. implexa*	4.6	16376	*A. dealbata*	3.2
14725	*A. mearnsii*	4.6	15502	*A. falciformis*	3.2
14922	*A. mearnsii*	4.6	17198	*A. implexa*	3.2
15850	*A. mearnsii*	4.6	15843	*A. fulva*	3.1
17123	*A. dealbata*	4.4	15538	*A. dealbata*	3.0
5933	*A. deanei*	4.2	17152	*A. glaucocarpa*	3.0
15538	*A. dealbata*	4.1	16378	*A. mearnsii*	3.0
14740	*A. implexa*	4.1	14768	*A. decurrens*	2.9
16378	*A. mearnsii*	4.1	16260	*A. silvestris*	2.9
14771	*A. mearnsii*	4.0	17123	*A. dealbata*	2.8
15832	*A. implexa*	3.9	14723	*A. parramattensis*	2.7
14726	*A. decurrens*	3.9	15842	*A. parvipinnula*	2.7
15848	*A. elata*	3.7	15832	*A. implexa*	2.5
14768	*A. decurrens*	3.7	14740	*A. implexa*	2.5
16723	*A. parramattensis*	3.7	15848	*A. elata*	2.4
14229	*A. trachyphloia*	3.7	14229	*A. trachyphloia*	2.4
9697	*A. deanei*	3.6	5933	*A. deanei*	2.2
15842	*A. parvipinnula*	3.5	9697	*A. deanei*	2.2
16358	*A. melanoxylon*	3.5	17145	*A. irrorata*	2.2
17145	*A. irrorata*	3.0	16358	*A. melanoxylon*	2.2
14767	*A. parramattensis*	2.9	9973	*A. binervata*	2.0
17538	*A. deanei*	2.8	14767	*A. parramattensis*	1.5
9973	*A. binervata*	2.6	17538	*A. deanei*	1.5
15863	*A. melanoxylon*	2.3	15863	*A. melanoxylon*	1.3
6611	*A. cardiophylla*	2.3	17260	*A. binervata*	1.2
17260	*A. binervata*	2.2	6611	*A. cardiophylla*	1.0
17071	*A. pycnantha*	2.1	17288	*A. melanoxylon*	0.9
17288	*A. melanoxylon*	1.9	17071	*A. pycnantha*	0.8
17317	*A. pycnantha*	1.9	17317	*A. pycnantha*	0.7
89003	*A. confusa*	1.5	89003	*A. confusa*	0.4

(S15841 — 5.6 m) followed by *A. fulva* (S15843 — 5.5 m), *A. dealbata* (S16384 — 5.4 m, and S16385 — 5.3 m) and *A. pruinosa* (S6879 — 5. 3 m). However there were no significant differences in height growth between the tallest 19 of the 44 seedlots, which ranged between 4.4 and 5.6 m in height (see Table 2 Duncan's Multiple Range Tests for height and diameter at breast height (18 months)).

Provenance variation at 18 months

The early results from this *Acacia* species trial are extremely promising, with new introductions of species and provenances growing rapidly on steeply sloping, degraded sites. All the Australian species and provenances tested grew larger than the locally used *A. confusa*.

Nine of the seedlots tested grew to 5 m or more. These were provenances of *A. filicifolia* (S15841 — 5.6 m), *A. fulva* (S15843 — 5.5 m, *A. dealbata* (S16384 — 5.4 m), S16385 — 5.3 m, S16269 — 5.0 m, S16376 — 5.0 m), *A. pruinosa* (S6879 — 5.3 m), *A. mearnsii* (S14925 — 5.0 m) and *A. glaucocarpa* (S17152 — 5.0 m).

Provenances and replicates of four species were analysed for their significance as sources of variation in the species means; *A. dealbata* (9 provenances), *A. implexa* (3 provenances), *A. mearnsii* (6 provenances) and *A. melanoxylon* (3 provenances). Highly significant variation was found among the three provenances of *A. melanoxylon* (see Table 3) with the Bli Bli provenance (S16358 — 3.5 m, 2.2 cm dbh) from southeast Queensland growing larger than the Tasmanian (S15863 — 2.3 m, 1.3 cm dbh) or New South Wales (S17288 — 1.9 m, 0.9 cm dbh) provenances. No significant variation was found between provenances or replicates of *A. dealbata, A. implexa* or *A. mearnsii.*

It is of interest to note that the *A. mearnsii* provenances from Blackhill Reserve Victoria (S14925), Bungendore NSW (S14725) and Braidwood NSW (S14922) are ranked in the top grouping in this trial, and grew 4.6-5.0 m in 18 months. By comparison, these provenances had grown 3.1-3.3 m at the same age (Gao 1989) at the Ganzhou (Jiangxi) site, which is a drier and slightly warmer site (Booth 1989).

