Recent Developments in Acacia Planting

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Foreword

The 1300 species in the genus *Acacia* extend around the globe, from Australia, through Asia to Africa and the Americas. These nitrogen-fixing trees and shrubs grow in a range of environments and fill an important niche in natural ecosystems. They have also been planted as exotics in over 70 countries for land rehabilitation and to produce a range of wood and non-wood products including firewood, charcoal, building poles, tannins and fodder. In recent years extensive plantations have been established to provide wood pulp for paper and textile manufacture.

In 1986 ACIAR sponsored its first workshop in Gympie, Queensland to consolidate knowledge on the taxonomy, genetic resources, ecology, silviculture and utilisation of Australian acacias of interest to developing countries. This workshop highlighted constraints to the use of acacias and identified research needs and priorities around which ACIAR could develop collaborative research projects. Consequently a number of projects emerged with support from ACIAR.

In 1991 another workshop was convened in Bangkok, Thailand—a forum for scientists involved in these projects to interact with other scientists researching tropical acacias and an opportunity to share new technologies and redefine research priorities.

In the seven years since that workshop there have been major advances in the use of acacias in tropical, subtropical and warm temperate environments. The aim of this third workshop was to bring together scientists in ACIAR projects, other scientists involved in developing new technologies for acacia planting and forest managers facing practical problems in growing acacias. This workshop both augments and complements the sound work undertaken by the Consultative Group for Research and Development of Acacias (COGREDA).

The Centre wishes to thank the Forest Science Institute of Vietnam for hosting the workshop and organising field tours, and the staff of the CSIRO Forestry and Forest Products and the Center for International Forestry Research who worked with ACIAR staff to organise the workshop. Also the contribution of Stephanie Adler of ACIAR's Forestry Program deserves special acknowledgment.

Fifty-seven participants came from Australia, People's Republic of China, Indonesia, Lao PDR, Malaysia, Pakistan, Papua New Guinea, Philippines, Thailand and Vietnam. Thanks are due to the many participants who prepared and presented papers. The presentations demonstrated the continuing interest and strong research effort underpinning the planting and utilisation of acacias in Australia and Asia. The economic, social and environmental impacts of this work will be very significant.

The contributions of Janet Lawrence to the editorial direction and preparation of these proceedings and of Michael Welbourn to the technical editing are much appreciated.

R.J. Clements
Director
ACIAR

Recommendations from the Meeting

J.W. Turnbull

The meeting divided into six groups to discuss major issues arising from the presentations. These were designated:

1. Genetic resources and tree improvement;
2. Silviculture and site management;
3. Pests and diseases;
4. Physiology including soil symbionts;
5. Social, economic, and utilisation issues; and
6. Mechanisms to foster future collaboration.

The following recommendations were brought forward by each group and approved at the final plenary session of the workshop:

Group 1. Genetic resources and tree improvement

1. Continued need for species/provenance testing, including:
   - need for continued exploration of genetic resources, particularly amongst dry-zone and temperate acacias
   - needs for stressful environments—saline, waterlogged and acid/alkaline sites
   - much work done, but we are not finished yet
   - consider species outside the Australia/Southeast Asia region
2. Information network:
   - email list people interested in acacia breeding/silviculture
   - sharing of information
   - development of collaborative research
3. Seed orchard management:
   - gene flows (inside and outside orchard)
   - pollen contamination
   - isolation—how much?
   - role of different vectors
   - inbreeding
   - distribution of genetic material
   - location of orchards to maximise seed production
4. Training in application of selection methods:
   - technology for computer-aided selection exists
   - need for training in application of technology, and the limitations of the technology
   - over next 3–5 years, many people will need to make forward selections in family w/n provenance trials
   - not just restricted to acacias
5. Breeding strategies and breeding objectives:
   - within species
   - hybridisation

- role of inbreeding in acacias
- what do we select for?
- what are the real economic weights of different traits?
- genetic parameters, non-additive variance?

6. Marker assisted selection:
   - can we afford to use MAS techniques?
   - can we afford not to use MAS?
   - what are the economics—is it feasible for many countries/organisations to develop this technology independently?
   - need to develop pedigrees that can be used to search for QTL (perhaps this can be done collaboratively).
   - can half-six pedigrees be used effectively for MAS?

7. Hybridisation:
   - need to list naturally occurring hybrids, so as to better define what hybrid combinations might be possible
   - other hybrid combinations?
   - what is the basis of hybrid vigour in A.m × A.a. hybrid? How do we breed a better hybrid?
   - flowering phenology

8. Technology transfer:
   - rapid development of improved genetic material
   - greater extension services required
   - integration with other disciplines to maximise potential of improved material

9. Regional collaboration:
   - across region/country analyses of trials required to assess extent of genotype × environment interaction, and potential of international breeding cooperatives
   - sharing of improved genetic material
   - conservation of genetic resources — some slower growing provenances may have utility to be maintained in breeding populations or commercial plantations
     - access in-situ conservation status
     - seed centres to maintain collections

10. Species identification:
    - need to maintain electronic data base which can be updated rapidly and regularly
      - taxonomic keys
      - species under cultivation and test
      - delivery of released taxonomic descriptive information
    - accurate names provide the fundamental basis for effectively communicating information about plants being selected and their subsequent utilisation under cultivation

11. Wood properties:
    - heritability and genetic parameters
    - what traits are important? Different products

12. Weed potential:
    - some acacias have become weeds
    - need for research to reduce weed potential of acacias
      - sterility, quality flowering

Group 2. Silviculture and site management

Gaps in knowledge

1. Critical aspects of management: (i) nutrition (need for guidelines for different planting systems, recognition of genotype × environment interaction, importance of mixtures), (ii) weed control and (iii) spacing
2. Effects on environment and sustainability
3. Species/provenance response to site
4. Lack of sufficiently rigorous site characterisation
5. Agroforestry interactions
6. Social context—purpose of planting

Recommendations

1. Collation of existing relevant information, in particular on species × nutrition (fertiliser) × site responses, effect of site preparation techniques (including weed control), management (e.g. spacing) and the production of 'guidelines' in a variety of forms.
2. Need for thorough characterisation of site variates relevant to plant growth as identified from physiology, growth models and trials (e.g. incidence of waterlogging) in addition to taxonomic and other descriptions.
3. Process-based studies dealing with nitrogen cycling in tree/soil/atmosphere and water balance and tree water use.
4. Site-specific research (and demonstration) related to silviculture and site preparation (e.g. weed control, fertiliser application) for key species and production systems, particularly as they relate to small farmers and also in an agroforestry context to produce a package of practices (and link back to 1).
5. Links to tree improvement programs that facilitate information gathering and production; e.g. (i) use of clones to detect physiological differences, (ii) use of realistic silvicultural designs in genotype evaluation trials, and (iii) better site characterisation in existing and planned species/ provenance trials.
6. A better understanding of the social context and reasons for planting, e.g. environment vs production.
7. Fostering training (e.g. in identification of nutritional stress) and education.

Group 3. Pests and diseases

Integrated pest management, including silvicultural, genetic, biological and chemical control options, is to be used to establish environmentally sustainable, cost-effective pest and disease management practices for the principal damaging agents in acacia plantations. To achieve this goal, the following activities are considered to have a high priority:

- Monitor plantations to identify key pathogens and insect pests. A network of practising pathologists and entomologists is needed, to include all countries in the region with an interest in acacia plantation forestry.
- Quantify the impacts of pathogens and insect pests on plantation productivity.
- Prioritise research into specific pathogens and insect pests, based on the above. In the case of acacia diseases, the pathogens causing root rots, stem cankers and phyllode rust have been identified as having high potential to impact on plantation productivity.

- Enhance skills in forest pathology and entomology in countries in the region through exchange visits, training and collaborative project activities.
- Consider quarantine issues and risks, particularly in development of procedures for the safe movement of germplasm. Investigate the potential weediness and other negative environmental impacts of acacias.

Group 4. Physiology including soil symbionts

Physiology

The physiological knowledge required to define and identify tree ideotypes for acacia species, for both rapidly growing trees under favourable conditions and trees tolerant of inhospitable sites, is still in its infancy.

At the canopy level verification of the importance of traits such as canopy area, degree of deciduousness and specific leaf area are required across a number of acacias species and their hybrids. Further research at the leaf level is also required to determine the physiological mechanisms underpinning these canopy strategies, for example:

- ability to retain foliage under seasonal water stress
- mechanisms used to produce 'cheaper' foliage (i.e. high specific leaf area)
- photosynthetic efficiency
- foliage respiration rates

Future physiology research will need to integrate results from the canopy and leaf level to determine the critical physiological parameters contributing to either rapid growth under favourable conditions or tolerance of inhospitable sites. Such knowledge can then assist breeding and selection programs for specific ideotypes to match environments and end uses.

Soil symbionts

The recommendation of the Second Acacia Workshop 1991, on the need to quantify net gains in soil nitrogen (N) from acacia species, is reiterated and extended to include gains in nitrogen from mixed stands including acacias.

The possible long-term negative effects of N-fixation (e.g. soil acidification, nitrous oxide release) during the second and subsequent rotations of acacia need to be considered, particularly in light of the large calcium losses by tree removal at harvest.

Information on the importance of inoculating with mycorrhizas, particularly in low fertility soils, is required.

Collections of over 800 strains of rhizobium and 2000 strains of mycorrhiza from Australia and Southeast Asia are under threat if a commitment is not made in the next 5 years to house and maintain these resources.

Group 5. Social, economic, and utilisation issues

Social

- There is a need to study the social impact of large-scale plantations (on a catchment scale).
- Realising that the smallholder sector will have to play a more important role in future planting of acacia and other tree species, some research resources should be invested in understanding the sociological factors in the smallholder production system which impinge on tree planting (land tenure issues, gender equity issues—e.g. who plants, who derives benefits from tree planting, what determines the planning horizon of the small holder).

Economic

- There is a need to study the option set available to farmers. In such a study, tree planting has to be taken as just one of the land-use options. The study should attempt to look at the economic factors that determine the ranking of tree planting in the full set of smallholder options.
- In a study of smallholder land-use options special attention should be paid to the constraints facing smallholders which in turn have a bearing on the feasibility and economic profitability of tree planting as a land use option.
- When assessing the tree species potential in scientific studies, greater attention should be paid to the diversity of end-uses of tree products. For example, a significant amount of resources is devoted to de-barking trees after harvest. The cost of de-barking is proportional to the thickness of bark. Why not have studies that select tree species for thickness of bark?

Utilisation

- There is a need to develop small-scale alternative technology suitable for community level industry to give greater opportunities for value-adding by smallholder tree planters.
- Technology from forest research may not be adopted because farmers are not aware of these research results. Where they are aware they may not know how to use the results on their farms. There is thus a need to develop mechanisms (a) to identify potential users of forest research results, (b) to educate the potential users about the available technology, and (c) to transfer technology to these potential users.

Group 6: Mechanisms to foster future collaboration

- Knowledge on acacias will continue to increase as it is being generated by various organisations. Hence, it is essential that collaboration be fostered at both national and international levels.
- Need to find a proper mechanism where funding and support could be drawn from as many sources as possible.
- Researchers should be aware of many and varied opportunities for research collaboration. This can be fostered through NGOs, foundations (eg. Rockefeller, Ford), donor agencies (eg. ACIAR, USAID, AusAID), APAFRI, IUFRO, private companies, CGIAR centres (e.g. CIFOR, ICRAF) and networks of national agencies.
- To foster collaboration, it is recommended that regular meetings should be held and communications improved. This can be done by: (1) reactivating COGREDA, (2) making more use of the existing networks such as IUFRO and APAFRI through their newsletters and homepage.
- The Australian Tree Seed Centre is encouraged to continue with the work of providing germplasm and information.
- Continue with the publication effort with contributions from scientists in the region e.g. proceedings, monographs.
- Training (short and long term) is an important element in future collaboration and activities.
- Encourage the COGREDA group to reconvene in 1999 and to hold an international meeting in 2001.

Tropical Acacias Planted in Asia: an Overview

J.W. Turnbull[1], S.J. Midgley[2] and C. Cossalter[1]

Abstract

Australian acacias are planted in over 70 countries and cover about 2 million ha. This area is dominated by *Acacia mearnsii*, *A. saligna* and *A. mangium*. In the past five years there has been a massive increase in the area of *A. mangium* plantations in Indonesia for pulpwood, and modest increases in China, India, Malaysia and Vietnam. The area now totals 600 000 ha. Recent development of plantations of tropical acacias is related to the profitability of growing acacia plantations due to the decreasing availability and higher costs of wood from natural forests, the opportunity to increase productivity of degraded sites, and the suitability of fast-grown wood for paper and reconstituted boards. Furthermore, research in genetics and breeding has identified superior provenances, developed seed orchards, and cloned fast growing hybrids. Molecular biology techniques have enabled rapid characterisation of genotypes and the detection of genetic variation. Nutrition research has demonstrated the value of phosphorus fertilisation on most sites and the benefits of inoculation with selected rhizobia and mycorrhizas. Surveys have identified potentially damaging pathogens and insects. All these have contributed greatly to reducing costs and increasing the potential returns from acacia plantations. There is increased market acceptance of tropical acacia wood but research on wood properties and development of new products is a priority. As the large area of first-rotation plantations is harvested there is an increasing priority to develop management options to ensure minimal decline in site productivity and plantation yield in successive rotations.

THE 1200–1300 species in the genus *Acacia* extend around the globe from Australia and the Pacific Islands through Africa to the Americas. More than 900 species occur in Australia alone (Maslin and McDonald 1996). The most generally accepted classification of *Acacia* recognises three large subgenera i.e. subgenus *Acacia* (120–130 species), subgenus *Aculeiferum* (180–190 species) and subgenus *Phyllodineae* (940 species) (Maslin 1995). Major nomenclatural changes were proposed by Pedley (1987) but they would have been very disruptive and have not been widely adopted (Maslin 1995).

Acacias are adapted to a wide range of environments, both tropical and temperate, and this adaptability has made them popular for planting on degraded lands in Asia and elsewhere. The spread of Australian acacias (almost all in subgenus *Phyllodineae*) was initially in subhumid subtropical areas and at higher altitudes in the tropics. In Asia, *A. decurrens*, *A. dealbata* and *A. melanoxylon* were introduced into Tamil Nadu, India in the 1840s as fast-growing trees to supply fuel for the army. They were subsequently used as shade trees on the tea estates and for utility timber. The black wattle, *A. mearnsii*, which was introduced into South Africa (1864) was also planted in Indonesia (1880) and Sri Lanka (1890). Its bark provided a superior source of tannin and tanning industries based on black wattle plantations emerged in South Africa, East Africa, Brazil, India and Indonesia (Sherry 1971; Brown and Ho 1997).

The planting of acacias as exotics in the lowland humid tropics has taken place more recently. *Acacia auriculiformis* originating in Australia, Papua New Guinea and parts of eastern Indonesia has been planted as an exotic in Asia for more than 60 years. It was introduced to Malaysia in 1932, to Thailand in 1935 and was planted in commercial plantations in West Bengal, India in 1946. It was used principally

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as an ornamental, for fuelwood or to revegetate denuded land following mining. Most plantations are currently in India and China where the species thrives on laterites and impoverished, often poorly drained, sites. Although *A. auriculiformis* was a successful exotic in tropical Asia, it was the introduction of *A. mangium* into Sabah, Malaysia from Australia in 1966 that created the major interest in tropical acacias. Initially introduced as a plant in firebreaks to protect pine plantations, its rapid growth suggested its potential for wood production and it was planted in Malaysia (Yap 1987).

There was recognition in the 1970s and 1980s that acacias from Australia and adjacent countries had potential as highly adaptable, multipurpose trees to provide fuelwood and other products in rural development as well as for industrial wood production. This stimulated major exploration of the rich genetic resources of the genus in Australia. In 1973 CTFT collected 20 species (40 provenances) in tropical and subtropical coastal dry zones and extensive sampling in inland arid and semiarid zones in the 1980s by CSIRO and CTFT followed (Cossalter 1987; Thomson and Cole 1987). In the early 1980s CSIRO, with the encouragement of FAO and the active support of various partners, began comprehensive seed collections of acacias in the humid tropics of Australia, Indonesia and Papua New Guinea (Turnbull et al. 1983; Skelton 1987; Searle 1989; Gunn and Midgley 1991).

Much of the early exploration and domestication of tropical acacias in Asia has been described in papers presented at a series of workshops organised by ACIAR, CSIRO, FAO, and Winrock International Institute for Agricultural Research between 1986 and 1993 (Turnbull 1987,1991; Carron and Aken 1992; Awang and Taylor 1992, 1993; Brown 1994). Since 1993 there has been further research directed towards the domestication of tropical acacias in both humid and arid/semiarid environments. There has also been extensive planting of acacias, particularly in the humid and subhumid tropics, for industrial and rural products, and for environmental protection. There was also formation of collaborative research networks for acacias including the Consultative Group for Research and Development of Acacias (COGREDA), fostered by the F/FRED Project, and two Species Improvement Networks (SPINS) for acacias in the humid tropics and acacias in the dry tropics supported by FAO's FORTIP project.

This paper aims to highlight some of the progress made in plantation development and in key areas of research during these five years and to suggest some directions for future research. Particular emphasis is given to acacias planted in the humid tropics of Asia because of their escalating importance in the region.

Extent of Current Planting

The largest *Acacia* plantations are in India where there are 3 million ha, including an estimate for line plantings (Pandey 1995). Much of this area is made up of the spiny species *A. nilotica*, *A. tortilis*, *A. catechu* and *A. leucophloia* (Hocking 1993). Spineless Australian acacias are now planted in over 70 countries (Maslin and McDonald 1996) and cover about 2 million ha. This area is dominated by just a few species: *A. mearnsii* (ca 500 000 ha), *A. saligna* (ca 500 000 ha) and *A. mangium* (ca 600 000 ha). The *A. mearnsii* was planted mainly for tannin and *A. saligna* for sand stabilisation, animal forage and fuelwood. In contrast, the recent development of plantations of *A. mangium* is related to the decreasing availability of wood from natural forests, the opportunity to increase productivity of low potential or degraded sites, and the newer technologies which make fast-grown wood with uniform properties a valuable resource for pulp and paper and the reconstituted board industries.

In the past five years there has been a massive increase in the area of *A. mangium* plantations in Indonesia for pulpwood. There have been modest increases in China, India, Malaysia and Vietnam. In Peninsular Malaysia there has been some disenchantment with *A. mangium* for timber production, primarily due to the incidence of heart rot in plantations established under the Compensatory Plantation Project since 1982. There is increasing interest in plantations of *A. mangium* in West Africa and South America but so far only small areas have been planted.

A. auriculiformis continues to be planted throughout Asia at a steady rate especially on a small scale by smallholders for non-industrial wood products and environmental enhancement. It is used commonly in China, India, Myanmar, Thailand and Vietnam and outside Asia in places such as Zaire (Khasa et al. 1994a). Poor stem form and mediocre growth rates have restricted its use but the recognition of more productive provenances with straighter stems in the last few years (e.g. Venkateswarlu et al. 1994) has enhanced the interest in this species. Translation of this knowledge into more improved plantations will depend on the availability of seed of the improved provenances from natural stands or seed orchards (Harwood et al. 1991).

A few other acacias, including *A. cincinnata*, *A. leptocarpa*, *A. aulacocarpa* and *A. crassicarpa*, have shown promise in trials in the humid tropics, but only *A. crassicarpa* has been planted on a commercial scale, chiefly in Indonesia. Hybrid combinations, especially of *A. auriculiformis* and *A. mangium*, have great potential (e.g. Kha 1996).

In the humid subtropics and at higher altitudes in the tropics the main Australian acacia planted has been the bipinnate *A. mearnsii* (black wattle) and about 400 000 ha have been planted in Brazil, South Africa, and east Africa (Brown and Ho 1997). In Asia, about 45 000 ha are grown in India, Indonesia and China. Historically the main reason for planting *A. mearnsii* has been for its bark, from which is extracted high quality tannin for tanning leather. The use of its tannin for the production of waterproof adhesives for reconstituted wood is increasing, but the wood is used for paper pulp, cellulose for rayon, charcoal and utility round timbers. Some lesser-known bipinnate acacias have shown considerable potential for planting in mild subtropical areas (e.g. Yang and Zeng 1991) but more testing on a range of sites is required before they can be recommended for commercial planting.

In drier areas of Asia, species such as *A. nilotica* have been most widely planted. However there are many species in the subtropical dry zone of Australia that have potential for farm planting and environmental protection (Thomson et al. 1994; Doran and Turnbull 1997). There may be a niche for salt-tolerant acacias such as *A. ampliceps* and *A. stenophylla* on the large areas of salt-affected land in the drier tropics of Australia, India, Pakistan and Thailand (Marcar et al. 1991, 1995). Small areas of *A. holosericea* and/or its related taxa are being planted in India and China, and *A. difficilis* and *A. tumida* show promise for environmental protection in drier areas of Vietnam. The potential of *A. colei* and other dry-zone acacias to provide seeds for human food is being realised in west Africa and the technology may be applied in similar environments in Asia (Thomson et al.1994).

Countries with Significant Areas of Tropical Acacia Plantations

Indonesia

Although introduced to Indonesia at an earlier date, *A. mearnsii* was taken to the tobacco growing areas of Central Java in 1922 and planted extensively for fuelwood, tannin, fodder and as a soil improver (Adjers and Hadi 1993). There is now an estimated area of 15 000 ha of this species (Wiersum 1992). Other acacias, such as *A. auriculiformis* and *A. oraria*, were planted as street trees, soil protection and farm use. It was not until 1986 when the Government of Indonesia established the Industrial Timber Estates scheme (HTI) that large-scale planting of *A. mangium* began. HTI aims to promote the production of raw material for Indonesian industry by reforesting *Imperata* grasslands (alang-alang) and scrublands (belukar). The aim is to establish 2.3 million ha of plantations by the year 2000 and 10.5 million ha by 2030 (Ginting et al. 1996) and 68% of logs will be derived from plantations by 2020 (FAO-MoF 1990). Although these targets may be optimistic (Hamilton 1997), it is clear that Indonesia is embarking on a plantation program comparable to that of Brazil in the 1970s and 1980s. HTI is currently financed primarily from the Government's Reforestation Fund, based on a levy on all timber harvested in natural forests. Although the subsidies and soft loans have stimulated planting by large companies, they have had some negative environmental and social effects. Some sites in remote locations, which will be uneconomic in the long term, have been planted, in some cases to secure land tenure rather than to produce an economic crop. Such practices impact negatively on traditional land tenure of local people and may also result in the clearing of productive natural secondary forest.

Most current HTIs have planned short-rotation plantations to produce wood for paper-making or medium density fibreboard. There is some interest in producing larger logs for plywood. Indonesia has currently 23 pulp production projects under way and 13 companies establishing pulpwood estates, most of them planting *A. mangium*. By 1996, 10 companies had planted 426 000 ha of *A. mangium*, of which 88% was planted in the five years 1992–1996. PT Musi Hutan Persada with 165 000 ha has the largest resource of *A. mangium* followed by PT Arara Abadi (Indah Kiat) with 100 600 ha. The latter also has 4400 ha of *A. crassicarpa* planted from 1989 to 1996. Some companies are experiencing difficulties in expanding their plantations due to conflict with local communities. In these situations socioeconomic studies are becoming very important to assist in resolving the problem.

Malaysia

Introduction of tropical acacias into Malaysia is described by Anwar Mohamad (1987), Udarbe and Hepburn (1987) and Yap (1987). By 1993 Peninsular Malaysia had established 50 250 ha of *A. mangium* through its Compensatory Forest Plantation Project for timber production, but in mid-1992 planting was suspended unless the objective was for pulp (Darus Ahmad and Ang 1993). In Peninsular Malaysia the area remains at about 50 000 ha, in Sabah the area has also reached about 50 000 ha and there are only small areas in Sarawak (Lee 1997). Although heart rot is present in Sabah there is little concern for the 50 000 ha which are being grown for pulpwood, and there are plans for a major expansion of *A. mangium* plantations in Sarawak for pulp. Much of the early research on breeding and vegetative propagation of tropical acacia was carried out in Malaysia (see papers in Carron and Aken 1992) and in Sabah there is considerable interest in using *A. mangium* × *A. auriculiformis* hybrids for plantations (Chia 1993).

Vietnam

In the early 1960s 16 Australian *Acacia* species were introduced for testing, but only *A. auriculiformis* was widely adopted for planting, mostly in southern provinces. The seeds used for plantations were mostly derived locally from southeastern Vietnam, but the natural provenance origin is not known. *A. auriculiformis*, *A. mangium* and *A. crassicarpa* have been identified as the acacia species with greatest potential for the most commonly available planting environments. Out of about 913 000 ha of forest plantations established during the period 1986–1992, *A. auriculiformis* constituted 43 000 ha and *A. mangium* 23 000 ha (Ministry of Forestry 1994, Midgley et al. 1996) At present, acacia wood is used in the paper industry and for other purposes including fuelwood. In intensive agricultural systems near Khe Sanh, *A. auriculiformis* is used as a windbreak around coffee and pepper fields (Midgley et al. 1995). It is easy to propagate and to maintain, and when mature can be used for small furniture items.

The planting of acacias will be increased in the next few years, up to an annual rate of 10 000–15 000 ha per year. Acacias are increasingly favoured over eucalypts as large-scale plantation species because they are perceived to be more environmentally benign, being nitrogen-fixers and producing a leaf litter, which is more protective of the soil. Also, they have not suffered the leaf pathogen attacks that have been experienced on some eucalypt provenances in southern Vietnam. A further incentive to use acacias is the disappearance of the price differential with eucalypts so that both have similar export prices for their wood chips. Growth potential of acacias in southern Vietnam is better than in northern Vietnam. Another development of great promise is the identification of *A. mangium* × *A. auriculiformis* hybrids, as these have outstanding growth potential (greatly superior to the two parents) and excellent wood properties. Outstanding clones have been tested and are being mass propagated for operational clonal forestry—as yet on a modest scale (Kha 1996).

Areas climatically suitable for *A. auriculiformis* and *A. mangium* in Vietnam have been determined (Nghia 1996) but there are some 200 000 ha of sandy soils on the southeast coast where the rainfall is too low for these species. Species trials have shown that *A. difficilis* and *A. tumida* have excellent potential for dune stabilisation and fuelwood production on these drier site types, with growth rates and survival far superior to indigenous or other exotic alternatives (Midgley et al. 1996).

China

About 200 000 ha of acacia plantations have been established in China (Zhang Fangqui pers. comm.) with the main species *A. mearnsii*, *A. mangium*, *A. auriculiformis* and *A. crassicarpa* (Wang Huoran et al. 1994). Also *A. confusa*, a native to China, is planted widely along roadsides and on farms. It is used as a shade tree in tea gardens and for fuelwood, farm tools, furniture, and house-building (Zheng and Yang 1993). *A. auriculiformis* was introduced in 1961 (Pan and Yang 1987) and its good growth attracted attention and it has been widely used in afforestation programs since the 1970s. It generally grows faster than *A. confusa* but both have crooked stems. *A. auriculiformis* has been used for soil and water conservation plantings in the uplands and about 60 000 ha have been established (Zheng and Yang 1993; Zhang Fangqui pers. comm.). It is also used for fuelwood, farm tools, biofertiliser and as a source of pollen for honey bees. Early introductions of *A. auriculiformis* have grown slowly relative to more recently introduced provenances (Turnbull 1988) indicating significant increases in the productivity of this species is possible using selected provenances. The area of *A. mangium* is expanding rapidly and is now about 120 000 ha for timber stands (Zhang Fangqui pers. comm.). *A. mangium* is expected to provide raw material for high quality paper pulp (Wang Huoran et al. 1994). *A. crassicarpa* and the shrubby *A. holosericea* are also planted on a small scale, the latter sometimes in mixed plantations. Selection and breeding of *A. crassicarpa* (Zhang and Yang 1996) suggest that it will be more widely planted in the future in China. *A. aulacocarpa*, *A. cincinnata* and *A. melanoxylon* are all potential plantation species (Zhang Fangqui pers. comm.).

The subtropical *A. mearnsii* was introduced into China in the early 1930s and was widely planted in Fujian, Zhejiang, Jiangxi and other central and southern subtropical areas for tannin, mine props, furniture and fuelwood (Gao 1989). The main plantations are in Yunnan (6700 ha) and Fujian (2000 ha). The total area is about 10 000 ha with planting increasing in Yunnan and Jiangxi and decreasing in Fujian provinces (Gao pers. comm.). However, according to Ho and Fang (1997), the area is now much larger than 10 000 ha.

India

Since the introduction of *A. auriculiformis* to West Bengal in 1946 it has been planted in many places in India, ranging from coastal sands to higher altitude lateritic soils in areas having from 500 to 7000 mm of rainfall annually. It has been a major species for afforestation in the southern Indian states and is most widely planted in Karnataka where it is of interest to the pulp and paper industry (Bulgannawar and Math 1991). These authors also report that newly introduced provenances have grown substantially better than local, possibly inbred, material. The tolerance of *A. auriculiformis* to a wide range of site conditions, including coastal sands and waterlogged soils, make it a major species for reforestation of degraded lands, usually as a cover crop and as a source of fuelwood (Kushalapa 1991; Nadagoudar 1993). It is used on industrial wasteland such as coal mine spoils and paper mill sludge (Prasad 1991; Hocking 1993). In Tamil Nadu *A. holosericea* has grown well on dry lateritic sites and is now planted extensively in that region (Jambulingam 1986). The area of exotic acacias planted in India has been steadily increasing in the past 10 years and about 45 000 ha, mainly *A. auriculiformis*, have been planted (Sharma and Florence 1997). Much *A. auriculiformis* seed from plantations around Midnapore, West Bengal has been traded internationally.

Philippines

Acacia auriculiformis has been planted as a cover crop on denuded hills for many years but tropical acacias for wood production were introduced in the 1950s and 1960s. *A. aulacocarpa*, *A. auriculiformis* and *A. mangium* comprise approximately 50% of Bukidnon Forests Incorporated's (BFI) annual 1500 ha plantation establishment program towards their total target industrial plantation area of 21 000 ha. This is the largest acacia establishment program in the Philippines and seedling seed orchards of *A. mangium* and *A. crassicarpa* established in 1995 at BFI represent the first comprehensive provenance tests of these species in the country. Other significant industrial acacia plantation resources are those of Provident Tree Farms Inc. in Mindanao and Mindoro with 4000 ha of *A. mangium*, and of Paper Industries Corporation of the Philippines in Mindanao with a lesser area of *A. mangium* (Arnold pers. comm.). The results have been variable and numerous problems, both social and technical, have been encountered. Initial attempts by Swedish Match Company in Mindoro suffered severely from typhoon damage. There is now an estimated area of 45 000 ha of acacia plantations in the Philippines (Midgley et al. 1996).

Thailand

Since it was introduced as an ornamental tree in 1935, *A. auriculiformis* has been used with notable success throughout Thailand, where it is used to make furniture and other products (Pinyopusarerk 1987). The plantations are scattered but there are now plans to have a major plantation area of *A. mangium* in northeast Thailand for pulp production. One company, Asia Tech, is promoting contract tree farming of *A. mangium* over 32 000 ha in four provinces (Carrere and Lohmann 1996).

Thailand has also been a major testing area for Australian acacias. Intensive trials of many species started in 1984 (Pinyopusarerk 1989), and species such as *A. aulacocarpa*, *A. crassicarpa*, *A. leptocarpa* and *A. cincinnata* have grown well on some sites. Broad genetic bases for breeding *A. aulacocarpa* and *A. crassicarpa* have been established. A genetic improvement program for *A. auriculiformis* is in place, and improved seed is already used by private growers and government agencies. Hybrids of *A. mangium* × *A. auriculiformis* are being developed for future use (Pinyopusarerk pers. comm.).

Recent Research Results

This section reviews recent results and indicates some priority areas in four keys areas of research—genetics and breeding, nutrition, pests and diseases, and utilisation.

Genetics and breeding

International and other provenance trials established in the 1980s have reached an age when reliable results are available e.g. for *A. mangium* coordinated trials (Harwood and Williams 1992); *A. auriculiformis* (Yang and Zeng 1991; Awang et al. 1994; Venkateswarlu et al. 1994; Nghia and Kha 1993; 1996); *A. aulacocarpa* (Zeng and Yang 1994; Pinyopusarerk et al. 1996); *A. crassicarpa* (Arnold et al. 1994; Zhang and Yang 1996); *A. mearnsii* (Fang et al. 1994). In all instances highly significant differences between provenances in the growth rate and other characteristics have been reported. A degree of generalisation regarding provenance performance is possible. Significant gains in plantations are therefore possible simply by using selected provenances. The need for more large-scale provenance trials in Asia has diminished, although some minor deficiencies, such as evaluation of *A. aulacocarpa* from the rainforest associations in north Queensland (Thomson 1994), need attention. *A. aulacocarpa* has been a very variable species both in its natural range and in its performance in provenance trials. Five informal variants (subspecies) based mainly on pod and seed characteristics have been recognised by Thomson (1994) and should assist in evaluation and domestication. Formal publication of these variants is now desirable, as *A. aulacocarpa* remains a species with considerable potential for plantations.

For the major planting species, comprehensive bases and breeding populations have been established in several countries including Australia (Harwood et al. 1991; Montagu et al. 1996), Fiji (Thomson pers. comm.), Indonesia (Kyoji et al. 1996), Malaysia (Sim 1992), the Philippines and Vietnam (ATSC 1997). Some of these plantings have already started to yield seeds. Development of seed production areas and seed orchards for *A. mangium* has been described by Awang and Bhumibhamon (1992). Some of the earliest seedling seed orchards of *A. mangium* in Sabah and Subanjeriji (Indonesia) in the early 1980s were established with too narrow a base and have produced poor quality seeds (e.g. Turvey 1995). The new orchards are designed to overcome these problems.

In parallel with the species and provenance testing in the past five years, a wide range of molecular biology and biotechnology techniques has been applied to enable rapid characterisation of genotypes and detection of genetic variation in acacias. This genomic mapping offers many opportunities to improve tree-breeding strategies, for example by elucidating the basis for inbreeding depression and hybrid vigour (heterosis) and in marker-assisted selection. Butcher et al. (1996) used restriction fragment length polymorphisms (RFLPs) to assess genetic variation in the nuclear genome of *A. mangium* of 10 natural populations and a derived population (a seed stand) at Subanjeriji, Sumatra. The ranking of populations based on growth performance in provenance trials corresponded to the rankings based on genetic diversity. The low level of diversity in the Subanjeriji population reflected the low variation in the natural populations in Queensland from which it was derived and highlights the danger of establishing breeding populations from a restricted base. Loss of productivity in plantations using Subanjeriji seed has been estimated as high as 70–80% (Turvey 1995)—a result corroborated by Vuokko (1996), who found in South Kalimantan that the volume produced by the Subanjeriji land race was only about one-third of the best provenances from western Papua New Guinea and the adjacent Merauke region in Irian Jaya. The use of RAPDs (random amplified polymorphic DNAs), RFLPs and newly available microsatellite markers complements the use of isozymes, which have been successfully used for some years for the estimation of genetic diversity and mating system parameters (e.g. Moran et al. 1989a, 1989b; Khasa et al. 1994b; Wickneswari et al. 1996).

Some tropical acacias hybridise in their natural habitats, and hybrids between planted *A. auriculiformis* and *A. mangium* were recorded in Sabah and the potential opportunities and problems noted by Sim (1987). Some hybrid individuals exhibit heterosis and are much taller with greater stem volume than the pure species (Pinso and Nasi 1992). Hybrids may also have finer branding, greater stem circularity and increased apical dominance (Rufelds 1987; Pinyopusarerk 1990) and greater potential pulp yield (Kha 1996). Research to develop technologies on vegetative propagation and controlled seed production to take advantage of the benefits of hybrids began in Malaysia and the results were summarised at an ACIAR Workshop in Sabah in 1991 (see papers in Carron and Aken 1992). International exchange of hybrid clones has taken place, e.g. between Vietnam and Malaysia, and this trend is likely to continue unless very site-specific hybrid clones are developed as has occurred for some eucalypt hybrids in South Africa.

Since 1991 the development of hybrid clones of *A. mangium* and *A. auriculiformis* has gained momentum, especially in Vietnam through the activities of the Forest Science Institute of Vietnam. Outstanding clones have been identified and tested and are now being mass propagated for operational clonal forestry (Kha 1996). To fully realise the potential of hybrids an effective and economical means of mass propagation is required. There has been significant progress in both micropropagation and conventional cuttings (e.g. Darus Ahmad 1992; Bon and Montenuuis 1996; Wong and Haines 1992; Banik et al. 1995; Bhaskar and Subhash 1996), but propagation of mature individuals is still a problem. Clonal forestry using hybrids will require a backup breeding program and experimental hybrid seed orchards have been established in Indonesia to build up a bank for clonal forestry (Arisman and Havmoller 1994).

Cloning is appropriate if: (1) selected high quality individuals are available, (2) there is a sufficient number of superior clones which can be propagated to provide genetic variability in the plantations and (3) the program is supported by a breeding program for regular provision of more productive and disease-resistant clones. Experience and economics indicate that clones and other improved planting material should be used on sites where there are possibilities for good site preparation, effective weeding and other intensive management interventions to permit full expression of the genetic superiority and enable rapid returns on the investment in selection and breeding.

Nutrition

One of the main characteristics of acacias selected for industrial plantations is their ability to grow fast on infertile sites. Some species show different degrees of adaptability, for example *A. auriculiformis* will tolerate both highly acidic and alkaline sites, *A. mangium* will tolerate only acidic conditions, and *A. crassicarpa* will grow better than *A. mangium* on less fertile sites. All these species are nitrogen-fixing and have mycorrhizal associations to aid their nutrition. However, recent experience has shown that major benefits can be gained from careful attention to the application of fertiliser and selection of symbiotic microorganisms. As plantations enter their second and subsequent rotations, management regimes that assist nutrient cycling will assume greater importance.

Many planting sites in the tropics become degraded once they lose their protective vegetative cover. Accelerated decomposition and leaching are often compounded by burning. Such degraded sites often have high acidity (pH < 5.5), high aluminium saturation and low fertility. Most tropical acacias planted on such sites respond to fertiliser applications (e.g. Cole et al. 1996). Responses to added P have been widespread, although less on burnt sites, and there have been benefits from nitrogen and general trace elements on infertile grassland sites (e.g. Mead and Miller 1991; Turvey 1995; Cole et al. 1996). Although there are usually strong responses to fertilisation at establishment, responses to fertiliser applied after canopy closure have been weak (Otsamo 1996). Most research has been empirical and there has been little research to determine critical foliar nutrient concentrations for acacias. Although critical foliar nutrient levels may indicate the need for fertilisers, these are not real guides to the amounts needed. There has been evidence of a relationship between foliar N and P levels and that low P limits nitrogen fixation (Mead and Speechly 1991). Critical and optimal levels for macronutrients and some micronutrients for *A. mangium* are given by Mead and Miller (1991). Guides to the diagnosis of pronounced nutrient deficiency have not been prepared for acacias.

The role of symbiotic associations in the nutrition of tropical acacias was reviewed by Dart et al. (1991) and Dela Cruz and Yantasath (1993). Experiments showed that some tropical acacias nodulate and fix nitrogen freely with a wide range of rhizobia strains isolated from host *Acacia* species while others, including *A. mangium*, nodulate effectively with only a restricted range of strains. In recent years efforts have been made to select effective rhizobia strains, including those for highly acid and saline conditions (Dart et al. 1991). An open question is: how effective and persistent are the rhizobia inoculated on to seedlings in the nursery when those plants re-established in the field? Very few field experiments have shown a positive effect of inoculation on leguminous tree species in the field. However, recent field inoculation experiments in different countries and different soil types showed a positive effect of inoculation of *A. mangium* with selected slow-growing *Bradyrhizobium* strains. The positive effect on tree growth persisted for several years after transplantation to the field. Immunological identification confirmed that the most efficient strains survived and were maintained within the nodules for several years (Galiana and Prin 1996). In a trial established in Côte d'Ivoire the percentage of nitrogen derived from symbiotically fixed atmospheric N reached a mean of 50% over the whole trial and 90% on the less fertile plots where the trees were inoculated with the most effective rhizobium strain (Galiana et al. 1996).

The benefit of ensuring effective inoculation with rhizobia appears to be well founded in *A. mangium* but whether the same holds true for *A. auriculiformis*, which is much less selective, is not resolved. Most efforts have been focused on the effect of rhizobia in young plantations, but as plantations age there is a problem of inhibition of nitrogen fixation following accumulation of nitrogen in the soil, and more work is required in this area (Dommergues 1993).

Inoculation of acacias with mycorrhizal fungi was reviewed by Reddell and Warren (1987) and Dart et al. (1991). Acacias can form both ecto- and endomycorrhizal associations. The dominant association for *A. mangium* is with endomycorrhizas (VAM fungi) (Dela Cruz and Yantasath 1993). The growth of *A. mangium* is assisted by a combination of selected VAM fungi and selected rhizobia and VAM inoculates are available on a commercial basis in the Philippines (Dela Cruz and Yantasath 1993). There has been less research on ectomycorrhizal associations and their effects on the growth of tropical acacias. In some cases they appear to be absent in exotic plantations (e.g. Khasa et al. 1994a). Osonubi et al. (1991) found that inoculation of *A. auriculiformis* with the ectomycorrhizal fungus *Boletus suillus* stimulated seedling growth.

Although species mixtures are often held up as being environmentally desirable, critical research on the long-term nutritional benefits and costs of tropical acacias in mixed-species plantings has yet to be carried out. Early results from a mixed *A. mearnsii*–*Eucalyptus globulus* planting suggest the growth of the eucalypt is positively affected by the presence of *Acacia*, that was attributed to be improved N status of the eucalypt (Khanna 1997).

Preliminary research has been carried out on above-ground growth, biomass accumulation and distribution in tree components in relation to nutrient cycling in young acacia plantations (e.g. Bernhard-

Reversat et al. 1993; Xu et al. 1994; Nykvist 1997). The whole question of nutrient cycling in plantations, including the long term role of symbiotic microorganisms, requires much more attention and will be a priority as the acacia plantation estate matures and moves into successive rotations.

Pest and diseases

There is widespread concern amongst forest managers and the wider community that large areas of monocultures increase the risk of catastrophic damage by pests and diseases (Ito and Nanis 1997). The rapid expansion of tropical acacias in Asia has resulted in increased interest in assessing the threats posed by pests and diseases.

Heart rot in thinnings in young stands of *A. mangium* in Malaysia (Gibson 1981; Lee 1985) caused considerable concern due to the projected large area of *A. mangium* for sawlogs in Peninsular Malaysia. Subsequent studies have confirmed that while *A. mangium* trees are very susceptible to heart rot and reduction in wood quality can be very high, *A. auriculiformis* and its hybrid with *A. mangium* are resistant to heart rot (Ito and Nanis 1997).