Discussion/Conclusion

These early results are an indication of the large and rapid gains that can be made through selection of appropriate species and provenances. Thirty-seven of the 43 Australian introductions grew significantly faster than the local *A. confusa*. Twenty-four of these grew 4 m or more in 18 months. Provenances of *A. filicifolia, A. fulva, A. dealbata, A. pruinosa, A. mearnsii* and *A. glaucocarpa* grew 5 m or more in the same period.

These results also demonstrate the great potential of the bipinnate (*Botrycephalae*) acacias for early rapid growth on degraded hill slopes in the subtropics. Within this grouping the lesser-known species such as *A. filicifolia, A. fulva, A. pruinosa* and *A. glaucocarpa* have performed particularly well. Due to lack of seed each of these species was represented in the trial by only one provenance. Provenance seed collections from these species should be given priority to enable a thorough examination of the potential of these species. In retrospect it would have been useful to have included *Cunninghamia lanceolata* and *Pinus massoniana* in the trial for a direct comparison with these local plantation species.

There does not appear to be any pattern of climatic similarity between the origin of the better-performing provenances and the trial site. However it is notable that acacia species from temperate Australia, including Tasmania, are performing well on this subtropical site. The exception is *A. melanoxylon*. Three provenances (Tasmania, New South Wales and Queensland) were tested and it is the subtropical provenance which has performed best.

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References

Boland, D.J. 1987. Genetic resources and utilisation of Australian bipinnate acacias (Botrycephalae). In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, 29-37.

Booth, T.H. 1989. Climatic conditions at trial sites in China, Kenya, Thailand and Zimbabwe compared to similar regions in Australia. In: Boland, D.J., ed., Trees for the Tropics: growing Australian multipurpose trees and shrubs in developing countries. ACIAR Monograph No. 10, 37-47.

Gao, C. 1989. *Acacia mearnsii* provenance trials in the People's Republic of China. In: Boland, D.J., ed., Trees for the Tropics: growing Australian multipurpose trees and shrubs in developing countries. ACIAR Monograph No. 10, 97-102.

Pedley, L. 1987. Australian acacias; taxonomy and phytogeography. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, 11-16.

Ryan, P.A and Bell, R.E. 1989. Growth, coppicing and flowering of Australian tree species in trials in southeast Queensland, Australia. In: Boland, D.J., ed., Trees for the Tropics: growing Australian multipurpose trees and shrubs in developing countries. ACIAR Monograph No. 10, 49-68.

Turnbull, J.W. 1986. Multipurpose Australian trees and shrubs: lesser-known species for fuelwood and agroforestry. ACIAR Monograph No. 1, 316 p.

Trials of *Acacia mangium* at the Sabah Forestry Development Authority

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Abstract

This paper highlights some of the *Acacia mangium* trials carried out and their results. These include pretreatment of *Acacia mangium* seeds, spacing, fertiliser and provenance trials.

SABAH Forestry Development Authority (SAFODA) began operation in mid-1977 with the aim of converting useless secondary forest and grasslands into forest plantations. By the end of 1990, a total of about 14 000 hectares had been planted, largely with *Acacia mangium*. With such vast plantations it is only natural that trials be carried out on *Acacia mangium*, so that SAFODA can improve the resources already available.

Trial Descriptions

Pretreatment of *A. mangium* seeds

Since beginning operations, SAFODA has always tried to find out the simplest method of germinating *Acacia mangium* seeds. The conventional SAFODA practice is to add seeds to boiling water removed from the heat source. Seeds and water are then left to cool overnight. Madius (unpubl.) reported that this was still the best method. Subsequently another trial was conducted by Okada (unpubl.) which indicated that soaking seeds in boiling water kept on the heat source for one minute (enough to submerge the seeds) followed by soaking in cold water for 10 minutes gave a better germination result.

In the light of the above controversy, an experiment was carried out to compare the two treatments. The germination percentages obtained did not show any significant difference between the treatments.