An annotated list of diseases of some tropical acacias was published by Boa and Lenné (1994) and during 1995–96 a series of disease surveys was undertaken in native stands, trials, and operational forestry plantations of tropical acacias in Australia, India, Indonesia, Malaysia and Thailand (Old et al. 1997). The results of the survey provide a benchmark of the current knowledge of the pathology of *A. mangium*, *A. auriculiformis*, *A. crassicarpa* and *A. aulacocarpa* in tropical areas of Southeast Asia, India and northern Australia.

The five most significant diseases are root rot (*Ganoderma* complex), stem canker (*Lasiodiplodia theobromae*, *Botryosphaeria* spp. etc.), pink disease (*Corticum salmonicolor*), heart rot (a range of wood-decay fungi) and phyllode rust (*Atelocauda digitata*). Heart rot is the only disease syndrome to have received serious attention in recent years but the survey suggests that rust disease, especially the gall rust (*A. digitata*), is an emerging problem in acacia plantations in Southeast Asia.

Insect attacks have tended to be sporadic and have not caused major problems for tropical acacias up to now. For example there has been little serious damage to *A. auriculiformis* and *A. mangium* (Pinyopusarerk 1990; Hutacharern 1992) but there are records of damage by stem borers, root feeders and defoliators for these and other species (Day et al. 1994). Baseline surveys of insect pests in *Acacia* species in Southeast Asia have started as part of an ACIAR-sponsored project (Wylie pers. comm.).

Planting acacias as exotics on a greater scale is raising concern about the potential international transmission of pests and diseases with seeds and other germplasm. Several tonnes of seed are moving each year in international trade. There is a need to develop basic protocols to enable safe passage of acacia germplasm as the International Plant Genetic Resources Institute (IPGRI) has done for eucalypts and many crop plants. Another concern is that a build up of pests and diseases in first-rotation plantations will have greater effects in subsequent rotations. This suggests that regular monitoring and the development and application management practices that minimise the risks of serious damage should be given high priority.

Utilisation

There has been increased market acceptance of the woods of acacia species following research on their properties and industrial utilisation. The physical, mechanical and processing characteristics of the more important species have been determined (e.g. Razali Abdul-Kader 1993; Razali Abdul-Kader and Mohd Hamani Sahri 1993). However the feasibility of converting plantation-grown acacias into various products has yet to be fully assessed.

A. mangium and *A. auriculiformis* timbers make attractive furniture and are also suitable for interior construction work such as framing and flooring. They are less suitable for exterior use. The major tropical species have good potential for composite wood products including veneer and plywood, particle board, cement board and medium density fibreboard (e.g. Rahim Sudin et al. 1991; Razali Abdul-Kader and Mohd Hamani Sahri 1993).

The pulping and paper-making properties of the tropical acacias have been assessed by Clark et al. (1994), Fang et al. (1994a) and others. The tests generally reported favourable results and *A. mangium* in Sabah and *A. mearnsii* in South Africa and Japan have been used for commercial pulping. The very large areas of *A. mangium* being established in Indonesia are aimed primarily at the pulp and paper industry. Balodis (1991) highlighted the need to compare species on the basis of their pulpwood productivity, which is defined as the kilograms of pulp produced per cubic metre of wood. There is considerable variation in this measure between species and possibly between provenances. It is also suggested that the hybrid *A. auriculiformis* × *A. mangium* will have higher pulp productivity than either parent (Kha 1996). The pulp yield will be an important characteristic influencing species and clonal selection and acacia breeding, and will require greater attention by tree breeders.

Acacias used in rural development can be utilised for wood products, posts, poles, fuelwood and charcoal (Pinyopusarerk 1990; Razali Abdul-Kader and Mohd. Hamani Sahri 1993; Doran and Turnbull 1997), as well as for a wide range of non-wood products such as fodder, bee forage, and tannins (Hsu-Ho 1993). For tannin production, *A. mearnsii* is already widely used, and a selection of higher-yielding provenances has been made (Li et al. 1994). There is the possibility that *A. mangium* could be exploited commercially for tannins (Razali Abdul-Kader and Mohd. Hamani Sahri 1993) and the little known *A. storyi*, which is adapted to relatively dry tropical conditions, has similar tannin properties to *A. mearnsii* and is a potential tannin-producing species (Yazaki 1997).

Speakers at a recent conference in Malaysia on the challenges in processing and utilisation of new timber crops emphasised that even in countries such as Malaysia that have been major suppliers of timber from natural forests there will be a shift to using wood produced in plantations and small-diameter, lesser-known local species. There will also be a shift from solid wood to reconstituted wood in response to the variation in wood properties (Saad 1997). It is expected that there will be innovations in technology to process the new materials, and examples include machines to produce the materials for laminated veneer lumber (LVL), oriented strand boards (OSB) and oriented strand lumbers (OSL) (Sasaki 1997). There seems little doubt that there is great potential to use wood from plantation acacias in these new technologies.

There has been some progress made in evaluating wood properties of plantation-grown acacias and their utilisation for a range of products. Nevertheless more needs to be done and research on acacia wood qualities and the development of new products should remain a priority. It is therefore pleasing to note that the Universiti Sains Malaysia, Penang and the Japanese International Research Centre for Agricultural Science (JIRCAS) will organise the first international conference on this topic in Malaysia in March 1998.

Sustainability of Fast-growing Acacia Plantations

Most of what has been written in the previous sections refers to research to develop techniques for first-rotation acacia plantations. As yet we have little experience in managing second and subsequent rotations, but there are going to be large areas in this state early next century. We need to develop management options to ensure there is no decline in site productivity and plantation yield in successive rotations.

There is no doubt that *A. mangium* is capable of a mean annual volume increment of 40 m^3/ha/yr although various constraints usually result in reduced growth rates, and 25 m^3/ha/yr is considered an economic and achievable growth rate for large-scale plantations (e.g. Otsamo 1996). Clearly there is potential for increasing yields in the short term through better species–site matching, intensive tree breeding, optimising fertiliser applications, controlling weed competition and managing pests and diseases. However, long-term maintenance or improvement of site productivity will require careful management of soil and water resources (Nambiar and Brown 1997).

Many current sites have low levels of fertility due to inherent properties of the substrate or due to mismanagement by removal of vegetative cover, fire, erosion etc. These low potential and 'degraded' lands are the sites mainly being used for plantation forestry. What is the nutrient-depletion effect of harvesting large volumes of young wood from such sites? Trees harvested on 7–12 year rotations will have a high proportion of juvenile wood, which contains higher concentrations of nutrients than older heart wood. It might be expected that nitrogen or phosphorus would be the nutrients most affected by tree removal but it is apparent from nutrient budget analyses that calcium is the nutrient most significantly depleted from most sites (e.g. Lim 1988; Nykvist 1997). It is doubtful if high levels of nutrient depletion can be continued without inputs of selected nutrients through fertilisers (Nambiar 1996).

Although nutrient depletion may be detrimental, the effect of harvesting on soil organic matter and carbon–nitrogen interactions may in the long term have the greatest impact on site productivity (Johnson 1994). In plantations of other genera in temperate areas the impacts of harvesting and inter-rotational site management practices have been identified as critical elements in the sustainable management of plantations (Nambiar 1996). Research on inter-rotational site management in fast-growing tropical species, including acacias, has been identified as a priority for the Center for International Forestry Research (CIFOR) and a network of trials is being established in Asia, Africa and South America. These studies will examine in particular the effects of changes in soil organic matter. Sustaining site productivity will be a high-priority research topic as the large areas of tropical acacias enter their second and subsequent rotations. Kile (1997) has listed some specific areas requiring investigations:

- well designed, long-term 'base line' productivity studies, to follow productivity across rotations and define major factors affecting it;

- better understanding of nutrient and organic matter cycles (particularly nitrogen, phosphorus and cations) in plantations and the impact of disturbance on nutrient budgets and cycling;
- more examination of the impacts of site disturbance on soil physical processes and the consequent effect on productivity;
- improve capacity to explain and predict the response of different soils to management practices;
- assessments of the impacts of pests and diseases and evaluation of plantation health strategies.

It will also be important to have quick, effective ways of monitoring the ecological, social and economic sustainability of plantations. Proposed timber certification schemes have provided a stimulus for this research. CIFOR, with support from ACIAR, has started to investigate criteria and indicators for sustainable management of acacias in Indonesia in cooperation with the plantation sector. It will also try to develop socioeconomic and simulation tools to facilitate negotiations with smallholders.

Concluding Remarks

The current rapid planting of tropical acacias is similar to that of eucalypts in South America in the 1970s. With such a development it is critical that supplies of high quality seeds and vegetative stocks are generated as quickly as possible. It is therefore appropriate that there has been heavy emphasis on species and provenance selection and tree breeding, and much progress has been made. This effort will need to continue but we should expect to see greater emphasis on selection and breeding for wood properties for specific end-uses and possibly for pathogen resistance.

We stress that the benefits of tree breeding will not be realised unless there is increased research effort to overcome the numerous soil and environmental constraints. Nambiar (1996) highlighted the need for tree breeders to cooperate more with those working on soil and water management and other aspects of tree management. Such cooperation will be essential to meet effectively the numerous research challenges of the second and subsequent rotations of tropical acacias.

To ensure that there is a more effective research effort there needs to be continuing international cooperation. It is unrealistic to expect that aid donors will facilitate research networks to the extent they have in the past. The momentum of the COGREDA and FORTIP networks was lost when the donor resources terminated. New networks need to be self sustaining, possibly organised along the lines of IUFRO working groups, seeking only minimal support from donors and regional bodies such as the Asia-Pacific Association of Forestry Research Institutions (APAFRI).

While it may be important for researchers to cooperate to tackle a range of biophysical problems, it is becoming increasingly important to think holistically about forestry and to consider the role of people and economics in relation to technological developments. There will be greater involvement of small landowners in growing acacia wood for industrial enterprises and this will present new opportunities and challenges for researchers and managers. Forest managers are making a painful transition in adapting to meet the challenges of managing forests in economically, environmentally and socially sustainable ways. Researchers must be aware of these problems and ensure that the research directions and priorities emerging from this workshop accord with those of our primary clients.

References

Adjers, G. and Hadi, T.S. 1993. Acacias in agroforestry. In: Awang, K. and Taylor, D.A., ed., Tropical Acacias in East Asia and the Pacific. Proceedings of the first meeting of the Consultative Group for Research and Development of Acacias (COGREDA), Phuket, Thailand, 1–3 June 1992. Winrock International, Bangkok, Thailand, 134–143.

Anwar Mohamad 1987. Growth of acacias on a logged-over forest in Sabah. In: Turnbull, J.W., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16. Australian Centre for International Agricultural Research, Canberra, 167–169.

Arisman, H. and Havmoller, P. 1994. Seed supply strategy for a pulpwood plantation project in southern Sumatra. In: Drysdale, R.M. and John, S.E.T., ed., Proceedings of an International Symposium on Genetic Conservation and Production of Tropical Forest Tree Seed, 14–16 June 1993, Chiang Mai. ASEAN–Canada Forest Tree Seed Centre, Saraburi, Thailand, 225–228.

Arnold, R.J., Harwood, C.E. and Haines, M.W. 1994. Growth, genetic parameters and selection gains from *Acacia crassicarpa* in the Northern Territory, Australia. In: Proceedings of the IUFRO Asia-Pacific Symposium on Forest Genetic Improvement, 19–22 October 1994, Beijing.

ATSC 1997. Production of improved seeds in Laos, Vietnam and the Philippines: project completion report. Australian Tree Seed Centre, CSIRO Forestry and Forest Products, Canberra.

Awang, K. and Bhumibhamon, S. 1992. Genetics and tree improvement. In: Awang, K. and Taylor, D.A., ed., *Acacia mangium*: Growing and Utilization. MPTS Monograph Series No. 3. Winrock International and FAO, Bangkok, 35–57.

Awang, K. and Taylor, D.A. ed., 1992. Tropical Acacias in East Asia and the Pacific. Proceedings of the first meeting of the Consultative Group for Research and Development of Acacias (COGREDA), Phuket, Thailand, 1–3 June 1992. Winrock International, Bangkok, Thailand.

Awang, K. and Taylor D.A. ed., 1993. Acacias for Rural, Industrial and Environmental Development. Proceedings of the second meeting of the Consultative Group for Research and Development of Acacias (COGREDA), Udorn Thani, Thailand, 15–18 February 1993. Winrock International Institute for Agricultural Research, and FAO, Bangkok, Thailand.

Awang, K., Venkateswarlu, P., Nor Aini, A.S., Adjers, G., Bhumibhamon, S., Kietvuttinon, B., Fuh-Junin Pan, Pitpreecha, K. and Samsiri, A. 1994. Three year performance on international provenance trials of *Acacia auriculiformis*. Forest Ecology and Management, 70, 147–158.

Balodis, V. 1991. Planning of pulpwood production from plantations. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 132–137.

Banik, R.L., Mannan, M.A., Sharmila Das, Islam, S.A.M.N. 1995. Vegetative propagation of adult trees of acacia hybrid (*Acacia auriculiformis* × *Acacia mangium*). Bangladesh Journal of Forest Science, 24, 74.

Bernhard-Reversat, F., Diangana, D. and Tstsa, M. 1993. Biomass, mineralomass et productivité en plantation d'*Acacia mangium* and *Acacia auriculiformis* au Congo. Bois et Forêts des Tropiques No. 238, 35–44.

Bhaskar, P. and Subhash, K. 1996. Micropropagation of *Acacia mangium* through nodal bud culture. Indian Journal of Experimental Biology, 34, 590–591.

Boa, E. and Lenné, J. 1994. Diseases of Nitrogen Fixing Trees in Developing Countries: an Annotated List. Natural Resources Institute, Overseas Development Administration, Chatham, U.K.

Bon, M.C. and Montenuuis, O. 1996. Biotechnologies forestiéres au Sabah. Bois et Forêts des Tropiques No. 248, 31–42.

Brown, A.G., ed. 1994. Australian Tree Species Research in China. ACIAR Proceedings No. 48. Australian Centre for International Agricultural Research, Canberra, 226 p.

Brown, A.G. and Ho, C.K., ed. 1997. Black Wattle and its Utilisation. Publication No. 97/72, Rural Industries Research and Development Corporation, Canberra, 167 p.

Bulgannawar, G.N. and Math, B.B.M. 1991. The role of *Acacia auriculiformis* in afforestation in Karnataka, India. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 110–115.

Butcher, P.A., Moran, G.F. and Perkins, H.D. 1996. Genetic resources and domestication of *Acacia mangium*. In: Dieters, M. J., Matheson, A.C., Nikles, D.G., Harwood C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI-IUFRO conference, 27 October–1 November 1996, Caloundra, Queensland, Australia, 467–471.

Carron, L.T. and Aken, K.M., ed. 1992. Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37. Australian Centre for International Agricultural Research, Canberra, 132 p.

Carrere, R. and Lohmann, L. 1996. Pulping the South: Industrial Tree Plantaions and the World Paper Economy. Zed Books, London and New Jersey, 280 p.

Chia, L. 1993. Recent developments in acacia improvement at Sabah Softwoods. In: Awang, K. and Taylor, D.A., ed., Acacias for Rural, Industrial and Environmental Development. Proceedings of the second meeting of the Consultative Group for Research and Development of Acacias (COGREDA), Udorn Thani, Thailand, 15–18 February 1993. Winrock International Institute for Agricultural Research, and FAO, Bangkok, Thailand, 179–185.

Clark, N.B., Balodis, V., Fang, G. and Wang, J. 1994. Pulpwood potential of acacias. In: Brown, A.G., ed., Australian Tree Species Research in China. ACIAR Proceedings No. 48. Australian Centre for International Agricultural Research, Canberra, 196–202.

Cole, T.G., Yost, R.S., Kablan, R. and Olsen, T. 1996. Growth potential of twelve *Acacia* species on acid soils in Hawaii. Forest Ecology and Management, 80, 175–186.

Cossalter, C. 1987. Introducing Australian acacias in dry, tropical Africa. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, Australian Centre for International Agricultural Research, Canberra, 117–122.

Darus Ahmad, 1992. Micro propagation techniques for *Acacia mangium* × *Acacia auriculiformis*. In: Carron L.T. and Aken, K.M., ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37. Australian Centre for International Agricultural Research, Canberra, 119–121.

Darus Ahmad and Ang, L.H. 1993. Acacias for rural, industrial and environmental development in Malaysia. In: Awang, K. and Taylor, D.A., ed., 1993. Acacias for Rural, Industrial and Environmental Development. Proceedings of the second meeting of the Consultative Group for Research and Development of Acacias (COGREDA), Udorn Thani, Thailand. 15–18 February 1993. Winrock International Institute for Agricultural Research, and FAO, Bangkok, Thailand, 46–49.

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

Day, R.K., Rudgard, S.A. and Nair, K.S.S. 1994. Asian Tree Pests: an Overview. Technical Document GCP/RAS/134/ASB. FORSPA Publication 12 FAO, Bangkok.

Dela Cruz, R.E. and Yantasath, K. 1993. Symbiotic associations. In: Awang, K. and Taylor, D.A., ed., *Acacia mangium*: Growing and Utilization. MPTS Monograph Series No. 3. Winrock International and FAO, Bangkok, 101–111.

Dommergues, Y. 1993. Workshop on *Acacia* symbioses. Bois et Forêts des Tropiques, No. 238, 34.

Doran, J.C. and Turnbull, J.W., ed. 1997. Australian Trees and Shrubs: Species for Land Rehabilitation and Farm Planting in the Tropics. ACIAR Monograph No. 24. Australian Centre for International Agricultural Research, Canberra, 384 p.

Fang, G., Wang, J. and Liu, G. 1994a. Kraft pulping properties of plantation-grown *Acacia mearnsii* from

Zhangzhou. In: Brown, A.G., ed., Australian Tree Species Research in China. ACIAR Proceedings No. 48. Australian Centre for International Agricultural Research, Canberra, 214–217.

Fang, Y., Gao, C., Zeng, F. Ren, H., Li, J., Liu, S. and Zhang, Q. 1994b. Field evaluation and selecton of *Acacia mearnsii* provenances. In: Brown, A.G., ed., Australian Tree Species Research in China. ACIAR Proceedings No. 48. Australian Centre for International Agricultural Research, Canberra, 149–157.

FAO-MoF 1990. Situation and Outlook for the Forestry Sector in Indonesia. Vol. 2: Forest Resource Base. Ministry of Forestry, Government of Indonesia, and FAO, Jakarta.

Galiana, A., N'Guessan Kanga, A., Gnahova, G.M., Balle, P., Dupuy, B., Domenach A.M. and Mallet, B. 1996. Fixation de L'azote chez *Acacia mangium* en plantation. Bois et Forêts des Tropiques No. 249, 51–60.

Galiana, A. and Prin, Y. 1996. The benefits of rhizobial inoculation in tropical forestry: response of *Acacia mangium* to the application of selected strains of *Bradyrhizobium* spp. In: Dieters, M. J., Matheson, A.C., Nikles, D.G., Harwood C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI-IUFRO conference, 27 October–1 November 1996, Caloundra, Queensland, Australia, 449–454.

Gao, C. 1989. *Acacia mearnsii* provenance trials in People's Republic of China. In: Boland, D.J., ed., Trees for the Tropics. ACIAR Monograph No. 10. Australian Centre for International Agricultural Research, Canberra, 97–101.

Gibson, I.A.S. 1981. Seed Source Establishment and Tree Improvement—Sabah, Malaysia. Forest Mycology. Consultants Report No. 3. FAO/UNDP/MAL/7B1009, Rome.

Ginting, N.A., Daryono, H. and Siregar, C.A. 1996. Ecological aspects of forest plantations. In: Otsamo, A., Kuusipalo, J. and Jaskari, H., ed., Reforestation: Meeting the Future Industrial Wood Demand. Proceedings of a workshop 30 April–1 May 1996, Jakarta, Indonesia. Enso Forest Development Oy Ltd, 122–132.

Gunn, B.V. and Midgley, S.J. 1991. Exploring and accessing the genetic resources of four selected tropical acacias. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 57–63.

Hamilton, C. 1997. The sustainability of logging in Indonesia's tropical forests: a dynamic input–output analysis. Ecological Economics, 21, 183–195.

Harwood, C.E., Matheson, A.C. Gororo, N. and Haines, M.W. 1991. Seed orchards of *Acacia auriculiformis* at Melville Island, Northern Territory, Australia. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 87–91.

Harwood, C.E. and Williams, E.R. 1992. A review of provenance variation in growth of *Acacia mangium*. In: Carron, L.T. and Aken, K.M., ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37. Australian Centre for International Agricultural Research, Canberra, 22–30.

Ho, C.K. and Fang, Y.L. 1997. Development of black wattle (*Acacia mearnsii* De Wild) plantations in China. In: Brown, A.G. and Ho, C.K., ed., Black Wattle and its Utilisation. Rural Industries Research and Development Corporation, Canberra, 83–88.

Hocking, D., ed. 1993. Trees for Drylands. International Science Publisher, New York, 370 p.

Hsu-Ho C. 1993. Acacias for non-wood products. In: Awang,. K and Taylor, D.A., ed., 1993. Acacias for Rural, Industrial and Environmental Development. Proceedings of the second meeting of the Consultative Group for Research and Development of Acacias (COGREDA), Udorn Thani, Thailand, 15–18 February 1993. Winrock International Institute for Agricultural Research, and FAO, Bangkok, Thailand.

Hutacharern 1992. Insect pests of acacia: an overview. In: Awang, K., and Taylor, D.A., ed., Tropical Acacis in East Asia and the Pacific. Proceedings of the first meeting of the Consultative Group for Research and Development of Acacias (COGREDA), Phuket, Thailand, 1–3 June 1992, Winrock International Bangkok, Thailand, 81–85.

Ito, S. and Nanis, L.H. 1997. Survey of heart rot on *Acacia mangium* in Sabah, Malaysia. Japanese Agricultural Research Quarterly, 31, 65–71.

Jambulingam, R. 1986. *Acacia holosericea* for afforestation in dry lateritic soils. Van Vigyan, 24, 13–16.

Johnson, D.W. 1994. Reasons for concern over impacts of harvesting. In: Dyck, W.J., Cole, D.W. and Comerford, N.B., ed., Impacts of Forest Harvesting on Long-term Site Productivity. Chapman and Hall, London, 1–12.

Kha, L.D. 1996. Studies on natural hybrids of *Acacia mangium* and *A. auriculiformis* in Vietnam. In: Dieters, M. J., Matheson, A.C., Nikles, D.G., Harwood C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI–IUFRO conference, 27 October–1 November 1996, Caloundra, Queensland, Australia, 328–332.

Khanna, P.K. 1997. Comparison of growth and nutrition of young monocultures and mixed stands of *Eucalyptus globulus* and *Acacia mearnsii*. Forest Ecology and Management, 94, 105–113.

Khasa, P.D., Vallee, G. and Bousquet, J. 1994. Biological considerations in the utilisation of *Racosperma auriculiforme* and *Racosperma mangium* in tropical countries, with emphasis on Zaire. Journal of Tropical Forest Science, 6, 422–443.

Khasa, P.D., Cheliak, W.M. and Bousquet, J. 1994. Genetic variation in 26 populations of *Racosperma auriculiforme* and *Racosperma mangium* using allozymes. Canadian Journal of Forest Research, 24, 1123–1132.

Kile, G.A. 1997. A biological assessment of the sustainability of fast growing plantation forests in the Asia–Pacific. Paper to the third annual Asia-Pacific Pulp and Paper Summit, 29–30 September 1997, Singapore, 15 p.

Kushalapa, K.A. 1991. Performance of *Acacia auriculiformis* in India. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 189–193.

Kyoji, H., Susumu, K. and Suhaendi, H. 1996. Establishment of seed sources of tropical tree species in Indonesia. In: Dieter, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement of Sustainable Forestry. Proceedings of QFRI–IUFRO conference, 27 October–1 November 1996, Caloundra, Queensland, Australia, 370–371.

Lee, S.S. 1985. Tree diseases and wood determination problems in Peninsular, Malaysia. Occasional Paper No. 5. Faculty of Forestry, Universiti Pertanian Malaysia.

—1997. Diseases of some tropical plantation acacias in Peninsular Malaysia. In: Old, K.M., Lee, S.S. and Sharma, J.K., ed., Diseases of Tropical Acacias. CIFOR Special Publication, 53–61.

Li, J., Gao, C., Zheng, F. and Ren, H. 1994. Bark quality of *Acacia mearnsii* provenances from different geographic origins growing in south China. In: Brown, A.G., ed., Australian Tree Species Research in China. ACIAR Proceedings No. 48. Australian Centre for International Agricultural Research, Canberra, 203–213.

Lim, M.T. 1988. Nutrient cycling in a young *Acacia mangium* stand. In: Proceedings of the Australian Bicentenary Forestry Conference, 25 April–1 May 1988, Albury, NSW. Vol. 5, 7 p.

Lupko, H., Susumu, K. and Suhaendi, H. 1996. Establishment of seed sources of tropical tree species in Indonesia. In: Dieters, M. J., Matheson, A.C., Nikles, D.G., Harwood C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI–IUFRO conference, 27 October–1 November 1996, Caloundra, Queensland, Australia, 370–371.

Marcar, N.E., Hussain, R.W., Arunin, S. and Beetson, T. 1991. Trials with Australian and other *Acacia* species on salt-affected land in Pakistan, Thailand and Australia. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 229–232.

Marcar, N.E., Crawford, D., Leppert, P., Jovanovic, T., Floyd, R. and Farrow, R. 1995. Trees for Saltland: A Guide to Selecting Native Species for Australia. CSIRO, Australia.

Maslin, B.R. 1995. Systematics and phytogeography of Australian species of *Acacia*: an overview. Institute of Foresters of Australia Newsletter, 36 (2), 2–5.

Maslin, B.R. and McDonald, M.W. 1996. A Key to Useful Australian Acacias for the Seasonally Dry Tropics. CSIRO, Australia. 80 p.

Mead, D.J. and Miller, R.R. 1991. The establishment and tending of *Acacia mangium*. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 116–122.

Mead, D.J. and Speechly, H.T. 1991. *Acacia mangium* for high quality sawlogs in Peninsular Malaysia. In: Sheik Ali Abod, Tahir, P. Md., Tsai, L.M., Shukor, N.A. Ab., Sajap, A.S. and Manikam, D., ed., Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia. Faculty of Forestry, Universiti Pertanian Malaysia, Serdang, 54–71.

Midgley, S.J. and Byron, R.N., Chandler, F.C., Ha Huy Thinh, Tran Vo Hung Son and Hoang Hong Hanh 1995. Do plants need passports? A socio-economic study of the role of exotic tree and other plant species in Quang Tri Province, Vietnam. CSIRO Division of Forestry, CIFOR and Forest Science Institute of Vietnam.

Midgley, S.J., Pinyopusarerk, K., Harwood, C.E. and Doran, J.C. 1996. Exotic plant species in Vietnam's economy—the contributions of Australian trees. Presentation to Seminar on Environment and Development in Vietnam, 6–7 December 1996, National Centre for Development Studies, Canberra, Australia, 20 p.

Ministry of Forestry 1994. Planting Technique of some Forest Tree Species. Agriculture Publishing House, Hanoi, Vietnam.

Montagu, K.D., Woo, K.C., Harwood, C.E. and Metcalfe, A.J. 1996. Tree growth and form in a clonal seed orchard of *Acacia auriculiformis*. In: Dieters, M. J., Matheson, A.C., Nikles, D.G., Harwood C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI–IUFRO conference, 27 October–1 November 1996, Caloundra, Queensland, Australia, 379–381.

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

—1989b. Breeding systems and genetic diversity in *Acacia auriculiformis* and *A. crassicarpa*. Biotropica 21, 250–256.

Nadagoudar, B.N. 1993. Acacias for rural, industrial and environmental development in India. In: Awang, K., and Taylor, D.A., Acacias for Rural, Industrial and Environmental Development. Proceedings of the second meeting of the Consultative Group for Research and Development of Acacias (COGREDA), Udorn Thani, Thailand, 15–18 February 1993. Winrock International Institute for Agricultural Research, and FAO, Bangkok, Thailand, 21–32.

Nambiar, E.K.S. 1996. Sustained productivity of plantation forests is a continuing challenge to tree improvement. In: Dieters, M. J., Matheson, A.C., Nikles, D.G., Harwood C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI–IUFRO conference, 27 October–1 November 1996, Caloundra, Queensland, Australia, 6–18.

Nambiar, E.K.S and Brown, A.G. ed., 1997. Management of Soil, Nutrients and Water in Tropical Plantation Forests. Australia Centre for International Agriculture Research with CSIRO and CIFOR, Canberra.

Nghia, N.H. 1996. Climatic requirements of some main plantation tree species in Vietnam. In: Booth, T.H., ed., Matching Trees and Sites. ACIAR Proceedings No. 63. Australian Centre for International Agricultural Research, Canberra, 43–49.

Nghia, N.H. and Kha, L.D. 1993. Acacias for rural, industrial and environmental development in Vietnam. In: Awang, K. and Taylor, D.A., ed., Acacias for Rural, Industrial and Environmental Development. Proceedings of the second meeting of the Consultative Group for Research and Development of Acacias (COGREDA), Udorn Thani, Thailand, 15–18 February 1993. Winrock International Institute for Agricultural Research, and FAO, Bangkok, Thailand, 86–93.

—1996. *Acacia* species and provenance selection for large-scale planting in Vietnam. In: Dieters, M. J., Matheson, A.C., Nikles, D.G., Harwood C.E. and Walker, S.M., ed.,

Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI–IUFRO conference, 27 October–1 November 1996, Caloundra, Queensland, Australia, 443–448.
Nykvist, N. 1997. Uptake of nutrients in a plantation of *Acacia mangium* in relation to decrease in soil amounts. Journal of Sustainable Forestry, 4, 131–139.
Old, K.M., Lee, S.S. and Sharma, J.K. ed., 1997. Diseases of Tropical Acacias. CIFOR Special Paper, Jakarta. 120 p.
Osonubi, O., Mulongoy, K., Awotoye, O.O., Atayesse, M.O. and Okail, D.U.U. 1991. Effects of ectomycorrhizal and vesicular–arbuscular mycorrhizal fungi and drought tolerance of four leguminous woody seedlings. Plant and Soil, 136, 131–143.
Otsamo, A. 1996. Technical solutions for plantation forestry on grasslands. In: Otsamo, A., Kuusipalo J. and Jaskari, H., ed., Reforestation: Meeting the Future Industrial Wood Demand. Proceedings of a workshop, 30 April–1 May 1996, Jakarta. Enso Forest Development Oy Ltd, 55–67.
Pan, Z. and Yang, M. 1987. Australian acacias in the People's Republic of China. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16. Australian Centre for International Agricultural Research, Canberra, 136–138.
Pandey, D. 1995. Forest Resources Assessment 1990—Tropical Forest Plantation Resources. FAO Forestry Paper 128, FAO, Rome.
Pedley L. 1987. Australian acacias: taxonomy and biogeography. In: Turnbull, J.W., ed., Australian Acacias for Developing Countries. ACIAR Proceedings No. 16, Australian Centre for International Agricultural Research, Canberra, 11–16.
Pinso, C. and Nasi, R. 1992. The potential of *Acacia mangium* × *Acacia auriculiformis* hybrid in Sabah. In: Carron, L.T. and Aken K.M., ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37. Australian Centre for International Agricultural Research, Canberra, 17–21.
Pinyopusarerk, K. 1987. Improving *Acacia auriculiformis* through selection and breeding in Thailand. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16. Australian Centre for International Agricultural Research, Canberra, 147–148.
—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, Australian Centre for International Agricultural Research, Canberra, 109–127.
—1990. *Acacia auriculiformis*: an annotated bibliography. Winrock International Institute of Agricultural Development, and ACIAR. Bangkok, Thailand, 154 p.
Pinyopusarerk, K., Luangviriyasaeng, V. and Rattanasavanh, D. 1996. Two-year perfomance of *Acacia* and *Eucalyptus* species in a provenance trial in Lao P.D.R. Journal of Tropical Forest Science, 8, 412–423.
Prasad, R. 1991. Use of acacias in wasteland afforestation. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 96–102.
Rahim Sudin, Chew, L.T. and Khozirah Shaari 1991. Cement-bonded particle board from some plantation species in Malaysia. In: Sheik Ali Abod, Tahir, P.Md., Tsai, L.M., Shukor, N.A. Ab., Sajap, A.S. and Manikam, D., ed., Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia. Faculty of Forestry, Universiti Pertanian Malaysia, Serdang, 725–730.
Razali Abdul-Kader 1993. Innovations in the utilization of small diameter trees, particularly acacias. In: Awang, K. and Taylor D.A., ed., 1993. Acacias for Rural, Industrial and Environmental Development. Proceedings of the second meeting of the Consultative Group for Research and Development of Acacias (COGREDA), Udorn Thani, Thailand, 15–18 February 1993. Winrock International Institute for Agricultural Research, and FAO, Bangkok, Thailand, 192–197.
Razali Abdul-Kader and Mohd Hamani Sahri 1993. Properties and utilisation. In: Awang, K and Taylor, D.A., *Acacia mangium*: Growing and Utilisation. Winrock International Institute for Agricultural Research, and FAO, Bangkok, 225–241.
Reddell, P. and Warren, R. 1987. Inoculation of acacias with mycorrhizal fungi: potential benefits. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16. Australian Centre for International Agricultural Research, Canberra, 50–53.
Rufelds, C.W. 1987. Quantitative comparison of *Acacia mangium* versus hybrid *A. auriculiformis*. FRC Publication No. 40, Forest Research Centre, Sandakan, Sabah.
Saad, H. 1997. New wood utilisation—current status and future directions. Presentation to International Tropical Wood Conference, 'New Tropical Timber Crops: Challenges in Processing and Utilisation', 17–20 June 1997, Kuala Lumpur, Malaysia.
Sasaki, H. 1997. New technologies and machines for conversion of low-grade logs into value-added products. Presentation to International Tropical Wood Conference, 'New Tropical Timber Crops: Challenges in Processing and Utilisation', 17–20 June 1997, Kuala Lumpur, Malaysia.
Searle, S.D. 1989. Seed collections of lesser-known trees and shrubs in Queensland, Australia. In: Boland, D.J. ed., Trees for the Tropics. ACIAR Monograph No. 10, Australian Centre for International Agricultural Research, Canberra, 27–34.
Sharma, J.K. and Florence, E.J.M. 1997. Fungal pathogens as a potential threat to tropical acacias: case study of India. In: Old, K.M. Lee, S.S. and Sharma, J.K., ed., Diseases of Tropical Acacias. CIFOR Special Publication, 70–107.
Sherry, S.P. 1971. The Black Wattle. University of Natal Press, Pietermaritzburg.
Sim, B.L. 1987. Research on *Acacia mangium* in Sabah: a review. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16. Australian Centre for International Agricultural Research, Canberra, 164–166.
—1992. Overview of *Acacia* research in Sabah. In: Awang, K. and Taylor D.A., ed., Tropical Acacias in East Asia and the Pacific. Proceedings of the first meeting of the Consultative Group for Research and Development of

Acacias (COGREDA), 1–3 June 1992, Phuket, Thailand. Winrock International, Bangkok, 18–22.

Skelton, D.J. 1987. Distribution and ecology of Papua New Guinea acacias. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16. Australian Centre for International Agricultural Research, Canberra, 38–49.

Thomson. L.A.J. 1994. *Acacia aulococarpa*, *A. cincinnata*, *A. crassicarpa* and *A. wetarensis*: an Annotated Bibiliography. CSIRO, Australia, 131 p.

Thomson, L.A.J. and Cole, E.G. 1987. Woody plant seed collections in tropical, arid and semi-arid Australia and recommendations for international species trials. FAO Forest Genetic Resources Information, 15, 37–49.

Thomson, L.A.J., Turnbull, J.W. and Maslin, B.R. 1994. The utilisation of Australian species of *Acacia*, with particular reference to those of the subtropical dry zone. Journal of Arid Environments, 27, 279–295.

Turnbull, J.W. ed., 1987. Australian Acacias in Developing Countries. ACIAR Proceedings No. 16. Australian Centre for International Agricultural Research, Canberra, 196 p.

—1988. Australian acacias in world forestry. In: Proceedings of the Australian Bicentenary Forestry Conference, 25 April–1 May 1988, Albury, NSW. Vol. 5, 15 p.

—1991. Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 234 p.

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

Turvey, N.D. 1995. Afforestation of Imperata Grasslands in Indonesia: Results of Industrial Tree Plantation Trials at Teluk Sirih on Pulau Laut, Kalimantan Selatan. ACIAR Technical Reports No. 33. Australian Centre for International Agricultural Research, Canberra, 43 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. Australian Centre for International Agricultural Research, Canberra, 157–159.

Venkateswarlu, P., Awang, K. and Nor Aini, A.S. 1994. Genetic variation in growth and stem form characteristics in *Acacia auriculiformis*. Malaysian Journal of Applied Biology, 22, 53–61.

Vuokko, R. 1996. Species and provenance selection for plantations forestry on grasslands. In: Otsamo, A. Kuusipalo, J. and Jaskari, H., ed., Reforestation: Meeting the Future Industrial Wood Demand. Proceedings of a workshop 30 April–1 May 1996, Jakarta. Enso Forest Development Oy Ltd., 68–79.

Wang, H., Jiang, Z. and Yan, H. 1994. Australian trees grown in China. In: Brown, A.G., ed., Australian Tree Species Research in China. ACIAR Proceedings No. 48. Australian Centre for International Agricultural Research, Canberra, 19–25.

Wickneswari, R., Norwati, M., Lee, S.L., Yeang, H.Y., Lokmal, N. and Rasip, A.G.A. 1996. Practical uses of molecular markers in tropical tree improvement. In: Dieters, M. J., Matheson, A.C., Nikles, D.G., Harwood C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI–IUFRO conference, 27 October–1 November 1996, Caloundra, Queensland, Australia, 506–511.

Wiersum K.F. 1992. *Acacia mearnsii* de Wild. In: Lemmens, R.H.M.J. and Wulijarni-Soetjipto, N., ed., Plant Resources of South East Asia No. 3. Dye and Tannin Producing Plants. PROSEA, Bogor, Indonesia, 41–45.

Wong, C.Y. and Haines, R.J. 1992. Multiplication of families of *Acacia mangium* and *Acacia auriculiformis* by cuttings from young seedlings. In: Carron, L.T. and Aken, K.M., ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37. Australian Centre for International Agricultural Research, Canberra, 112–114.

Xu, D., Yang, M. Zeng, Y. and Li, W. 1994. Above-ground net primary production and nutrient cycling of a young plantation of *Acacia mangium*. In: Brown, A.G., ed., Australia Tree Species Research in China. ACIAR Proceedings No. 48, 185–190.

Yang, M. and Zeng, Y. 1991. Results from a four-year-old tropical *Acacia* species/provenance trial on Hainan Island, China. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 170–172.

Yap, S.K. 1987. Introduction of *Acacia* species to Peninsular Malaysia. In: Turnbull, J.W., ed., Australian Trees in Developing Countries. ACIAR Proceedings No. 16. Australian Centre for International Agricultural Research, Canberra, 151–153.

Yazaki, Y. 1997. *Acacia storyi*: a potential tannin-producing species. Australian Forestry, 60, 24–28.

Zeng, Y. and Yang, M. 1994. Provenance trials of *Acacia aulacocarpa*. In: Brown, A.G., ed., Australian Tree Species Research in China. ACIAR Proceedings No. 48. Australian Centre for International Agricultural Research, Canberra, 180–184.

Zhang, F. and Yang, M. 1996. Comprehensive selection of provenances and families of *Acacia crassicarpa*. In: Dieters, M. J., Matheson, A.C., Nikles, D.G., Harwood C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI–IUFRO conference, 27 October–1 November 1996, Caloundra, Queensland, Australia, 401–403.

Zheng, H. and Yang, Z. 1993. Acacias for rural, industrial and environmental development in southern China. In: Awang, K. and Taylor D.A., ed., Acacias for Rural, Industrial and Environmental Development. Proceedings of the second meeting of the Consultative Group for Research and Development of Acacias (COGREDA), Udorn Thani, Thailand, 15–18 February 1993. Winrock International Institute for Agricultural Research, and FAO, Bangkok, Thailand, 15–20.

Performance of Australian Dry-zone *Acacia* Species on White Sandy Soil in Dry, Southeastern Vietnam

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Abstract

Eleven *Acacia* species native to Australia's tropical dry zone and a local control, *Cassia siamea*, were tested in a species trial at Tuy Phong in coastal southeastern Vietnam. The aim of the trial was to find species suitable for site rehabilitation and wood production under dry tropical conditions (mean annual rainfall 700 mm, mean annual temperature 27°C) on infertile white sands where other tree species had performed poorly.

Assessments of height and diameter growth and survival were made 6, 10, 26 and 41 months after planting. Initial establishment was successful with survival at 6 months good (over 60%) to excellent (over 90%). Significant differences between species in growth traits were evident at 6 months and in subsequent measures. By age 41 months, *Acacia difficilis* was clearly the fastest-growing species with mean height of 5.6 m, mean dbh of largest stem of 6.5 cm and survival of 60%. *Acacia tumida* (height 4.6 m, dbh 5.1 cm, survival at 41 months 68%) and *A. torulosa* (height 3.6 m, dbh 3.9 m and survival 84%) also performed well. *A. auriculiformis*, *A. elachantha*, *A. longispicata*, and *Cassia siamea* were poorly adapted to the site conditions, with less than 30% survival at 41 months. Inoculation in the nursery with selected strains of *Bradyrhizobium* produced an improvement in nursery growth for some *Acacia* species but this effect was not sustained in the field. The trial results suggest that successful plantations for fuelwood production, dune stabilisation and site amelioration could be established under semi-arid conditions on the white sands by planting *A. difficilis*, *A. tumida* and *A. torulosa*.

In recent years, large plantations of *Acacia auriculiformis* and *A. mangium* have been successfully planted in many regions of Vietnam. However, *A. mangium* requires an annual rainfall over 1500 mm and a dry season not longer than 5 months for good growth. *A. auriculiformis* performs better than *A. mangium* under dry conditions in Vietnam, but its growth and survival are poor on white sands in dry coastal areas (Nguyen Hoang Nghia 1996).

The total area of sandy soils along Vietnam's coastline exceeds 100 000 ha, with 46 500 ha in Binh Thuan and Ninh Thuan provinces in the southeast (Nguyen Xuan Quat 1996; Figure 1). Hoang Xuan Ty (1996) briefly described the characteristics of three main types of sandy soils found in coastal Vietnam, namely white, yellow and red sands. White sands are the most infertile type, with the surface 0–20 cm soil having only 0.07–0.5% organic matter and 0–0.01% nitrogen. The corresponding values cited for red sands are 0.3–1.3% organic matter and 0.02–0.06% nitrogen. The extensive areas of white sands in Binh Thuan and Ninh Thuan provinces are little used. Agricultural crops and plantations of cashews, *A. auriculiformis*, *Casuarina equisetifolia* and *Eucalyptus camaldulensis* have been largely unsuccessful. Early height growth in *C. equisetifolia* plantations is typically less that 0.5 m per year on white sands (Nguyen Xuan Quat 1996). Wind-blown drifting sands pose a problem for crops and people.