Based on the above results, SAFODA is still using its old conventional method as it is much easier to carry out especially for field staff. This is an important consideration as the later method required strict adherence to soaking and cooling times. For instance, increasing the soaking time in boiling water to two minutes can decrease the germination by about 38%.

Spacing trial of *A. mangium*

A spacing trial was established by SAFODA at Nahaba, Kota Belud. Soil within the area is generally derived from sedimentary rocks of mainly sandstone and mudstone. A randomised complete block design with four replicates was used. Table 1 shows the results of the trial.

Table 1. Mean diameter and height of *Acacia mangium* spacing trial at Nahaba at 2 years.

Treatment	Mean diameter (cm)	Mean height (m)
2 × 2 m	6.7	8.4
2.5 × 2.5 m	6.5	7.6
3 × 3 m (control)	6.2	6.9

The diameter growth of the trial did not show any significant difference between the spacing. An analysis of variance, however, shows significant differences on height growth between them. Comparison between mean heights using least significant difference (LSD) indicates that spacings of 2 × 2 m and 2.5 × 2.5 m are significantly different from the control at the 1 and 5% levels of significance, respectively.

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The above results indicate that trees planted at closer spacing can produce significantly higher height growth compared with wider spacing. Latiff and Brini (unpubl.) reported that trees planted at 2 × 2 m produced significantly higher basal area and yield per hectare compared with other wider spacings. These preliminary results indicate there may be justification for a spacing of 2 × 2 m.

Fertiliser trial of *A. mangium*

A fertiliser trial was laid out in a randomised complete block design with four replicates at Lumat, Beaufort. There were 16-tree square plots at 3 × 3 m spacing. The soil within the area is generally derived from sedimentary rock, mainly sandstone and mudstone. Results of the trial are shown in Table 2.

Table 2. Mean diameter and height of *Acacia mangium* fertiliser trial at Lumat at 6.25 years.

Treatment	Mean diameter (cm)	Mean height (m)
Without litter, with fertiliser (–L+F)	15.2	15.8
With litter, without fertiliser (+L–F)	14.4	15.7
Without litter, without fertiliser (–L–F)	13.8	15.1
With litter, with fertiliser (+L+F)	14.5	15.4

The diameter and height growth did not show any significant difference between treatments.

From the above results, it was observed that when NPK-Blue fertiliser was broadcast on the soil around the tree at 60, 120 and 180 g/plant respectively 3, 8 and 24 months after field planting (with or without removal of leaf litter) there was no significant difference from those without fertiliser under the same condition. Li (unpubl.), who carried out a similar fertiliser trial except that the fertiliser was incorporated into the soil, recommended a new fertiliser regime to suit the soil conditions of the area. It was suggested that in future fertiliser should be incorporated into the soil.

Provenance trial of *A. mangium*

There were two provenance trials of *A. mangium* — one in Mentanau, Kota Belud and another in Tanjung Piring, Bengkoka, which, although some distance apart, are on similar soils derived from sedimentary rock of mainly sandstone and mudstone. Due to the nature of the terrain of the area, the trial in Mentanau was laid down in a completely randomised design while the one in Tanjung Piring was established in a randomised complete block design. The results of the two trials are shown in Tables 3 and 4, the particulars of the various provenances being as shown in Table 5.

Table 3. Mean diameter and height of *A. mangium* provenance trial at Mentanau at 6.1 years.

SEP* No.	Provenance	Mean diameter (cm)	Mean height (m)
513	Brumas, Sabah	18.7	19.5
1001	Jalan Madu, Sabah	18.6	19.3
1004	Jalan Lee, Sabah	18.4	20.1
1101	Sook, Sabah	18.7	19.4
1133	Western Province, PNG	18.1	19.3
1134	Oriomo River, PNG	18.2	20.2
1137	Western Province, PNG	19.1	19.3
1158	Claudie River, Qld	19.1	19.6
1159	Olive River, Qld	18.7	20.1
1160	Claudie River, Qld	18.5	19.8
1163	Broken Pole Creek, Qld	18.4	19.5

* Sabah Forest Research Centre seed collection number.

Table 4. Mean diameter and height of *A. mangium* provenance trial at Tg. Piring at 5.7 years.