It is therefore important to identify other tree species that might perform better on white sands in dry parts of coastal Vietnam, enabling successful

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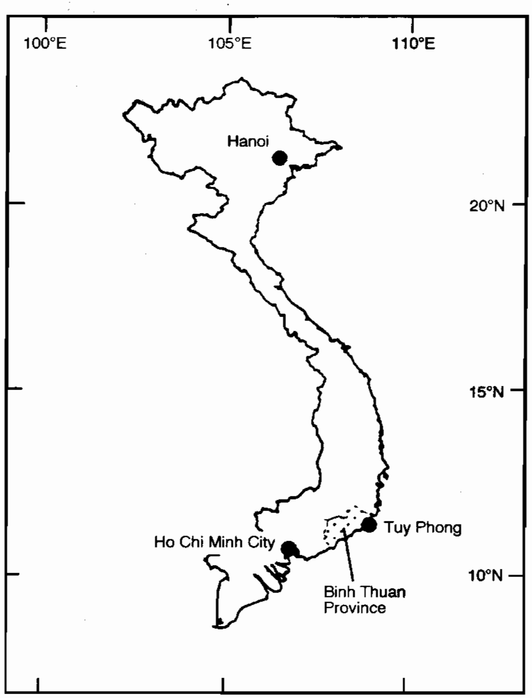

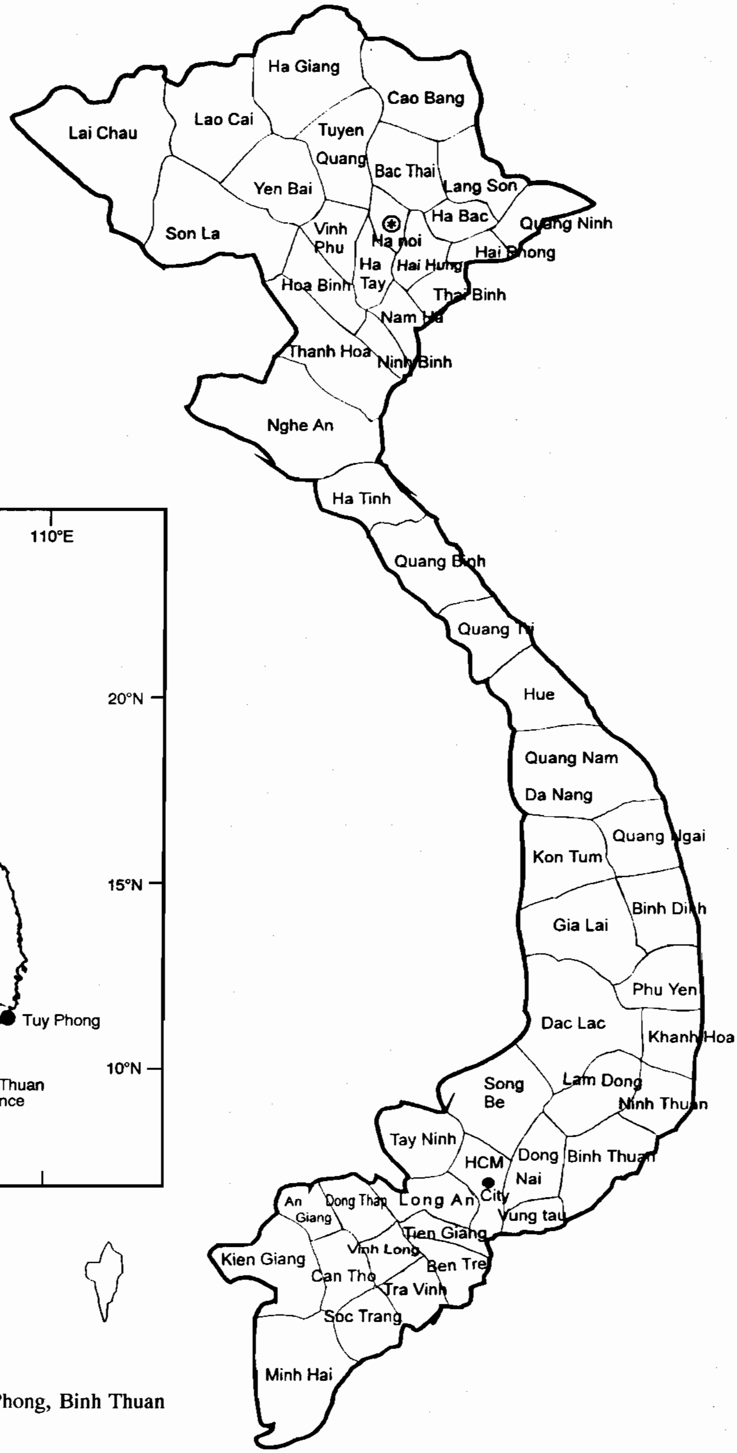

Figure 1. Location of trial site at Tuy Phong, Binh Thuan Province, Vietnam.

plantings for site stabilisation and economic production of forest products from these under-utilised lands. In 1993, the Research Centre for Forest Tree Improvement of the Forest Science Institute of Vietnam, in collaboration with CSIRO's Australian Tree Seed Centre, established a trial of promising dry-zone *Acacia* species on a representative white sand site in Binh Thuan province.

Materials and Methods

Species selection

The *Acacia* species tested in the trial are from tropical areas in northern Australia with mean annual rainfall in the range 400–1100 mm and a 6–8 month dry season (Doran and Turnbull 1997). The 11 species shown in Table 1 were selected as being likely to perform well at Tuy Phong on the basis of results of previous trials in tropical sub-humid and semi-arid conditions (Turnbull 1991; Thomson et al. 1994). Most of the species tested are multistemmed shrubs or small trees in their natural environment (Maslin and McDonald 1996). Where information on provenance variation was available, provenances known to attain large adult size and display good stem form were selected. *Cassia siamea* was chosen as a local control: this species is grown with reasonable success in the region, but has not performed well on white sands. Seedlots of all *Acacia* species were bulked seeds of natural provenances from at least 10 seed trees except for *A. holosericea* (four trees), *A. leptocarpa* (five trees) and *A. tumida* (eight trees).

Trial location, design and establishment

The trial site was located on deep wind-blown greyish-white sand about 1 km from the coast at Tuy Phong, Binh Thuan province (latitude 11°20′N, longitude 108°58′E). Mean annual rainfall at Tuy Phong is around 700 mm, highly variable from year to year, with a dry season of 6–7 consecutive months in which monthly rainfall totals are less than 40 mm (Truong Trong Quan 1984). Mean annual temperature is about 27°C, mean daily maximum temperature of the hottest month 37.6°C and mean daily minimum of the coldest month 19.6°C. Excavation of the soil profile indicated little variation in the soil profile to 1 m depth, and the site was well-drained with the water table below 1 m throughout the year. Chemical and physical data for the white sand soil at the trial site are shown in Table 2. Rainfall records for the period of the experiment were available from Lien Huong, 12 km from the dry-zone acacia trial site at Tuy Phong. The annual totals were somewhat lower than the long-term average (Table 3).

Table 2. Chemical and physical analysis of white sand soil profile at Tuy Phong (Forest Science Institute of Vietnam, unpublished).

Soil depth (cm)	0–10	10–20	90–100
pH (H_2O)	6.1	5.4	5.35
pH (HCl)	5.3	4.2	4.25
carbon %	0.08	0.16	0.08
nitrogen (%)	0.01	0.01	—
Al^{3+} (mg/100g)	0.04	0.20	0.24
Ca^{2+} (meq/100g)	0.6	0.1	0.1
Mg^{2+} (meq/100g)	0.4	0.6	0.3
P_2O_5 (mg/100g)	5.4	5.4	2.8
Particle diameter (mm)			
<0.001	1.2	2.8	2.4
0.001–0.005	0.4	0.4	0.4
0.005–0.01	1.2	0	0.8
0.01–0.05	1.2	2.0	1.2
0.05–0.25	31.71	47.23	41.23
0.25–1.0	64.29	47.57	53.94

Table 1. Provenance details for seedlots tested at Tuy Phong.

Species	Seedlot	Provenance[1]	Latitude (S)	Longitude (E)	Altitude (m)
A. auriculiformis	17966	Boggy Creek, Qld	15°52′	144°53′	240
A. colei	14660	Turkey Ck, WA	17°04′	128°12′	400
A. cowleana	18169	Wauchope, NT	20°18′	118°35′	450
A. difficilis	16170	NW Lake Evella, NT	12°24′	135°44′	55
A. elachantha	14634	SE Hooker Ck, NT	18°48′	131°13′	300
A. holosericea	16179	Blythe R, NT	12°25′	134°42′	40
A. leptocarpa	15478	S Musgrave, Qld	14°55′	143°22′	80
A. longispicata	17262	W Duaringa, Qld	23°45′	149°53′	150
A. neurocarpa	18170	Attock Ck, NT	19°03′	134°09′	350
A. torulosa	17490	Elliot, NT	17°33′	133°30′	500
A. tumida	17500	E Kununurra, WA	15°54′	128°54′	500
Cassia siamea	—	local	11°20′N	108°58′	10

[1] NT = Northern Territory, Qld = Queensland, WA = Western Australia

Table 3. Monthly rainfall (mm) at Lien Huong, 12 km from Tuy Phong, 1993–1995.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Total**
1993	0	0	1	3	108	32	71	11	189	87	49	45	**594**
1994	0	0	0	2	28	167	86	76	180	159	7	39	**743**
1995	0	0	0	0	3	23	132	143	184	67	46	16	**614**

Acacia seedlots were treated with boiling water to promote germination and plants were raised in the nursery at Tuy Phong in black polythene bags, 15 × 5 cm in size, using a nursery potting mix of 89% sand, 10% well-rotted cow manure and 1% superphosphate fertiliser. It was known that *A. auriculiformis* developed *Bradyrhizobium* nodules under standard nursery conditions at Tuy Phong. Inoculation with selected strains of *Bradyrhizobium* was carried out to study whether this might lead to improved performance of the different *Acacia* species. Three strains had been isolated from natural stands in northern Australia and glasshouse-tested on some of the species by Dr Alan Gibson. The strains were available in peat medium; combinations of these three strains were matched to species based on their known glasshouse performance. Two hundred seedlings of each species were inoculated at the two-leaf pair stage, while a further 200 seedlings of each species were not inoculated. The inoculated and non-inoculated treatments were kept well separated in the nursery to avoid cross-contamination. Four months after inoculation, just before outplanting, seedling heights were measured and 10 representative seedlings from each treatment were sacrificed for dry-weight measurements and inspection for root nodules. *Cassia siamea*, which does not produce nitrogen-fixing root nodules (Gutteridge 1997), was also inoculated although no improvement in growth was anticipated.

The field trial was a randomised split-plot design with four replicates of 12 main plots (species), and 50 seedlings per main plot. Each main plot comprised two randomly allocated 25-tree sub-plots (inoculated and non-inoculated treatments). Spacing between plants was 2 × 2 m. The trial was planted in September 1993, during the rainy season. One kg of well rotted cow manure was placed at the bottom of each 30 × 30 × 30 cm planting hole at planting time. For some species there were insufficient seedlings to plant all the planting positions. The most serious shortfalls were for *A. difficilis* (123 out of 200 planting positions not planted) *A. tumida* (62 not planted) *A. colei* (56 not planted) and *A. elachantha* (52 not planted). For the other eight species, at least 180 out of the 200 available positions in the design were planted. Two hundred individuals of a second provenance of *A. tumida* (provenance 17964, Port Hedland, WA 20°18′S, 118°35′E, 50 metres above sea level) were planted along the eastern border of the trial at the same spacing.

Assessments and analysis of data

The trial was assessed 6, 10, 26 and 41 months after planting. Total heights were measured on each occasion. Diameter at ground level was measured at the first three assessments, and diameter at breast height (1.3 m) of the largest stem was measured at age 41 months. The data were entered into the computer using the Datachain software package, and checked for incorrect entries and outliers. The calculations of survival percentages were based on the initial numbers of seedlings planted (less than 200 for most species) and thus took into account the shortfalls in initial establishment. Analysis of variance was carried out using the Genstat 5.3 software package. The following statistical model was applied to sub-plot means to investigate the significance of seedlot and inoculation treatments and their interaction (Williams and Matheson 1994, p 66):

individual observation = overall site mean + replicate effect + seedlot effect + main-plot residual + inoculation treatment effect + seedlot-by-inoculation interaction effect + sub-plot residual.

The *C. siamea* data were excluded from this analysis, which showed that inoculation treatment did not produce significant effects for most variates of the 11 *Acacia* species. The analysis was re-run, incorporating the *C. siamea* data to obtain treatment mean values for this species.

Results

Initial establishment of all species was successful. Survival percentages at age 10 months ranged from 72% (*A. elachantha*) to 93% (*A. neurocarpa*) (Table 4). At this stage, species did not differ significantly in their survival. By age 26 months, significant differences in survival had developed, some species proving poorly adapted to the site. Survival at 41 months had fallen below 30% for *A. auriculiformis*, *A. elachantha*, *A. longispicata* and *C. siamea*. The best survival at age 41 months (84%) was displayed by *A. torulosa*. Survival percentages of inoculated and non-inoculated treatments of the *Acacia* species (not shown) did not differ significantly at any of the four field assessments.

Table 4. Percentage survival of species in the trial at Tuy Phong 6, 10, 26 and 41 months after field planting. Best survivals shown in bold.

Species	Seedlot	6	10	26	41
		Time after planting (months)			
Acacia auriculiformis	17966	88.9	83.9	51.4	25.7
A. colei	14660	89.8	87.8	69.7	50.6
A. cowleana	18169	89.9	87.5	87.5	76.1
A. difficilis	16170	85.5	80.8	64.9	59.6
A. elachantha	14634	74.0	71.7	52.8	21.6
A. holosericea	16179	88.3	89.0	86.7	70.7
A. leptocarpa	15478	86.9	82.9	65.8	47.9
A. longispicata	17262	77.6	74.9	40.4	18.9
A. neurocarpa	18170	**94.5**	**93.0**	81.3	45.5
A. torulosa	17490	91.0	90.5	**88.5**	**84.0**
A. tumida	17500	85.1	85.1	77.2	68.3
Cassia siamea	—	92.0	86.0	42.5	22.5
s.e.d. means[1]				11.3	12.8
F-probability[2]		n.s.	n.s.	***	***

[1] s.e.d. means = standard error of the difference of means
[2] n.s. = not significant, *** = P < 0.001

Considering height and diameter growth (Table 5), the main effects of the inoculation treatment and the inoculum × species interaction effect were not significant, except for diameter at ground level at age 6 months, for which the inoculation main effect was just significant at the 5% level with a positive response to inoculation. The inoculation treatments are therefore not shown in Table 5. Heights and stem diameters of the species differed significantly at every field assessment (Table 5). *Acacia difficilis*, *A. tumida* and *A. torulosa* were clearly the fastest-growing species, and *Cassia siamea* the slowest. By age 41 months, *A. difficilis* had attained a mean height of 5.61 m and a mean diameter at breast height of the largest stem of 6.52 cm.

Consideration of survival, growth in height and diameter and development of foliage showed clearly that the best species were *A. tumida* (Kununurra provenance), *A. difficilis* and *A. torulosa*. *A. holosericea* had reasonable height and diameter growth but by age 41 months had very light crowns and appeared to have stopped growing.

Discussion

Poor initial stocking of some of the *A. difficilis* and *A. tumida* plots would have favoured faster diameter growth in the third and fourth years once canopy

Table 5. Height and diameter growth of species in the trial at Tuy Phong 6, 10, 26 and 41 months after field planting. DGL = diameter at ground level, DBH = diameter at breast height of largest stem. Best growth performance for each variate shown in bold.

Species	Seedlot	6 months height (m)	6 months DGL (cm)	10 months height (m)	10 months DGL (cm)	26 months height (m)	26 months DGL (cm)	41 months height (m)	41 months DBH (cm)
Acacia auriculiformis	17966	0.87	1.26	1.25	1.82	2.37	4.27	2.72	2.97
A. colei	14660	0.75	1.21	1.14	1.66	2.68	3.59	3.05	2.61
A. cowleana	18169	0.59	1.07	1.00	1.51	2.29	3.68	2.58	1.71
A. difficilis	16170	0.83	**1.28**	1.35	**2.31**	**4.69**	**7.17**	**5.61**	**6.52**
A. elachantha	14636	0.92	1.10	1.49	1.44	3.14	3.22	3.12	2.32
A. holosericea	16179	0.86	1.24	1.39	1.80	3.06	4.09	3.17	2.85
A. leptocarpa	15478	**1.15**	1.07	**1.59**	1.76	3.33	4.59	3.14	3.60
A. longispicata	17262	0.72	0.88	1.45	1.59	3.95	4.38	4.50	4.46
A. neurocarpa	18170	0.76	1.17	1.26	1.62	2.78	3.67	2.97	2.37
A. torulosa	17490	0.91	0.95	1.52	1.71	3.40	4.96	3.58	3.90
A. tumida	17500	0.73	1.18	1.26	2.05	4.17	5.99	4.59	5.14
Cassia siamea	—	0.46	0.82	0.62	1.25	0.85	2.38	0.95	0.97
s.e.d. means[1]		0.07	0.10	0.11	0.22	0.26	0.46	0.30	0.45
F-probability[2]		***	***	***	**	***	***	***	***

[1] s.e.d. means = standard error of the difference of means
[2] n.s. = not significant, ** = 0.001 < P < 0.01, *** = P < 0.001

closure and competition had set in for these species. Also, from age 2 to 3 years the faster-growing species overgrew the borders of adjacent plots of poorly performing species. These factors would lead to diameter growth being somewhat overestimated. Nevertheless, the Tuy Phong trial was very effective in ranking *Acacia* species for their performance on white sands under semi-arid conditions. *A. auriculiformis*, a species widely planted on red and white sands in Binh Thuan province, performed very poorly in the trial. *Casuarina equisetifolia*, planted in an international provenance trial adjacent to the *Acacia* species trial at the same time, had provenance survival levels at 24 months after planting ranging from 8 to 74%, with most provenances below 50% (Phi Quang Dien et al. 1996). Two-year heights of *C. equisetifolia* averaged 1.7 m, the best provenance attaining a height of 2.3 m, much smaller than the mean height of 4.7 m for *A. difficilis* at age 26 months.

The trial results suggest that successful plantations for fuelwood (and perhaps pulpwood) production, dune stabilisation and site amelioration could be established under semi-arid conditions on the white sands by planting *A. difficilis*, *A. tumida* and *A. torulosa*. Some provenances of all three species attain small tree stature and form in the wild, whereas *A. difficilis* and *A. torulosa* displayed multi-stemmed shrub form at Tuy Phong. Maslin and McDonald (1996) record maximum heights of 12, 15 and 15 m respectively for *A. difficilis*, *A. tumida* and *A. torulosa* in their natural environments in north and northwestern Australia. Observations made of the two provenances of *A. tumida* grown at Tuy Phong showed that provenance 17500 (Kununurra) had tree form and large phyllodes whereas provenance 17964 (Port Hedland) planted adjacent to the trial was slower growing, multi-stemmed from ground level and had smaller phyllodes. Substantial provenance variation may also be anticipated for *A. difficilis* and *A. torulosa* given their extensive natural distributions (Doran and Turnbull 1997).

Inoculation with selected strains of *Bradyrhizobium* resulted in a clear improvement in nursery growth for some of the *Acacia* species (Phi Quang Dien et al. 1996). Nodules were detected on the sampled inoculated seedlings of all *Acacia* species except *A. difficilis*, *A. leptocarpa* and *A. longispicata*, but only *A. holosericea* had nodules on non-inoculated seedlings. Inoculated seedlings of *A. auriculiformis*, *A. holosericea*, *A. neurocarpa* and *A. torulosa* were all more than 50% taller than their respective controls just prior to field planting. The dry weight of 10 representative inoculated seedlings was over 100% greater than that of 10 seedlings from the respective non-inoculated controls for *A. cowleana*, *A. holosericea*, *A. leptocarpa*, *A. longispicata*, *A. neurocarpa* and *A. tumida*. Surprisingly, the better growth of inoculated seedlings was not maintained in the field trial. This is in contrast to a similar trial on a vertisol in Timor, Indonesia, in which positive effects of nursery inoculation with *Bradyrhizobium* strains on the growth of *A. colei*, *A. holosericea* and *A. neurocarpa* were still highly significant after two years of field growth (Setiadi et al. 1998). Shortfalls in field planting stock for some species, particularly *A. difficilis* and *A. tumida*, reduced the precision of statistical comparison of inoculated versus non-inoculated treatments in the field trial at Tuy Phong. *Bradyrhizobium* nodules were found on surface roots of seedlings of all *Acacia* species in both inoculated and non-inoculated sub-plots of the field trial at the start of the rainy season, 10 months after planting. *Acacia difficilis*, *A. tumida* and *A. torulosa* seedlings appeared to respond positively to *Bradyrhizobium* inoculation in the nursery, so further inoculation trials to improve nursery, and possibly field, performance would be warranted if these species are to be widely planted in Vietnam.