SEP No.	Provenance	Mean diameter (cm)	Mean height (m)
1304	Jalan Lee, Sabah	13.9	17.3
1396	Gum Gum, Sandakan	14.7	17.8
1574	Jalan Madu, Sabah	14.6	17.0
1692	Sook, Sabah	14.5	18.6
1716	Mourilyan Bay, Qld	14.4	16.6
1719	Mission Beach, Qld	14.9	17.4
1721	Cardwell, Qld	13.9	16.5
1722	Broken Pole Creek, Qld	15.6	18.0
1723	Abergowrie, Qld	15.2	17.4
1725	Oriomo River, PNG	15.1	17.1
1726	Piru, Ceram, Indonesia	14.5	16.9
1727	Mossman, Qld	13.0	17.2

The diameter and height growth of both the provenance trials did not show any significant difference between the various provenances.

From these results it can be inferred that recommendation of a particular provenance suitable for SAFODA based on growth performance may not be possible. However, the above results are only applicable in areas where the soils are derived from

Table 5. Location and altitude of the provenances seed sources.

SEP No.	Provence	Latitude	Longitude	Elevation (m)
1001, 1574	Jalan Madu, Sabah	6°29'N	116°34'E	140
513	Brumas, Sabah	4°25'N	118°00'E	50
1101, 1692	Sook, Sabah	5°60'N	116°21'E	1000
1004, 1304	Jalan Lee, Sabah	6°29'N	116°34'E	140
1396	Gum Gum, Sabah	5°51'N	117°56'E	10
1719	Mission Beach, Qld	17°56'S	146°02'E	30
1158, 1160	Claudie River, Qld	12°44'S	143°13'E	60
1723	Abergowrie, Qld	18°26'S	146°01'E	60
1163, 1722	Broken Pole Creek, Qld	18°21'S	146°03'E	50
1716	Mourilyan Bay, Qld	17°35'S	146°05'E	20
1721	Cardwell, Qld	18°17'S	145°58'E	6
1727	Mossman, Qld	16°30'S	145°58'E	30
1159	Olive River, Qld	12°11'S	143°01'E	50
1134, 1725	Oriomo River, PNG	8°48'S	143°05'E	10
1137, 1133	Western Province, PNG	9°09'S	141°20'E	10
1726	Piru, Ceram, Indonesia	3°04'S	128°12'E	150

sedimentary rock or sandstone and mudstone. Soils in other SAFODA areas derived from other materials or of the same material but different soil conditions may exhibit different results.

Conclusion

The results of the above trials were by no means exhaustive and the recommendations that followed may not be perfect or ideal. Assessment of other criteria should also be included so that a more meaningful recommendation can be made. Further technical reports on these trials should be produced.

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Reference

Jaffirin, L. 1986. *Acacia mangium* provenance trial in Sabah. Paper presented in 9th Malaysian Forestry Conference, Kuching Sarawak, 13-20 October, 1986.

Australian Acacias in Laos

Sylavong Latsamay*

Abstract

This paper outlines some of the difficulties confronting the forestry sector in Laos, and the possible role of Australian acacias in restoring land degraded by slash-and-burn agriculture. Early results are given for growth trials of 14 different tropical acacia seedlots.

LAOS has a total land area of 237 000 km^2 and a forest survey in 1981 reported a total forest area of 113 000 km^2. The climate is tropical to monsoon subtropical, with a wet season from April to October and rainfall ranging from 1250 to 3000 mm per annum.

In 1990 the population was estimated at 4 170 000, with an annual population increase of 2.9%. Eighty-five per cent of the population are dependent on agriculture and forestry, and 60% live in the limited lowland area which is only 20% of the total area of the country.

Apart from the forest area, Laos is believed to have rich mineral resources and a high potential for hydroelectric power. However agriculture and forestry presently account for 65% of gross domestic product. The average income is less than US$200 per capita.

Of the total 11.3 million ha of forest, the distribution of forest types is as follows: tropical evergreen, 3.4 million ha; tropical semideciduous, 5.7 million ha; tropical deciduous, 1.7 million ha; other, 0.5 million ha. In this distribution some 80 species are considered commercially important. The more significant species belong to the family Dipterocarpacae.

Forest areas are under heavy pressure by people with no alternative for subsistence other than shifting cultivation or encroachment on forest land. Annually about 250 000 ha of land are under slash-and-burn cultivation. This ongoing degradation of land is a serious threat to environmental welfare, in spite of the fact that Laos is less densely populated than most other countries in the region; and in the long run continued degradation of the uplands will have serious implications for the lowlands, reducing agricultural production and frustrating economic development.

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Trial Establishment

Since 1988, the Nam Souang Silviculture Research Center (NSSRC) with support from SIDA, has begun extended trials of acacias. The trial establishment of these acacias was the main task for the Silviculture Project. Acacias are tested for fodder production, and soil and environment improvement. *Acacia auriculiformis* has long been known for its ability to thrive in Laos, and *A. mangium* has been recently introduced. This paper reports height growth of 14 different acacia seedlots 8 months after field establishment (Table 1).

Major soil types at Nam Souang are Haphic Acrisols with some Ferric Acrisols (FAO classification). The average pH value is around 5, with minimum and maximum values 4.2 and 6.2 respectively, depending on location.

The site was an abandoned shifting cultivation area entirely covered with *Pterocarpus macrocarpus* and *Afzelia xylocarpa* until trial establishment.

Nursery practices

Before sowing, all acacia seed is given standard hot water treatment, using water brought to boiling point and allowed to stand for 5 minutes before immersing the seed. After cooling, the seed is removed and sown directly into polythene bags filled with nursery soil (20% husk, 80% local soil).

Table 1. Mean height growth of *Acacia* trials after 8 months.

Species	CSIRO Seed No.	Location	Lat. (°S)	Long. (°E)	Alt. (m)	Mean ht (cm)	Survival (%)
A. auriculiformis	15477	Morehead River, Qld	15°02′	143°40′	70	127	93
A. auriculiformis	15483	Archer River, Qld	12°26′	142°57′	100	142	94
A. auriculiformis	15697	Coen, Qld	14°07′	143°16′	160	140	96
A. aulacocarpa	13866	Garioch, Qld	16°40′	145°18′	400	82	75
A. leptocarpa	15478	Musgrave, Qld	14°55′	143°32′	80	146	88
A. cincinnata	13864	Shoteel, Qld	16°57′	145°38′	440	133	64
A. crassicarpa	13683	Woroi Wipim, PNG	8°49′	143°00′	20	142	83
A. mangium	15644	Oriomo, PNG	8°50′	143°08′	10	175	100
A. mangium	15687	Daintree, Qld	16°16′	145°22′	12	116	69
A. mangium	15700	Cardwell, Qld	18°32′	146°05′	55	108	76
A. aulacocarpa	15715	Borroloola, NT	15°38′	136°25′	3	30	93
A. aulacocarpa	17154	18 Mile Creek, Qld	25°33′	152°28′	50	32	93
A. aulacocarpa	15651	Oriomo, PNG	8°50′	143°08′	15	34	86
A. crassicarpa	15479	40 km S of Coen, Qld	14°17′	143°26′	80	109	68

Fertilisers are used in the nursery when the seedlings are over 1 month old. Urea and NPK (15.15.15) are applied at 0.16 g per seedling when the seedlings are 5 cm and above.

Seedlings were raised in the nursery for 6 months. By that time *A. auriculiformis* was 20–50 cm high with satisfactory root/shoot ratio. However *A. mangium* showed poor development and the seedlings were about 20 cm high when planted out.

A. crassicarpa was 20–40 cm tall with good shoot/root ratio. Other species such as *A. leptocarpa, A. cincinnata* and *A. aulacocarpa* averaged around 20 cm high. Root pruning was undertaken before planting out.

Field establishment

Site preparation included deep ripping, ploughing and discing prior to pitting. Land preparation on sites being re-established is done manually, digging 30 × 30 × 30 cm holes at 3 × 3 m spacing, with five replications within each block. Each replication is 21 × 21 m, and around each block fire breaks were established.

All planting was done in June and July, and each plant given 75 g of NPK (15.15.15). Weeds were controlled by disc-harrowing between rows in two directions, and manually weeding around each seedling by cutting the grass.

Results

The height growth 8 months after planting is given in Table 1. *A. mangium* is quite impressive with its straight stem and symmetrical crown compared with the other species.

Early results indicate marked differences in height growth between the eight *Acacia* species tested. *A. mangium* (15644), *A. leptocarpa* (15478), *A. crassicarpa* (13683) and *A. auriculiformis* (15488) were the fastest growing at each planting site. Relatively slower growth was recorded for *A. aulacocarpa*.