The very low fertility levels of the white sands and their poor capacity to hold water and nutrients (because of the low proportion of small, adsorptive soil particles, Table 2) are limiting factors to plantation production. Judicious application of fertilisers will be required for good long-term growth. The key to improving site productivity is to increase the organic matter content of the soil. Provenance trials of *A. difficilis* and *A. tumida* using large plot sizes and incorporating different fertiliser regimes were established in 1997 on red and white sands near Tuy Phong. Soil changes during stand development will be studied in these trials.

Acknowledgments

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References

Doran, J.C. and Turnbull, J.W., ed., 1997. Australian Trees and Shrubs: Species for Land Rehabilitation and Farm Planting in the Tropics. ACIAR Monograph No. 24. Australian Centre for International Agricultural Research, Canberra.

Gutteridge, R.C. 1997. *Senna siamea* (Lamk) Irwin & Barneby. In: Faridah Hanum, I. and van der Maesen, L.J.G., ed., Plant Resources of South-East Asia No. 11. Auxiliary Plants. Backhuys Publishers, Leiden, 232–236.

Hoang Xuan Ty 1996. Relationship between the properties of coastal sandy soils and planting potential of *Casuarina equisetifolia* in Vietnam. In: Pinyopusarerk, K., Turnbull, J.W. and Midgley, S.J., ed., Recent Casuarina Research and Development. CSIRO Forestry and Forest Products, Canberra, 214–217.

Maslin, B.R. and McDonald, M.W. 1996. A Key to Useful Australian Acacias for the Seasonally Dry Tropics. CSIRO Forestry and Forest Products, Canberra 80 p.

Nguyen Hoang Nghia 1996. Climatic requirements of some of the main tree plantation species in Vietnam. In: Booth, T.H., ed., Matching Trees and Sites. ACIAR Proceedings No. 63, Australian Centre for International Agricultural Research, Canberra, 43-49.

Nguyen Xuan Quat 1996. Planting *Casuarina equisetifolia* in Vietnam. In: Pinyopusarerk, K., Turnbull, J.W. and Midgley, S.J., ed., Recent Casuarina Research and Development. CSIRO Forestry and Forest Products, Canberra, 175–179.

Phi Quang Dien, Le Dinh Kha, Harwood, C.E. and Gibson, A. 1996. Effect of rhizobia on seedlings of dry zone *Acacia* species at Tuy Phong nursery (Bin Thuan Province) in Vietnam. In: Yapa, A.C., ed., Proceedings of the International Symposium on Recent Advances in Tropical Tree Seed Technology and Planting Stock Production. ASEAN Forest Tree Seed Centre, Muak-Lek, Saraburi, Thailand, 191–193.

Setiadi, D., McKinnell, F.H., Harwood, C.E. and Dart, P. 1998. Survival and growth of Australian *Acacia* species and their response to rhizobium inoculation in field trials on two contrasting soil types in Nusa Tenggara Timur, Indonesia. Community, Farm and Forest Tree Research Reports (Vol 2, in press).

Thomson, L.A.J., Turnbull, J.W. and Maslin, B.R. 1994. The utilisation of Australian species of *Acacia*, with particular reference to those of the subtropical dry zone. Journal of Arid Environments, 27, 279–295.

Truong Trong Quan 1984. Climatic features of Thuan Hai Province. Scientific and Technological Committee and Meteorological Station of Thuan Hai, Vietnam. 108 p.

Turnbull, J.W. ed. 1991. Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra.

Williams, E.R. and Matheson, A.C. 1994. Experimental Design and Analysis for Use in Tree Improvement. CSIRO and ACIAR, Melbourne, 174 p.

Temperate Australian *Acacia* Species Elimination Trials in Southern China

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Abstract

This paper present preliminary results from three acacia species/provenance elimination trials planted in two provinces in southern China in 1994. These trials aimed to identify the most productive woody legumes for soil amelioration and wood production in the cool subtropics of southern China on low fertility soils subject to limiting cold temperatures. At 30 months of age, provenances of eight species (*Acacia filicifolia, A. glaucocarpa, A. implexa, A. leucoclada, A. mearnsii, A. melanoxylon, A. parramattensis* and *A. parvipinnula*) performed well in terms of survival, volume and form.

THE need for nitrogen-fixing, broad-leaved tree species has become increasingly important in southern China to overcome the acidification and decreasing productivity of soils that has occurred under several rotations of Chinese fir and exotic pines. More than 80% of forested land in southern China is located in mountainous regions characterised by poor, acid soils. These mountainous areas have been estimated to cover 105 000 km^2 (Chou et al. 1991). Species that grow well on such soils are also needed to meet large domestic demands for pulpwood, fibre board and plywood.

Acacias, most of which are endemic to Australia, are adapted to a wide range of tropical and temperate environments, and this adaptability has made them popular for planting on degraded lands in Asia and elsewhere (Turnbull these Proceedings). In China there are five indigenous *Acacia* species but these are not economically important. To identify more productive *Acacia* species for China, the Australian Centre for International Agriculture Research (ACIAR) has funded research since 1985. This has resulted in the introduction of more than 105 *Acacia* species in trials across southern China (Wang and Fang 1991). Selection of superior species/provenances, especially among the tropical acacias in these field trials, has played an important role in China's economy. The total area of acacia plantations is now estimated to be more than 200 000 ha, with about 20 000 ha of *A. mangium, A. auriculiformis* and *A. crassicarpa* planted each year (Wang et al. 1994).

The most recent *Acacia* collaborative research project between the Chinese Academy of Forestry and Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) is ACIAR Project FST/92/27, Australian acacias for sustainable development in China, Vietnam and Australia. This research involved the planting of the same acacia species and provenances in species elimination trials in Australia (Searle et al. these Proceedings), Vietnam (Thinh et al. these Proceedings) as well as China. In China, trials were planted at three sites in Guangdong and Jiangxi provinces to determine the potential of temperate Australian species/provenances in terms of survival, growth and tree form for mountainous areas of tropical and subtropical China. These sites were selected to represent a range of climates and soils in southeastern China.

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This paper presents the nursery performance of three-month seedlings grown in the nursery of the Research Institute of Tropical Forestry, Guangzhou, and records the average survival, height, diameter, volume and stem number of 64 acacia seedlots at 30 months of age at each of the three sites.

Materials and Methods

Twenty-eight species represented by 64 provenances (Table 1) were planted in 1994 at each of three sites: Longdong forest farm (Guangzhou, Guangdong), Yangdong forest farm (Shixing county, Guangdong) and Ganzhou (Jiangxi). The location of these is shown on Figure 1 and the details of each site are given in Table 2.

The field trials, in common with two identical trials established in Australia (Searle et al. these Proceedings), were arranged in a square lattice (8 × 8) with four replications. The 10-tree plots were arranged in two rows of five trees (2.5 m spacing between trees within rows and 3.0 m between rows). The trials were surrounded by two rows of buffer trees to minimise the impact of edge effects upon the trees in the trial; the outer row was a species/ provenance that was expected to grow well.

At each trial site, local nurseries were used to grow the seedlings for trial. Seed was pretreated with boiling water and sown into sand beds. About 20 days later, the seedlings were transplanted into plastic bags (8 × 12 cm) filled with 15% burned earth, 80% yellow deep soil and 5% sand. These

Table 1. General characteristics of three Acacia trial sites in southeastern China.

General site description	Trial site		
	1. Longdong forest farm, Guangzhou (Guangdong)	2. Yangdong forest farm, Shixing County, (Guangdong)	3. Forestry Research Institute of Ganzhou, (Jiangxi)
Latitude (°N)	23°14′	24°59′	25°50′
Longitude (°E)	113°24′	114°02′	115°01′
Altitude (m)	350	250	200
Mean annual temperature (°C)	21.8	19.7	18.9
Mean annual rainfall (mm)	1694	1640	1569
Maximum monthly mean temperature (°C)	28.1	28.7	27.2
Minimum monthly mean temperature (°C)	13.3	9.0	8.1
Maximum temperature (°C)	38.1	41.2	38.4
Minimum temperature (°C)	0	–5.0	–7.5
Soil description	Yellow/red soil derived from granite and sandstone pH 4.5	Red soil derived from granite pH 4.3	Red soil pH 3.8.

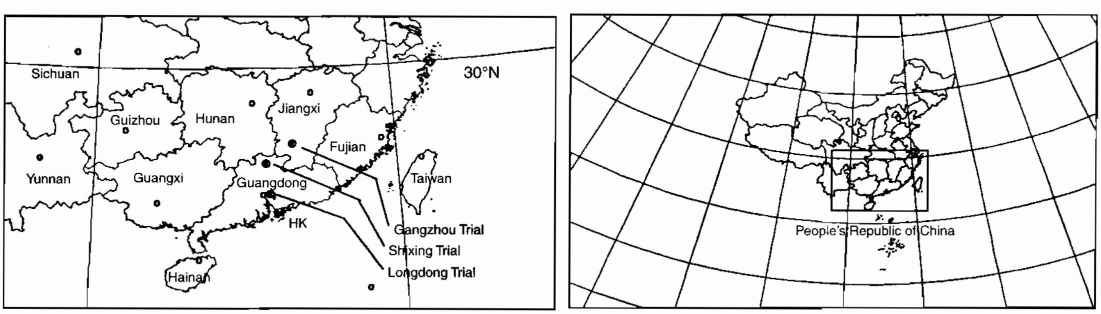

Figure 1. Location of the three trial sites.

Table 2. Temperate acacia trials planted in 1994 at three sites in southeastern China.

Treat. No.	*Acacia* species	Seedlot	Location	Latitude (°'S)	Longitude (°'E)	Altitude (m asl)
2	*binervata*	17260	1.5 km from Springbrook Qld	28 12	153 16	500
3	*binervata*	16245	7 km W of Kiama NSW	34 40	150 43	240
4	*binervia*	15845	Richmond-Springwood NSW	33 38	150 40	15
1	*blayana*	18068	Brogo NSW	36 29	149 40	500
5	*chrysotricha*	18620	Newry State Forest NSW	30 32	152 55	50
6	*dangarensis*	18608	Mt Dangar NSW	32 20	150 28	600
7	*dealbata* ssp. *dealbata*	16269	26 km S of Cooma NSW	36 28	149 07	910
8	*dealbata* ssp. *dealbata*	16376	2218 km WNW Bemboka NSW	36 37	149 26	1035
9	*dealbata* ssp. *dealbata*	16271	Errinundera Plateau Vic	37 11	148 52	960
10	*dealbata* ssp. *dealbata*	16384	18.6 km S Orford Tas	42 41	147 52	120
11	*dealbata* ssp. *dealbata*	18024	Captains Flat NSW	35 37	149 26	700
12	*deanei*	15470	Goondiwindi NSW	28 49	150 43	260
13	*deanei*	18063	Dawson Qld	25 31	150 14	350
14	*decurrens*	14726	SW of Goulburn	34 53	149 17	685
15	*decurrens*	15847	PictonMittagong NSW	34 17	150 35	380
16	*elata*	18243	Mount Boss State Forest NSW	31 14	152 22	800
17	*elata*	18251	Gloucester Tops NSW	32 05	151 38	1000
18	*elata*	18252	Mt Wilson NSW	33 30	150 21	650
19	*falciformis*	15502	S of Warwick Qld	28 32	151 58	900
20	*falciformis*	17740	S Gladstone Qld	23 53	151 16	50
43	*falciformis*	16253	11 km WNW of Narooma NSW	36 11	150 01	150
21	*filicifolia*	15841	19 km SW of Singleton NSW	32 41	151 01	150
22	*filicifolia*	17893	Yadboro Flat NSW	35 19	150 14	60
23	*fulva*	15843	Howes Valley NSW	32 52	150 52	240
24	*glaucocarpa*	15473	Ca 20 km NW Gayndah Qld	25 32	151 29	390
25	*glaucocarpa*	18065	Cadarga Qld	26 07	150 55	350
26	*implexa*	18019	Pyalong Vic	37 08	144 53	200
27	*implexa*	18611	Sofala NSW	33 11	149 41	850
28	*implexa*	15832	Swansea NSW	33 05	151 37	10
29	*irrorata*	15840	Craven-Stroud NSW	32 10	151 57	110
30	*irrorata*	18619	Bodalla NSW	36 08	150 02	20
31	*irrorata*	18626	Gloucester NSW	31 59	151 47	650
32	*irrorata* ssp. *velutinella*	18623	Congarinni State Forest NSW	30 41	152 53	60
33	*irrorata* ssp. *velutinella*	18622	Newry State Forest NSW	30 31	152 59	10
34	*leucoclada* ssp. *leucoclada*	18621	Inverell NSW	29 44	150 57	700
35	*leucoclada* ssp. *argentifolia*	18067	Dalveen Warwick Rd Qld	28 23	151 55	750
36	*mearnsii*	15329	Apsley River Bridge Tas.	41 56	148 14	10
37	*mearnsii*	16246	10 km S of Nowra NSW	34 59	150 36	10
38	*mearnsii*	16621	Tuross R, SW Bodalla NSW	36 11	149 58	15
39	*mearnsii*	17928	Tarpeena SA	37 36	140 58	70
40	*mearnsii*	17933	Wattle Circle Omeo Hwy Vic	37 27	147 50	200
41	*mearnsii*	17937	Cooma NSW	36 14	149 05	1000
42	*mearnsii*	18607	Berrima NSW	34 30	150 20	750
CK	*mearnsii*		Land race – Yunnan Province, China			
45	*melanoxylon*	18021	Lancefield Vic	37 14	144 46	500
46	*melanoxylon*	17230	Arthurs Ck Rd Yanyean Vic	37 34	145 08	214
47	*melanoxylon*	16526	25 km SE Mount Gambier SA	37 57	141 56	40
48	*melanoxylon*	16358	Bli Bli Qld	26 37	153 02	95
49	*melanoxylon*	15863	Blackwood Park Lileah Tas	40 57	145 10	250
50	*melanoxylon*	17263	Mt Mee-Sellins Rd Qld	27 06	152 44	500
51	*nano-dealbata*	17195	Mt Macedon Vic	37 22	144 35	900
52	*nano-dealbata*	17940	Lavers Hill Vic	38 45	143 15	200
44	*obliquinervia*	16273	13 km WNW of Bemboka NSW	36 36	149 25	960
53	*obliquinervia*	16875	15 km SE Yarrangobilly NSW	35 45	148 31	1000
54	*obliquinervia*	18070	Ruoaks Rd, Blue Range Vic	37 26	145 50	1200
55	*parramattensis*	17711	Tarago NSW	35 10	149 35	740
56	*parramattensis*	17925	Numeralla NSW	36 11	149 18	900
57	*parramattensis*	18610	N Windsor NSW	33 08	150 41	400
58	*parvipinnula*	15842	Howes Valley NSW	32 52	150 52	240
59	*parvipinnula*	15844	Colo Heights-Putty NSW	33 14	150 39	360
60	*silvestris*	15852	Deua River, Deua N. Park NSW	35 58	149 45	350
61	*silvestris*	16254	11 km WNW of Narooma NSW	36 11	150 01	130
62	*silvestris*	17939	Bruthen Vic	37 35	147 54	200
63	*trachyphloia*	14229	Monga State Forest NSW	35 36	149 55	710
64	*trachyphloia*	17894	Currowan Creek NSW	35 35	150 03	100

were fertilised with a general-purpose fertiliser once to twice a week and covered with plastic sheeting when temperatures were low. At the trial sites all existing vegetation was cut down and burnt before planting holes (5 × 4 × 30 cm) were dug for each tree, Fertiliser (100 g general-purpose fertiliser and 50 g of phosphate) was placed in each hole prior to planting. This occurred in April or May 1994 (depending on the site) and the seedlings were, on average, 20–25 cm in height. Weed control and fertilising were carried out once in both the first and second year at each site.

The performance and characteristics of seedlings at three months of age, just prior to planting at the Longdong trial site, was assessed in the nursery at the Research Institute of Tropical Forestry (RITF) located at Longdong. Percentage germination (G %), height (H), diameter at base (D) and the number of prostrate (< 45° above the soil surface) stems (B) were assessed for all seedlings in the nursery. The length of main root (LR), rootlet number (NR), presence of root nodules (R), and dried weight above (W_a) and under the ground (W_u) were recorded for six seedlings from each seedlot. Ratios (H/D and W_a/W_u) were calculated to rank the seedling growth in terms of vigour. In China, forestry seedling height/diameter ratios of < 120 are regarded as desirable, particularly if the seedlings are to be planted in the mountains. Similarly, the smaller the root to shoot ratio (W_a/W_u), the better the seedling growth in the field.

At 30 months of age, each tree in the three field trials was assessed for survival, height (H), diameter at breast height (DBH) and form, in terms of number of stems (F). For each tree, the tallest stem only was measured for height, and diameter at breast height was measured for the largest stem(s). Branches were assessed as stems if their diameter at major forks was ≥ 50% of the diameter of the largest stem. The volume (V) of each individual tree was calculated as follows:

$$V\ (dm^3) = \pi \times DBH^2 \times H \times 0.00833.$$

Results and Discussion

There were large differences in seedling performance at 3 months of age between seedlots raised in the RITF nursery at Longdong (Table 3):

Table 3. Seedling performance (mean and stan dard deviation) at three months of age in the RITF nursery at Longdong, Guangzhou. These are ranked in order of descending height.

Treat No.	*Acacia* species	Seedlot	G (%)	H (cm)	D (mm)	B	Wa (g)	L (cm)	N	R	Wu (g)	H/D	Wa/Wu
14	*decurrens*	14726	78.6	47.0±2.7	3.1±0.4	0.3	1.3±0.48	12.3±0.5	5.3±0.4	0	0.23±0.05	151.6±17.9	5.8±1.1
39	*mearnsii*	17928	76.5	42.3±2.9	2.9±0.1	0	1.6±0.27	19.1±3.3	9.0±2.2	1	0.31±0.09	145.9±10.0	5.2±1.6
29	*irrorata*	15840	74.6	41.8±4.7	2.8±0.2	1.5	1.2±0.25	14.0±1.2	12.0±3.6	1	0.23±0.07	149.3±15.9	5.1±2.8
42	*mearnsii*	18607	77.8	39.0±3.4	2.1±0.5	0.8	1.5±0.56	16.5±0.9	7.7±1.1	1	0.23±0.08	185.7±30.6	6.5±3.2
61	*silvestris*	16254	64.8	38. 9±2.7	2.5±0.3	0	1.1±0.39	11.1±1.4	5.5±1.1	0	0.14±0.05	155.6±14.6	7.6±1.4
16	*elata*	18243	93.4	38.5±3.4	2.4±0.4	2.5	1.6±1.00	10.4±1.0	5.8±1.1	0	0.29±0.16	160.4±20.9	5.5±3.9
40	*mearnsii*	17933	74.6	37.4±2.1	2.3±0.3	1	0.8±0.19	14.6±3.0	7.5±2.2	1	0.17±0.08	162.6±26.4	5.0±3.4
13	*deanei*	18063	76.4	36.1±5.7	1.9±0.2	0	0.4±0.22	13.9±1.4	8.5±1.5	0	0.11±0.04	190.0±19.9	3.6±0.6
26	*implexa*	18019	85.7	35.6±2.0	2.4±0.2	0	0.8±0.25	12.2±1.5	5.0±1.2	0	0.11±0.03	148.3±14.8	6.9±1.7
15	*decurrens*	15847	75.4	33.0±3.6	2.1±0.3	1	0.7±0.25	11.9±0.5	8.5±0.5	0	0.16±0.03	157.1±13.4	4.2±1.8
57	*parramattensis*	18610	71.3	32.8±2.6	2.6±0.2	0.8	1.1±0.41	12.6±1.6	10.0±1.4	0	0.23±0.02	126.2±14.9	4.7±2.3
37	*mearnsii*	16246	78.6	32.3±3.7	2.5±0.5	0	0.7±0.24	17.4±5.2	14.1±5.4	0	0.16±0.06	129.2±21.4	4.6±1.5
27	*implexa*	18611	86.9	32.0±4.1	2.5±0.2	0	0.7±0.26	15.4±1.3	9.0±3.2	1	0.16±0.06	128.0±13.9	4.2±2.4
20	*falciformis*	17740	74.8	32.0±2.2	2.3±0.2	0	0.8±0.09	13.0±1.4	6.3±0.8	0	0.14±0.03	139.1±18.1	5.6±1.2
22	*filicifolia*	17893	74.6	31.8±2.2	2.2±0.2	0	0.5±0.05	16.1±1.8	7.0±1.9	1	0.32±0.09	144.5±16.8	1.7±0.8
63	*trachyphloia*	14229	78.5	31.6±2.8	2.3±0.3	0	0.7±0.21	13.0±0.8	8.7±1.6	0	0.39±0.21	137.4±5.9	1.8±0.8
50	*melanoxylon*	17263	95.8	29.5±3.8	2.3±0.2	0	0.6±0.28	13.1±1.0	8.0±1.0	1	0.19±0.04	128.3±6.2	3.2±1.0
38	*mearnsii*	16621	77.3	29.1±5.2	2.4±0.3	0	0.9±0.26	15.5±1.1	8.0±0.7	1	0.2±0.04	121.3±29.3	4.4±1.2
56	*parramattensis*	17925	69.8	28.9±1.9	2.6±0.2	0	0.8±0.26	14.2±1.8	5.5±0.9	1	0.15±0.03	111.2±1.7	5.1±2.0
64	*trachyphloia*	17894	74.9	28.8±3.8	2.0±0.3	0.8	0.6±0.21	11.2±0.8	7.2±0.8	0	0.11±0.07	143.8±9.0	5.4±1.8
23	*fulva*	15843	36.7	28.5±2.0	2.0±0.2	0	0.5±0.03	13.8±1.4	6.2±1.2	1	0.27±0.06	142.5±15.4	1.7±0.8
21	*filicifolia*	15841	78.4	28.4±3.2	1.9±0.2	0	0.6±0.16	12.8±1.1	10.0±2.1	0	0.11±0.04	149.5±14.4	5.4±1.5
31	*irrorata*	18626	75.6	28.0±2.2	1.9±0.2	0	0.5±0.13	13.9±1.7	7.2±0.4	0	0.10±0.02	147.4±13.9	4.6±1.8
18	*elata*	18252	91.5	27.6±3.1	2.5±0.3	0	1.1±0.40	15.4±1.8	10.0±1.6	1	0.39±0.34	110.4±16.4	2.8±1.6
10	*dealbata*	16384	30.5	27.6±2.3	2.0±0.1	0.3	0.4±0.11	15.9±2.0	11.3±2.2	1	0.13±0.02	138.0±11.4	2.9±1.0
2	*binervata*	17260	73.5	27.5±1.1	2.3±0.2	0	0.7±0.24	13.3±2.0	13.3±2.2	0	0.11±0.02	119.6±11.1	6.6±0.2
33	*irrorata* ssp. *velutinella*	18622	68.9	27.4±3.4	2.4±0.4	0	0.7±0.29	11.0±1.1	9.5±2.1	1	0.13±0.05	114.2±9.4	5.2±2.0
49	*melanoxylon*	15863	80.4	26.6±1.6	2.5±0.3	0.3	0.5±0.22	14.7±1.0	8.7±3.0	1	0.23±0.08	106.4±5.6	2.1±0.7
59	*parvipinnula*	15844	72.9	26.4±2.8	2.0±0.2	1.2	0.8±0.16	12.8±1.9	9.0±1.6	1	0.12±0.03	132.0±11.2	6.2±2.0