Trials with Australian and other *Acacia* Species on Salt-affected Land in Pakistan, Thailand and Australia

N.E. Marcar*, R.W. Hussain, S. Arunin*** and T. Beetson******

Abstract

Land degradation, resulting from soil salinisation, sodicity, waterlogging and combinations of these, is a major impediment to land utilisation in many countries with semi-arid to arid climates. This paper presents some preliminary results of trials with Australian and other *Acacia* species conducted in Pakistan, Thailand and Australia. It also presents preliminary results from a trial in Thailand dealing with the effect of preplanting techniques on the survival and growth of *Acacia ampliceps*.

LAND degradation, resulting from soil salinisation, sodicity, waterlogging and combinations of these, is a major impediment to land utilisation in many countries with semi-arid and arid climates. These problems, in particular irrigation-induced salinity, are responsible for serious declines in crop productivity (Pakistan, India and Thailand) and the development of unproductive wastelands in Pakistan and India. It is widely acknowledged that such unproductive land can be harnessed for the production of fuelwood, forage, timber and/or pulpwood with suitable species and establishment/management techniques.

This paper presents some preliminary results from trials at three experimental sites in Pakistan, Thailand and Australia as part of an ACIAR-sponsored project 'Australian Woody Species for Saline Sites in Asia'. The objectives of this project are:

- to extend the range of tree and shrub germplasm for salt-affected soils;
- to identify nutritional and other constraints that limit establishment and early growth on these soils.

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The overall project is managed by CSIRO Division of Forestry, Canberra, with components in Thailand, Pakistan and Australia. Field-based studies commenced in 1989. The Thailand component is managed by the Department of Land Development; trials have been established near Korat and Kalasin in northeast Thailand. In Pakistan, trials have been established near Peshawar (by the Pakistan Forest Institute), Lahore (by the Nuclear Institute for Biology and Agriculture) and Tando Jam (by the Atomic Energy Agricultural Research Institute). In Australia, a site has been established near Gympie in Queensland (by the Queensland Forest Service).

In this paper, reference is made to the performance of *Acacia* species only although species from other genera have also been evaluated.

Materials and Methods

Site 1: Toolara, near Gympie, Queensland, Australia

This experiment is located on a saline discharge site subject to seasonal waterlogging in summer/autumn near Toolara (25°57'S and 152°46'E). Mean annual rainfall is 1370 mm. The soil type is podzolic, pH is 5.5–7.0 and salinity is low-moderate.

The site was surveyed for salinity variations by the electromagnetic induction technique using an EM38. The experiment was planted in June 1989. It was laid out as a randomised complete block with 89 blocks. Each plot consisted of a single tree of a given taxon.

Prior to planting, the site was pretreated with glyphosate herbicide. Crop King 88 (15:4:11:14) fertiliser was applied as a split spot basal dressing about 15 cm from each tree (100 g/tree) at planting.

Site 2: Korat, Northeast Thailand

This site is located near Kum Phaya, Amphor Khamtalaesor, about 200 km northeast of Bangkok. The climate is hot, tropical with 1000–1400 mm annual average rainfall, mostly falling in April–November with a pronounced 6-month dry season. Soil texture is sandy loam to loam, pH varies from 6.0 to 8.0 and soil salinity (EC_e) ranges from approximately 10 to 35 dS/m.

Several species trials have been planted here since 1988, with varying success. Soil salinity levels were surveyed with an EM38.

The most recent species trial was planted in July 1990 according to a lattice design with 9 replicate blocks on an area of moderate salinity (EC_e = 10–20 dS/m) and not subject to waterlogging. Farm yard manure (3 kg/tree) and rice hulls were incorporated into each planting hole.

A treatment trial, using *A. ampliceps*, was also planted in July 1990 using an RCB design with four replicates. Salinity levels ranged from EC_e 15 to 25 dS/m. The objective was to determine the magnitude of responses possible with amelioration of the root zone environment of newly planted seedlings. Twelve treatments were included (see Table 1).

Site 3: Risalpur, Pakistan

This site, located near Nowshera in the North West Frontier Province, has a semi-arid climate, with an annual average rainfall of 300–400 mm, mostly falling between July and September. Soil texture is sandy loam to loam and pH ranges from 7.5 to 9.5. The site is saline-sodic.

The trial was planted in July 1989 on a non-saline (EC_e < 4 dS/m) but sodic area. The highly sodic nature of the soil hinders water infiltration and subsequently surface waterlogging occurs during the monsoon season. Weed competition was controlled manually and no fertiliser was used.

Results and Discussion

Preliminary results are presented to indicate species growth, survival and responses to pre-planting techniques.

Tables 2, 3 and 4 present data for species comparisons from sites in Australia, Thailand and Pakistan respectively. Although these trials contained species from several genera, only data for *Acacia* species are given.

Table 1. Survival percentage and height growth at age 6 months for *Acacia ampliceps* (15741; Wolfe Creek Crater, Western Australia) planted in July 1990, with various pre-planting treatments applied, on a saline site near Korat, northeast Thailand. Data are means of up to 32 plants (4 replicates of 8-tree rows). Numbers in brackets are standard errors.

Treatment	Survival (%)	Height (m)
Rice hulls mulch	94	0.28 (0.03)
Gypsum (2 kg/tree)	100	0.34 (0.02)
Farm yard manure (3 kg/tree)	59	0.29 (0.04)
NP Fertiliser[1] (15 g/tree)	59	0.25 (0.04)
Mulch + gypsum + farm yard manure	100	0.50 (0.04)
Mulch + gypsum + NP fertiliser	100	0.58 (0.03)
Salt pretreatment[2]	88	0.19 (0.02)
Waterlogging pretreatment[3]	88	0.25 (0.04)
Plastic covering over soil	97	0.36 (0.03)
Mulch + gypsum + NP + salt pretreatment	100	0.60 (0.03)
Large plastic bag buried into soil	91	0.41 (0.04)
Control (no treatment)	72	0.18 (0.02)

[1] ammonium nitrate, superphosphate
[2] for 2 weeks using water with electrical conductivity of 2 dS/m
[3] for 2 weeks using good quality water

At Toolara, Queensland, the best performing species, in terms of survival and height growth, was *A. auriculiformis.* All acacias have proven to be considerably less tolerant than the eucalypts, casuarinas and melaleucas included in the trial. Many species, for example *A. holosericea*, suffered from severe waterlogging x salinity interaction due to heavy rains that occurred post-planting. The foliage of many species was chlorotic which probably indicated nitrogen deficiency. This observation suggests that seedlings may benefit from inoculation with rhizobia in the nursery, since this was not done. Only acacias with proven or potential timber, pole or pulp end-users were included. Considerable provenance variation in survival and height growth is evident for *A. aulacocarpa*.

At Korat, Thailand, survival for all acacias has been high to date. This contrasts with poor survival rates recorded in earlier plantings on areas of higher salinity with seasonal surface waterlogging on the same site. In this trial species with forage potential (e.g. *A. ampliceps, A. salicina*) were also included. In earlier plantings, *A. ampliceps* has been the best performer. The high salt tolerance of this species has also been demonstrated in the field in Pakistan, on

Table 2. Survival percentage and height growth at age 16 months of *Acacia* species and provenances planted in July 1989 on a saline site near Toolara, Queensland, Australia.

Species	CSIRO Seedlot No.	Survival (%)				Height (m)			
		Class No.*				Class No.*			
		I	II	III	IV	I	II	III	IV
A. auriculiformis	16147	68	54	23	20	1.27	0.87	0.68	0.72
A. auriculiformis	16142	73	58	50	27	1.69	1.22	1.16	0.61
A. aulacocarpa	16113	50	42	23	20	0.99	0.66	0.58	0.56
A. aulacocarpa	15715	9	4	4	0	0.40	0.07	0.43	—
A. crassicarpa	15949	14	31	19	13	0.71	0.58	0.58	0.88
A. crassicarpa	15646	9	31	27	13	1.52	1.36	1.15	1.11
A. holosericea	14637	0	0	7	0	—	—	—	—
A. holosericea	15712	0	7	4	0	—	—	—	—
A. melanoxylon	17279	50	50	23	6	1.35	0.85	0.80	0.93
A. difficilis	16177	0	4	0	0	—	—	—	—
A. leptocarpa	15478	36	31	35	6	1.85	1.48	1.67	0.75
A. leptocarpa	16110	27	12	15	7	1.72	1.43	1.31	1.21

* Class I through to Class IV represents areas of increasing salinity. Survival data are means of 22 (class I), 26 (class II), 26 (class III) and 15 (class IV) plants, whereas height data are means of surviving plants in each class.

Table 3. Survival percentage and height growth at age 5 months for *Acacia* species planted on a saline site near Korat, northeast Thailand, in July 1990. Data are means of up to 45 plants (9 replicates of 5-tree rows).