Table 3. (continued)

Treat No.	*Acacia* species	Seedlot	G (%)	H (cm)	D (mm)	B	Wa (g)	L (cm)	N	R	Wu (g)	H/D	Wa/Wu
60	*silvestris*	15852	68.7	25.9±1.6	1.9±0.4	0.3	0.7±0.23	12.5±1.6	5.8±0.8	1	0.13±0.04	136.3±26.5	5.2±4.0
44	*obliquinervia*	16273	75.1	25.8±1.9	2.3±0.1	0	0.6±0.16	15.6±1.7	7.5±2.1	1	0.15±0.03	112.2±6.9	4.3±2.0
8	*dealbata*	16376	65.4	25.6±3.5	2.1±0.3	0	0.8±0.28	15.6±2.4	16.2±3.5	1	0.32±0.12	121.9±19.0	2.3±1.4
30	*irrorata*	18619	77.5	25.4±2.9	2.5±0.1	1	0.9±0.10	12.2±0.8	13.5±1.5	1	0.17±0.03	101.6±7.6	5.4±1.1
7	*dealbata*	16269	64.1	25.4±1.9	2.3±0.1	0	0.4±0.07	13.5±0.7	8.5±1.7	1	0.12±0.02	110.4±7.6	3.7±0.6
4	*binervia*	15845	72.1	23.9±6.3	2.1±0.5	1	0.7±0.37	14.3±3.3	5.5±3.9	0	0.14±0.04	113.8±28.3	5.0±1.4
11	*dealbata*	18024	55.6	23.4±2.6	2.1±0.2	0	0.5±0.24	14.0±2.2	9.5±1.8	1	0.14±0.5	111.4±10.7	3.5±1.5
28	*implexa*	15832	88.1	23.3±2.7	2.3±0.5	0.8	0.6±0.17	11.9±0.6	7.7±0.4	1	0.18±0.09	101.3±23.2	3.6±2.1
9	*dealbata*	16271	61.2	23.3±3.2	2.3±0.4	0	0.7±0.25	15.0±2.3	14.8±2.9	1	0.30±0.12	101.3±19.1	2.3±1.6
12	*deanei*	15470	78.5	22.6±1.6	1.9±0.2	0	0.4±0.08	13.8±1.0	4.5±1.5	1	0.09±0.22	118.9±12.4	4.3±1.0
1	*blayana*	18068	68.5	22.0±3.5	2.1±0.2	1.3	0.5±0.2	16.8±4.6	8.0±1.4	0	0.11±0.03	104.8±8.5	4.4±1.6
43	*falciformis*	16253	74.3	21.6±2.5	2.1±0.5	0	0.6±0.23	17.7±3.3	14.6±3.6	0	0.11±0.05	102.9±17.2	5.7±1.1
46	*melanoxylon*	17230	67.1	17.5±1.9	2.1±0.5	0	0.3±0.15	10.6±1.1	11.7±4.0	1	0.25±0.22	83.3±32.7	1.2±0.9
19	*falciformis*	15502	76.4	21.4±4.3	2.3±0.5	0	0.7±0.43	13.8±0.8	7.0±1.0	1	0.18±0.07	93.0±16.3	3.9±2.1
41	*mearnsii*	17937	79.1	21.1±3.3	2.2±0.6	0	0.7±0.50	14.1±1.4	5.7±1.3	0	0.15±0.05	95.9±14.7	4.8±2.7
3	*binervata*	16245	72.4	21.0±3.6	2.6±0.1	0	0.7±0.20	14.4±3.2	13.3±3.2	1	0.17±0.02	80.8±11.1	4.2±1.2
58	*parvipinnula*	15842	75.6	20.8±1.0	1.9±0.2	0	0.5±0.09	16.7±6.5	11.0±1.6	1	0.73±0.01	109.5±13.7	0.7±0.3
55	*parramattensis*	17711	70.4	20.5±2.4	1.8±0.3	0	0.4±0.15	16.1±4.3	10.7±1.1	1	0.12±0.04	113.9±14.7	3.2±0.8
17	*elata*	18251	92.6	20.0±1.1	2.1±0.4	0.5	0.6±0.17	10.5±0.8	6.8±1.6	0	0.14±0.03	95.2±18.4	4.1±1.6
CK	*mearnsii*	Yunnan	78.7	19.4±1.7	2.0±0.2	0	0.5±0.12	17.1±0.7	6.0±0.7	1	0.15±0.04	97.0±19.9	3.5±1.8
5	*chrysotricha*	18620	65.7	18.8±3.4	1.8±0.1	0.5	0.4±0.04	12.3±1.0	10.0±2.7	1	0.09±0.02	104.4±17.8	4.3±2.0
35	*leucoclada* ssp. *argentifolia*	18067	77.6	17.8±1.0	1.7±0.1	0	0.4±0.13	13.9±1.4	4.2±1.5	0	0.10±0.02	104.7±3.3.0	3.7±0.7
45	*melanoxylon*	18021	87.3	21.6±1.6	1.9±0.1	0	0.3±0.07	11.2± 0.4	8.5±1.7	1	0.17±0.05	120.0±12.9	3.1±2.0
36	*mearnsii*	15329	76.3	17.4±0.8	1.9±0.1	0.3	0.4±0.12	13.0±0.6	9.5±0.8	1	0.1±0.02	91.6±4.4	4.0±0.7
25	*glaucocarpa*	18065	43.5	16.8±2.4	2.3±0.4	0.8	0.7±0.46	16.5±2.6	4.2±0.4	0	0.12±0.05	73.0±8.4	6.2±4.8
6	*dangarensis*	18608	21.8	16.3±2.1	1.3±0.3	0	0.4±0.03	13.2±1.3	13.0±1.7	0	0.10±0.02	125.4±21.4	3.7±0.5
47	*melanoxylon*	16526	84.5	16.1±3.6	1.9±0.3	0.3	0.2±0.05	13.5±1.4	5.2±1.6	1	0.16±0.03	84.7±25.2	1.4±0.3
52	*nano-dealbata*	17940	35.7	14.6±0.8	1.7±0.4	0.5	0.3±0.14	13.7±1.2	11.2±3.1	1	0.13±0.07	84.4±24.9	2.0±0.9
24	*glaucocarpa*	15473	20.1	14.5±2.0	2.0±0.4	0.6	0.6±0.38	14.3±3.0	4.0±0.9	0	0.11±0.03	72.5±10.3	5.9±1.1
62	*silvestris*	17939	73.1	13.6±1.5	1.6±0.1	1	0.2±0.04	16.8±3.2	10.0±2.4	0	0.08±0.02	85.0±12.1	2.8±1.8
54	*obliquinervia*	18070	28.7	13.5±2.1	1.4±0.2	0.4	0.2±0.08	9.4±1.2	5.6±0.8	0	0.08±0.02	96.4±11.5	2.0±1.0
32	*irrorata* ssp. *velutinella*	18623	71.2	13.3±2.6	1.8±0.2	0	0.4±0.11	12.5±1.7	9.0±1.7	0	0.1±0.03	73.9±25.4	3.6±1.0
48	*melanoxylon*	16358	86.5	13.1±2.2	1.8±0.1	0	0.3±0.09	14.1±1.7	7.2±0.8	1	0.15±0.04	72.8±9.50	1.9±0.5
53	*obliquinervia*	16875	10.6	11.2±1.6	1.2±0.1	0.5	0.1±0.07	8.7±1.2	5.4±0.8	0	0.07±0.02	93.3±10.1	1.7±0.5
34	*leucoclada*	18621	70.3	8.0±1.5	1.2±0.2	0	0.2±0.12	4.2±0.9	3.8±0.9	0	0.09±0.02	66.7±11.2	2.8±0.9
51	*nano-dealbata*	17195	18.1	7.9±1.4	1.6±0.2	0.2	0.2±0.10	8.7±1.1	6.5±1.2	1	0.10±0.01	49.4±8.6	2.0±0.7

Notes:
G = germination of seed (%), H seedling height (cm), D = diameter (mm) of seedling at base, B = number of prostrate stems, Wa = dry weight of seedling above the ground (g), Wu = dry weight of seedling under ground (g), L = length (cm) of main root, NR = number of rootlets and R = rhizobia produced (1 means present, 0 means absent) respectively.

- Most species, such as *A. melanoxylon*, *A. implexa* and *A. elata*, germinated well with germination greater than 80%. The highest germination (95%) was recorded for *A. melanoxylon* (17263). Seven seedlots (*A. nano-dealbata* 17195, *A. dealbata* 16384, *A. fulva* 15843, *A. obliquinervia* 16875, 18070, *A. dangarensis* 18608 and *A. glauococarpa* 15473) showed poor germination (c. 11–37%).
- This wide range of species generally grew well in the nursery, reaching average heights between 8 cm (*A. nano-dealbata* 17195) and 47 cm (*A. decurrens* 14726) at three months of age. Diameters at the base of the seedlings averaged 1.2–3.1 mm at the same age. In descending order of height, *A. decurrens* 14726, *A. mearnsii* 17928, *A. irrorata* 15840, *A. mearnsii* 18607, *A. silvestris* 16254, *A. elata* 18243, *A. mearnsii* 17933, *A. deanei* 18063, *A. implexa* 18019, *A. decurrens* 15847, *A. parramattensis* 18610 and *A. mearnsii* 16246 grew particularly well, reaching c. 32–47 cm in height after 3 months. The slowest seedlots, those that grew less than 10 cm, were *A. leucoclada* (18621 8.0 cm) and *A. nano-dealbata* (17195 7.9 cm).
- Seventeen of the 28 species in trial showed prostrate form in some of their seedlings in the nursery although this characteristic did not persist. Prostrate stems were defined as those that grew on an angle less than 45° above the soil surface and these were recorded for 27 seedlots

which represented the following species: *A. binervia*, *A. blayana*, *A. chrysotricha*, *A. dealbata*, *A. decurrens*, *A. elata*, *A. glaucocarpa*, *A. implexa*, *A. irrorata*, *A. mearnsii*, *A. melanoxylon*, *A. trachyphloia*, *A. nano-dealbata*, *A. obliquinervia*, *A. parramattensis*, *A. parvipinnula* and *A. silvestris*.

- The best height/diameter (H/D) ratios were recorded for *A. nano-dealbata* (17195 49.4), *A. leucoclada* (18621 66.7), *A. melanoxylon* (16358 72.8) and *A. glaucocarpa* (18065 73.0). The survival of these in the Long Dong trial at 30 months was 63, 30, 98 and 65% respectively. (*A. leucoclada* was very small at planting (8.0 cm) and did not compete well with weeds.)
- Seedlots with the smallest and therefore most desirable root to shoot (W_a/W_u), ratios were *A. parvipinnula* (15842 0.68), *A. melanoxylon* (17230 1.16), *A. melanoxylon* (16526 1.44).
- Six species (nine provenances) were easily infected by a wire-stem disease caused by fungus. They were *A. dealbata* (18024, 16376, 16269), *A. dangarensis* 18608, *A. nano-dealbata* 17195, *A. glaucocarpa* 15473, *A. fulva* 15843 and *A. obliquinervia* (16875, 18070).
- Seedlings of 17 species produced root nodules within 3 months of sowing. These were provenances of *A. binervata*, *A. chrysotricha*, *A. dealbata*, *A. deanei*, *A. elata*, *A. falciformis*, *A. filicifolia*, *A. fulva*, *A. implexa*, *A. irrorata* ssp. *irrorata*, *A. irrorata* ssp. *velutinella*, *A. mearnsii*, *A. melanoxylon*, *A. nano-dealbata*, *A. obliquinervia*, *A. parramattensis*, *A. parvipinnula*, *A. silvestris*. Not all provenances of a particular species formed root nodules in the nursery. Provenances of *A. melanoxylon* formed the largest number (>25/seedling) of root nodules and *A. falciformis* (16253) produced the largest nodules (c. 0.5 cm in diameter).
- Twelve species including *A. elata* and *A. falciformis* grew obvious taproots, while four species (*A. melanoxylon*, *A. dealbata*, *A. nano-dealbata* and *A. irrorata*) formed particularly well developed fibrous root systems. Seedlings with the longest main roots (LR) and therefore possibly greater resistance to wind damage and drought were *A. mearnsii* (17928 19.1 cm), *A. falciformis* (16253 17.7 cm), *A. mearnsii* (16246 17.4 cm) and *A. mearnsii* (Yunnan, China 17.1 cm). Those with the largest number of rootlets (NR) were *A. dealbata* (16376 16.2), *A. dealbata* (16271 14.8) *A. falciformis* (16253 14.6) and *A. mearnsii* (16246 14.1).

Results from 30-month field measurement of 64 temperate acacia seedlots planted across three sites are presented in Table 4. The performance in terms of survival, growth and stem number of individual seedlots varied between sites although the overall survival was low: 38% at Ganzhou; 40% at Shixing and 45% at Longdong. The three trials suffered heavy losses within 12 months after planting due to unseasonal humidity in summer at Longdong, uncontrolled weed growth at Shixing and very dry conditions at planting at Ganzhou. Trees grew largest at the Longdong site with an overall average of 3.7 m in height and 3.6 cm dbh. Tree growth was poorest at the Shixing site (average height 2.4 m and dbh 2.1 cm). Species with potential in terms of survival, volume and form at each site were as follows:

Table 4. Performance of temperate acacias at 30 months of age across three trials sites. These are presented in descending order by the average volume across the three sites.

Treat. No.	*Acacia* species	Seedlot	Trial sites															Average across sites		
			Longdong					Shixing					Ganzhou							
			S	H	D	V	F	S	H	D	V	F	S	H	D	V	F	S	V	F
48	*melanoxylon*	16358	97.5	6.3	8.7	12.5	2.3	25	2.6	2.3	0.36	2.1	27.5	1.5	0.5	0.01	2.2	50	4.28	2.20
55	*parramattensis*	17711	43	5.5	6.3	5.71	2.4	60	3.9	4.0	1.63	2.1	25	4.0	4.6	2.21	2.2	43	3.19	2.23
34	*leucoclada*	18621	30	4.3	3.4	1.30	1.0	38	4.1	4.2	1.89	1.0	27.5	5.6	6.3	5.82	1.0	32	3.00	1.00
CK	*mearnsii*	China	47.5	5.5	6.7	6.46	2.3	50	3.7	3.5	1.19	2.0	60	3.8	3.4	1.15	2.1	53	2.93	2.13
37	*mearnsii*	16246	67.5	6.0	6.7	7.04	1.6	47	3.0	2.7	0.57	1.5	50	3.7	3.2	0.99	1.9	55	2.87	1.67
50	*melanoxylon*	17263	100	5.7	6.7	6.69	2.5	62	3.1	3.0	0.73	2.4	90	3.5	2.9	0.77	2.3	84	2.73	2.40
1	*blayana*	18068	23	5.5	7.2	7.46	1.6	—	—	—	—	—	—	—	—	—	—	8.0	2.49	1.60
41	*mearnsii*	17937	42	5.3	5.5	4.19	1.3	80	2.5	2.7	0.48	1.4	42.5	3.9	4.3	1.89	1.6	55	2.19	1.43
57	*parramattensis*	18610	45	5.7	5.7	4.84	2.3	40	3.2	3.0	0.75	2.0	32.5	2.9	2.5	0.47	2.3	39	2.02	2.20
24	*glaucocarpa*	15473	85.7	5.5	5.3	4.04	1.0	80	3.1	3.0	0.73	1.1	36	3.6	3.5	1.15	1.2	67	1.97	1.10
39	*mearnsii*	17928	35	4.5	5.4	3.43	1.7	60	2.9	3.2	0.78	1.7	36	3.4	4.3	1.64	1.8	44	1.95	1.73
26	*implexa*	18019	85	5.2	4.6	2.88	1.0	30	3.7	3.4	1.12	1.0	65	4.5	3.7	1.61	1.0	60	1.87	1.00
42	*mearnsii*	18607	43	5.0	5.0	3.27	2.1	40	2.1	1.9	0.20	1.5	50	4.4	4.2	2.03	1.7	44	1.83	1.77

Table 4. (continued)