Species	CSIRO Seedlot No.	Survival (%)	Height (m)
A. ampliceps	15737	100.0	0.61
A. ampliceps	15762	97.8	0.41
A. ampliceps	14668	100.0	0.50
A. auriculiformis	16484	95.6	0.61
A. auriculiformis	16106	86.7	0.59
A. plectocarpa	14696	86.7	0.31
A. salicina	16648	100.0	0.49

a saline site near Tando Jam (R. Ansari, pers. comm.) and a saline-sodic site near Lahore (I. Haq, pers. comm.) as well as in glasshouse studies (Aswathappa et al. 1986; Marcar et al. 1991).

At Risalpur, Pakistan, marked variation occurred in both survival and growth between *Acacia* species. Survival of the non-Australian species *A. nilotica* and *A. modesta* at 1.5 years was as good as the best Australian species *A. ampliceps* and *A. stenophylla*. The decrease in survival percentage that occurred between February and December was mainly due to the hot, dry summer. Height and biomass growth of the Australian species (including *A. saligna*) was very impressive, only rivalled by a proven species for sodic soils, *A. nilotica* (Gill et al. 1987). The excellent performance of *A. ampliceps* accords with its good growth on alkaline soils in Timor, Indonesia (McKinnell and Harisetiono, these proceedings).

Data from Korat, Thailand, on the response of *A. ampliceps* to various planting treatments (Table 1) highlight the substantial gains in survival and early growth possible by use of appropriate techniques. Both the incorporation of gypsum and the addition of mulch have had a major effect on tree performance. Gypsum (calcium sulphate) incorporation helps to reduce soil sodicity and therefore to improve soil structure by replacing sodium with calcium, and it also supplies calcium for plant nutrition. Mulch addition helps conserve soil moisture and minimise the upward movement of salts. Addition of fertiliser is also beneficial. In this study the use of mulch, gypsum and fertiliser increased survival from 72 to 100% and height growth by over 300%. Other treatments also had major benefits. It is likely that the performance of species with moderate salt tolerance can be considerably improved on salt-affected land by application of appropriate preplanting and planting techniques.

The results reported here from three trial sites give an early indication of the performance of some acacias on salt-affected land. Coupled with information being collated for other genera over a range of sites, this project should provide demonstrable evidence that salt-affected land can be successfully revegetated by useful trees and shrubs.

Table 4. Survival percentage and height growth at age 6 and 16 months of *Acacia* species planted on a sodic site near Risalpur, North West Frontier Province, Pakistan in August 1989. Data are means of up to 60 plants (20 replications of 3-tree rows).

Species	CSIRO Seedlot No.	Survival (%)		Height (m)		
		Feb '90	Dec '90	Feb '90	Dec '90	
					Mean	Range
A. adsurgens		35	8	0.22	0.70	0.3–1.1
A. albida		62	50	0.35	2.09	0.4–2.2
A. ampliceps	15741	87	75	0.32	3.11	0.8–4.1
A. aneura		55	27	0.23	0.45	0.2–0.6
A. cyclops		72	17	0.24	1.01	0.2–2.7
A. modesta		97	77	0.33	1.09	0.4–2.0
A. nilotica		85	73	0.55	3.34	0.3–5.3
A. raddiana		65	58	0.32	1.43	0.6–3.1
A. sclerosperma		57	32	0.33	2.23	0.7–3.5
A. saligna	15795	75	60	0.40	2.06	0.4–3.6
A. stenophylla	14670	85	77	0.29	2.25	0.4–4.2
A. victoriae	17209	55	37	0.26	1.44	0.4–3.0

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References

Aswathappa, N., Marcar, N.E. and Thomson, L.A.J. 1986. Salt tolerance of Australian tropical and subtropical acacias. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, 70–73.

Gill, H.S., Abrol, I.P. and Samra, J.S. 1987. Nutrient recycling through litter production in young acacia plantations of *Acacia nilotica* and *Eucalyptus tereticornis* in a highly alkaline soil. Forest Ecology and Management, 22, 57–69.

Marcar, N.E., Dart, P. and Sweeney, C. 1991. Effect of root-zone salinity on growth and chemical composition of *Acacia ampliceps* B.R. Maslin, *A. auriculiformis* A. Cunn. ex Benth. and *A. mangium* Willd. at two nitrogen levels. New Phytologist (submitted).

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