Treat. No.	*Acacia* species	Seedlot	Trial sites															Average across sites		
			Longdong					Shixing					Ganzhou							
			S	H	D	V	F	S	H	D	V	F	S	H	D	V	F	S	V	F
40	*mearnsii*	17933	58	5.1	4.8	3.07	1.2	70	2.7	3.0	0.64	1.6	32	4.3	3.6	1.46	1.9	53	1.72	1.57
27	*implexa*	18611	88	5.0	4.0	2.09	1.0	52	4.1	3.5	1.31	1.0	100	4.3	3.6	1.46	1.0	80	1.62	1.00
38	*mearnsii*	16621	45	4.2	4.3	2.03	1.8	75	2.8	3.0	0.66	1.6	60	4.1	4.3	1.98	1.8	60	1.56	1.73
36	*mearnsii*	15329	53	3.7	4.9	2.32	1.6	30	2.2	2.0	0.23	1.8	30	4.0	4.5	2.12	1.8	38	1.56	1.73
22	*filicifolia*	17893	30	4.3	5.5	3.40	1.0	48	2.9	2.7	0.55	1.0	32.5	3.3	2.6	0.58	1.0	37	1.51	1.00
59	*parvipinnula*	15844	67.5	4.0	4.2	1.85	3.3	66	3.5	3.2	0.94	3.2	35	4.4	3.9	1.75	3.5	56	1.51	3.33
14	*decurrens*	14726	32.5	5.0	4.2	2.31	1.8	60	3.7	3.2	0.99	1.7	35	3.3	3.4	1.00	2.2	43	1.43	1.90
44	*obliquinervia*	16273	37.5	4.4	4.3	2.13	3.1	—	—	—	—	—	32.5	4.0	4.5	2.12	3.2	23	1.42	3.20
58	*parvipinnula*	15842	35	4.5	4.2	2.08	3.1	33	4.2	4.0	1.76	3.0	27	3.0	2.2	0.38	3.3	32	1.40	3.13
25	*glaucocarpa*	18065	65	5.2	4.1	2.29	1.0	65	3.3	3.2	0.88	1.2	80	3.6	3.3	1.03	1.3	70	1.40	1.17
33	*irrorata* ssp. *velutinella*	18622	75	4.8	5.3	3.53	1.3	—	—	—	—	—	72.5	2.8	2.4	0.42	1.5	49	1.32	1.40
61	*silvestris*	16254	42.5	4.5	5.0	2.94	1.6	60	2.7	2.4	0.41	1.7	30	2.9	2.2	0.37	2.1	44	1.24	1.80
21	*filicifolia*	15841	35	4.0	3.1	1.01	1.0	35	3.3	3.0	0.78	1.0	60	4.2	4.1	1.85	1.0	43	1.21	1.00
43	*falciformis*	16253	22.5	5.0	4.2	2.31	2.5	50	3.1	2.8	0.64	2.4	40	3.2	2.5	0.52	2.4	38	1.16	2.43
28	*implexa*	15832	74.1	4.5	4.0	1.88	1.0	65	3.8	3.5	1.22	1.0	40	2.6	2.3	0.36	1.0	60	1.15	1.00
15	*decurrens*	15847	25.9	4.3	5.0	2.81	1.5	60	3.0	2.6	0.53	1.4	25	2.2	1.4	0.11	1.7	37	1.15	1.53
32	*irrorata* ssp. *velutinella*	18623	75	4.3	4.2	1.98	1.4	30	3.1	2.8	0.64	1.4	77.5	3.0	3.1	0.75	1.6	61	1.12	1.47
49	*melanoxylon*	15863	52.5	4.8	4.6	2.66	2.3	35	2.8	2.6	0.50	2.4	22.5	1.9	1.6	0.13	2.4	37	1.09	2.37
13	*deanei*	18063	45	5.2	3.5	1.67	4.2	50	3.5	2.4	0.53	4.2	35	4.1	2.7	0.78	4.2	43	0.99	4.20
23	*fulva*	15843	35	2.3	2.5	0.38	1.0	40	3.2	2.8	0.66	1.0	40	4.4	3.9	1.75	1.2	38	0.93	1.07
62	*silvestris*	17939	42.5	4.5	3.9	1.79	1.7	55	2.5	2.1	0.29	1.9	32.5	3.0	2.9	0.66	2.3	43	0.91	1.97
51	*nano-dealbata*	17195	62.9	3.7	3.8	1.40	1.2	—	—	—	—	—	55	3.2	3.9	1.27	1.3	39	0.89	1.30
30	*irrorata*	18619	70	3.7	3.8	1.40	1.2	35	3.4	3.2	0.91	1.4	38	2.8	2.0	0.29	1.4	48	0.87	1.33
46	*melanoxylon*	17230	50	4.3	3.0	1.01	2.2	65	3.8	3.8	1.44	2.1	25	2.0	1.2	0.08	2.3	47	0.84	2.20
60	*silvestris*	15852	30	5.0	4.0	2.09	1.8	25	2.8	2.4	0.42	1.7	—	—	—	—	—	18	0.84	1.80
56	*parramattensis*	17925	37.5	3.4	4.1	1.49	2.2	43	3.1	2.8	0.64	2.1	22.5	3.0	2.0	0.31	2.2	34	0.81	2.17
31	*irrorata*	18626	77.5	4.7	3.7	1.68	1.2	69	2.7	2.4	0.41	1.2	65	2.8	2.0	0.29	1.4	71	0.79	1.27
19	*falciformis*	15502	60	3.0	3.1	0.75	2.0	48	3.1	2.7	0.59	2.1	35	3.2	3.4	0.97	2.1	48	0.77	2.07
29	*irrorata*	15840	90.5	4.3	3.2	1.15	1.1	43	2.9	2.6	0.51	1.3	75	2.9	2.5	0.47	1.5	70	0.71	1.30
4	*binervia*	15845	67.8	4.3	3.9	1.71	2.5	52	3.1	1.8	0.26	3.2	82.5	2.4	1.6	0.16	3.3	67	0.71	3.00
47	*melanoxylon*	16526	35	5.3	3.7	1.90	2.4	28	2.1	1.7	0.16	2.3	22.5	1.6	0.2	0.00	2.4	29	0.69	2.37
12	*deanei*	15470	45	3.4	3.8	1.28	4.6	35	2.1	1.9	0.20	4.3	37.5	3.8	2.4	0.57	4.3	39	0.69	4.40
35	*leucoclada* ssp. *argentifolia*	18067	55	3.5	4.3	1.69	1.1	—	—	—	—	—	—	—	—	—	—	18	0.56	1.10
64	*trachyphloia*	17894	30	2.3	2.2	0.29	1.5	53	2.5	2.1	0.29	1.4	40	3.9	3.3	1.11	1.7	41	0.56	1.53
52	*nano-dealbata*	17940	—	—	—	—	—	—	—	—	—	—	30	4.0	3.9	1.59	1.4	10	0.53	1.40
53	*obliquinervia*	16875	—	—	—	—	—	—	—	—	—	—	37.5	3.0	4.1	1.32	3.6	13	0.44	3.60
20	*falciformis*	17740	40	3.3	2.9	0.73	2.2	35	2.8	2.4	0.42	1.8	75	2.5	1.6	0.17	2.3	50	0.44	2.10
63	*trachyphloia*	14229	30	2.5	2.0	0.26	1.4	40	2.3	2.0	0.24	1.6	25	2.5	2.5	0.41	1.7	32	0.30	1.57
54	*obliquinervia*	18070	33.3	3.2	3.0	0.75	3.6	—	—	—	—	—	—	—	—	—	—	11	0.25	3.60
8	*dealbata*	16376	27.5	1.5	0.2	0.00	1.3	—	—	—	—	—	27.5	3.3	2.9	0.73	2.2	18	0.24	1.80
3	*binervata*	16245	—	—	—	—	—	28	2.3	1.3	0.10	3.5	32.5	3.2	2.5	0.52	3.5	20	0.21	3.50
17	*elata*	18251	47.5	2.6	2.0	0.27	2.1	43	2.2	2.0	0.23	2.8	25	1.6	0.4	0.00	3.4	39	0.17	2.77
5	*chrysotricha*	18620	55	2.5	2.0	0.26	2.2	0	0	0	0.00		35	2.9	1.7	0.22	4.5	30	0.16	3.40
18	*elata*	18252	52.5	2.0	1.3	0.09	2.4	28	1.8	1.6	0.12	3.1	42.5	2.5	2.0	0.26	3.1	41	0.16	2.87
10	*dealbata*	16384	50	2.5	2.0	0.26	1.4	56	2.0	1.7	0.15	1.1	—	—	—	—	—	35	0.14	1.30
2	*binervata*	17260	55	3.0	2.0	0.31	3.7	50	2.2	0.8	0.04	3.2	32.5	1.8	0.6	0.02	3.4	46	0.12	3.43
7	*dealbata*	16269	—	—	—	—	—	62	2.3	1.8	0.19	1.8	25	2.5	1.6	0.17	2.1	29	0.12	2.00
45	*melanoxylon*	18021	25	1.8	1.2	0.07	1.8	35	1.9	1.5	0.11	1.6	25	1.8	1.7	0.14	1.9	28	0.11	1.77
11	*dealbata*	18024	—	—	—	—	—	65	2.5	2.0	0.26	1.8	22.5	2.1	0.8	0.04	2.3	29	0.10	2.10
16	*elata*	18243	25	2.0	1.3	0.09	2.3	30	2.0	1.8	0.17	2.9	22.5	1.7	0.2	0.00	3.2	26	0.09	2.80
9	*dealbata*	16271	—	—	—	—	—	50	1.7	1.0	0.04	1.2	—	—	—	—	—	17	0.01	1.20
6	*dangarensis*	18608	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		Average	45.1	3.7	3.6	2.1	1.7	40.1	2.4	2.1	0.5	1.6	37.5	2.8	2.5	0.8	1.9	41.0	1.1	2.0
		Standard dev.	24.7	1.7	2.0	2.2	1.0	22.7	1.2	1.2	0.5	1.0	22.6	1.3	1.5	0.9	1.1	17.6	0.9	0.9

Note: S = survival (%), H = height (m), D = diameter (cm) at breast height, V = Volume (dm^3) and F = number of stems per tree.

Table 5. The correlation between seedling performance at three months of age in the RITF nursery and field performance at 30 months after planting at Longdong trial site.

	Tree performance at 30 months of age at Longdong trial site			Seedlings performance at 3 months of age in the RITF nursery, Longdong								
	S	V	F	G	H	D	B	Wa	Wu	L	N	H/D
S												
V	0.3307*											
F	−0.1648	−0.0170										
G	0.3285*	0.0400	−0.3086*									
H	0.3856**	0.1568	−0.1637	0.4175**								
D	0.2620*	0.2107	−0.3047*	0.5024**	0.7484**							
B	0.3509**	0.3297*	0.0914	0.0276	0.1956	0.0736						
Wa	0.5126**	0.3770**	−0.2816*	0.3789**	0.7914**	0.7339**	0.3377**					
Wu	0.0593	0.1793	−0.0709	0.2524	0.2920*	0.3121*	−0.0292	0.3513**				
L	0.0078	0.1589	−0.2444	0.1783	0.3313*	0.4458**	−0.0874	0.3205*	0.3287*			
N	−0.1300	−0.0136	−0.1631	0.048	0.1108	0.2092	−0.1064	0.0890	0.2655*	0.3211*		
H/D	0.3050*	0.0603	−0.0200	0.2572	0.8921**	0.3886**	0.1970	0.5949**	0.2052	0.2198	0.0550	
Wa/Wu	0.2774*	0.0756	−0.3239	0.1933	0.5196**	0.4585**	0.2264	0.6181**	−0.3337*	0.1189	−0.1042	0.4237*

Note:
S = survival (%), V = Volume (dm^3), F = number of stems per tree, G = seed germination (%), H = seedling height (cm), D = diameter (cm) of seedling at the base, B = number of prostrate stems (<45° above soil surface), Wa = dry weight (g) of seedlings above ground, Wu = dry weight (g) of seedlings under the ground, L = length (cm) of main root, N = number of rootlets

* and ** means the correlation is significant at 0.05 and 0.01 levels respectively.

- Ganzhou, Jiangxi province (the most northerly site): *A. filicifolia* 15841, *A. fulva* 15843, *A. glaucocarpa* 15473, 18065, *A. implexa* 18019, 18611, *A. leucoclada* 18621, *A. mearnsii* 15329, 16621, 17928, 17933, 17937, 18607, *A. melanoxylon* 17263, *A. obliquinervia* 16273, *A. parramattensis* 17711 and *A. parvipinnula* 15844;
- Yangdong forest farm, Shixing county, northern Guangdong province: *A. decurrens* 14726, *A. filicifolia* 15841, *A. glaucocarpa* 18065, 15473, *A. implexa* 15832, 18019, 18611, *A. irrorata* 18619, *A. leucoclada* 18621, *A. mearnsii* 17928, *A. melanoxylon* 17230, 17263, *A. parramattensis* 17711, 18610, *A. parvipinnula* 15842, 15844;
- Longdong forest farm, Guangzhou, central Guangdong province (the most tropical and southerly of the sites): *A. blayana* 18068, *A. filicifolia* 17893, *A. glaucocarpa* 15473, *A. irrorata* ssp *velutinella* 18622, *A. mearnsii* 16246, 17928, 17933, 17937, 18607, *A. melanoxylon* 16358, 17263, *A. parramattensis* 17711, 18610. The performance of *A. melanoxylon* (16358 Bli Bli S.E. Qld) was relatively outstanding on this site with 98% survival, average height of 6.3 m and dbh of 8.7 cm.

Common to all three sites was the above-average performance, in terms of survival and volume, of four species: the subtropical (southern Queensland) provenances of *A. glaucocarpa* (15473 Gayndah) and *A. melanoxylon* (17263 Mt Mee-Sellins Rd, north of Brisbane) and the temperate provenances of *A. mearnsii* (17928 Tarpeena, SA) and *A. parramattensis* (17711 Tarago, NSW). The best performing species, in terms of volume and form, common to the two subtropical sites (excluding the tropical Longdong site) were *A. filicifolia* 15841, *A. glaucocarpa* 18065, *A. implexa* 18611, 18019, *A. leucoclada* 18621, *A. mearnsii* 17928, *A. melanoxylon* 17263, *A. parramattensis* 17711 and *A. parvipinnula* 15844.

Correlations between seedling performance in the RITF nursery and early performance at the Longdong field trial are shown in Table 5. There was no significant correlation between the initial prostrate form of particular seedlots in the nursery and their later form in the field. There were highly significant correlations between percentage germination and height and diameter growth in the nursery as well as between the survival of seedlots in the field and their number of prostrate stems in the nursery. At 30 months of age in the field there was also a highly significant relationship between the survival of seedlots and seedling height in the nursery.

Conclusions

Acacias have much to offer Chinese farmers, who have limited capital to establish plantations on relatively poor soil and seek early return on their investment. The most productive and adaptable species across the tropical and two subtropical sites were provenances of *A. glaucocarpa*, *A. mearnsii*, *A. melanoxylon* and *A. parramattensis*. At 30 months of age, eight species (*A. filicifolia*, *A. glaucocarpa*, *A. implexa*, *A. leucoclada*, *A. mearnsii*, *A. melanoxylon*, *A. parramattensis* and *A. parvipinnula*) were found to have performed well in terms of relative survival, growth and form at two subtropical sites. These latter species have potential to grow well in the cool subtropics of the mountainous regions of southern China. The very size of this mountainous area suggests the importance that temperate acacias may assume in farm and plantation forestry. These promising species are being further studied through subsequent species and provenance trials. The next challenge will be to supply Chinese farmers with the quality and quantity of seed of these best species/provenances they need to establish their plantations.

Acknowledgments

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References

Chou, G., Lin, X., Wu, C. et al. 1991. In: Lands Utilization and Harness for Guangdong Mountain Area, 1–12.

Wang, H. and Fang Y. 1991. The history of *Acacia* introduction to China. In: Turnbull J.W., ed., Advances in Tropical Acacia Research: Proceedings of a workshop held in Bangkok, Thailand, 11–15 February 1991. ACIAR Proceedings No. 35, Australian Centre for International Agricultural Research, Canberra, 64–66.

Wang, H., Jiang, Z. and Yan, H. 1994. Australian trees grown in China. In: Brown, A.G., ed., Australian Tree Species Research in China; Proceedings of an international workshop held from 2 to 5 November 1992 in Zhangzhou, Fujian Province, PRC. ACIAR Proceedings No. 48, Australian Centre for International Agricultural Research, Canberra, 19–25.

The Performance of *Acacia angustissima, A. auriculiformis* and *A. mangium* as Potential Agroforestry Tree Species in the Highlands of Papua New Guinea

Bire Bino[1]

Abstract

In this study *Acacia auriculiformis* A. Cunn. ex Benth., *Acacia mangium* Wild. and *Acacia angustissima* Mill. were evaluated for their growth performance at three sites (Tabibuga, 1300 m above sea level (asl); Aiyura, 1700 m asl; and Gumine, 1950 m asl) in the highlands of Papua New Guinea (PNG). Based on the early results of this study, *A. angustissima* was tested in a hedgerow intercropping system at Aiyura to determine the optimum alley spacing and to assess the sustainability of growing sweet potato, the main highland staple crop.

The evaluation trial used a randomised block design at all sites. The hedgerow intercropping study used systematic design and the treatments were replicated four times. The treatments were arranged in decreasing order down the slope in one replicate, while in the other replicate the order was reversed.

In the growth evaluation study, *A. angustissima* had early vigorous growth at all sites and at 11 months, it had a height range of 1.0–3.0 m at all sites. Growth rates at Gumine and Aiyura were initially very slow for *A. auriculiformis* and *A. mangium*. However, later assessment shows the performance of these species was better at Tabibuga followed by Aiyura. *A. auriculiformis* never recovered at Gumine and was either static or dying.

The hedgerow intercropping study showed that a 5 m alley was a better prospect because the hedges produced more biomass (20 t/ha) and returned more nutrients to the soil; the 5 m alleys also yielded more sweet potato tubers (14 t/ha).

This study shows that *A. angustissima*, due to it's vigorous growth and higher biomass production, may be suitable for intercropping/agroforestry systems where biomass can be cut back and applied as mulch. *A. auriculiformis* and *A. mangium* could be more suitable at lower altitudes.

NITROGEN-FIXING trees (NFTs) are those that demonstrate evidence of symbiotic association with nitrogen-fixing organisms—usually nodule-forming bacteria of the genus *Rhizobium* or actinomycetes of the genus *Frankia* (MacDicken 1994). As a group, NFT species offer a great deal of unexploited potential, partly because many have multiple uses, but primarily because they fix nitrogen.

Use of NFT species in farming systems, especially agroforestry technology, can help ensure that the agriculture resource base and the biophysical environment are not depleted for future generations (Lundgren 1989). For example, the hedgerow systems on sloping land can alter the length of slope, degree of slope, soil profile depth, and soil chemical and hydrological properties (Garrity 1996).

Nitrogen-fixing multipurpose tree species can play an important role in sustainable farming systems of the PNG highlands. However, there are only a limited number of this group of trees that can grow at highland altitudes. Much of the traditional PNG highlands farming practices are classified as agroforestry practices because trees and shrubs are often an integral component of the farming systems. For this reason it is important to identify suitable

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multipurpose tree species and test them for their suitability in sustainable farming systems.

This paper reports on two studies: the first is on the evaluation of three *Acacia* species for their suitability in the highland environment; the second is on using one of the promising *Acacia* species in an alley-cropping study, to determine the best alley width and to assess the sustainability of crop production using this system.

Materials and Methods

Two studies on three *Acacia* tree species were conducted in the highlands of PNG. The first study was to assess the growth performance of *A. angustissima, A. auriculiformis* and *A. mangium* at three different agro-ecological zones in the highlands. The study was conducted between 1990 and 1992. The study locations were Aiyura, Gumine and Tabibuga.

Based on the initial results of the first study, the second study was conducted using *A. angustissima* as the hedgerow species in a trial to determine the best spacing for alley cropping. The species was selected because of its fast growth rate, its coppicing ability and high biomass production potential. The study was conducted at Aiyura between 1992 and 1995.

Location 1: Aiyura

The Highlands Agriculture Experiment Station is located at Aiyura (latitude 6°19′S; longitude of 145°55′E; and altitude 1700 m asl) in the Eastern Highlands Province of PNG. The seven-year rainfall data to 1996 showed an average annual rainfall of 2150 mm, with a relatively dry period occurring from May to September. The soils of Aiyura are highly variable and major soil groups described included Tropaqualfs, Argiaquaolls and Plinthaquults (DAL and IBSRAM 1989). These include shallow dark mineral soils with light–heavy clay subsoil, and on hill slopes, iron/manganese concretions are common. The general soil fertility is good (Table 1). The vegetation cover was grassland dominated by *Imperata cylindrica.*

Location 2: Gumine

One of the studies was conducted on a 25° slope at Boromil village, Gumine district, Chimbu province. The site was located at an altitude of 1950 m asl. Ten-year rainfall data at the nearby Gumine station (McAlpine et al. 1975) show that on average the site would receive some 2450 mm of rainfall annually, three-quarters of which is expected from October to April. The soil was typically volcanic ash in origin. The topsoil was friable and coarse structured, dark brown in colour, while the subsoil was light brown to yellowish orange. The soil is strongly acid with P and K being at suboptimal levels. P-retention is high (Table 1). The vegetation cover was short bush (*Miscanthus* spp.).

Location 3: Tabibuga

The other study was conducted on a typical 40° slope at Tabibuga, Jimi district, Western Highlands Province. The site, located at an altitude of 1300 m asl, has a mean annual rainfall of 2700 mm. The topsoil was shallow yellowish clay with good fertility (Table 2). The vegetation cover was short grassland fallow dominated by imperata grass.

Table 1. Initial soil fertility levels at the three *Acacia* growth evaluation sites in the highlands of PNG.

Soil chemical	Aiyura		Gumine		Tabibuga		Critical level
	Mean 0–30 cm	Mean 30–50 cm	Mean 0–30 cm	Mean 30–50 cm	Mean 0–30 cm	Mean 30–50 cm	
pH	5.1	5.3	5.2	5.3	5.4	5.1	<5.5
Ca	6.7	4.8	3.7	2.1	14.7	11.6	<5.0
Mg	3.7	2.9	1.1	0.4	5.0	4.9	<1.0
K	1.2	0.7	0.2	0.1	0.8	0.3	<0.3
Na	0.03	0.2	0.1	0.1	0.2	0.1	>0.7
CEC	27.1	16.8	13.5	12.6	15.6	14.1	<6.0
BS	39.9	30.7	39.5	16.5	100	100	<30
P	7.3	6.1	5.5	2.0	8.0	3.0	<5.0
Org.C	7.3	5.8	5.6	5.6	4.7	1.8	<3.0
Total N	0.5	0.4	0.6	0.4	0.3	0.2	<0.3
C/N Ratio	13.2	13.6	9.0	15.0	14.0	8.0	>15

Metabolisable energy % extractable bases (cmol (+)/kg); P Olsen mg/kg; organic C %; total N %.
Methods used: pH (1:5 soil:distilled water); phosphorus (Olsen extraction); CEC and cations (ammonium acetate pH 7 method); organic C (Walkley-Black); total N (Kjedahl).

Table 2. Diameter (mm) and height (cm) growth of three *Acacia* species 11 months after planting.

Location	Aiyura[1]		Gumine[2]		Tabibuga[3]	
Species	Diameter	Height	Diameter	Height	Diameter	Height
A. angustissima	50.1	340.5	6.0	115.4	26.5	276.7
A auriculiformis	Not planted	—	4.3	32.1	8.6	74.4
A. mangium	19.8	66.3	Not planted	—	10.7	57.4

[1] Average of four replicates. Each replicate has nine measurable trees
[2] Average of three replicates. Each replicate has nine measurable trees
[3] Average of three replicates. Each replicate has nine measurable trees

Acacia species used

All seeds were obtained from the PNG Tree Seed Centre, Bulolo. The seedlings were raised in a centralised nursery following all recommended nursery practices and seedlings were planted out after five months in the nursery.

A. angustissima

A. angustissima is a multi-branched, thornless shrub or small tree and grows to a maximum of about 5 m. It is well adapted to free draining acid, infertile soils and shows excellent drought tolerance (Gutteridge 1994). It is a prolific seed producer and its preferred environment is humid tropics. *A. angustissima* is native to central America but it has been introduced to many tropical countries. It can coppice well after cutting and can fix atmospheric nitrogen.

A. auriculiformis

A. auriculiformis is a vigorous, nitrogen-fixing tree with an outstanding ability to grow well in tropical lowlands on a variety of soil types, including very infertile, clayey, saline and seasonally waterlogged soils. It is more commonly a low tree of 8–20 m, heavily branched and with a short crooked stem. Natural stands of *A. auriculiformis* are found in Australia, Papua New Guinea and Indonesia.

A. mangium

A. mangium is a fast-growing tree that can be grown successfully in the humid tropical lowlands. It fixes nitrogen and tolerates acidic soils of low fertility (Turnbull 1986). It is a large, fast-growing tree, to 30 m tall. Natural stands of *A. mangium* are found in Australia, Papua New Guinea and Indonesia.

Acacia species growth evaluation

A. angustissima, A. auriculiformis and *A. mangium* were planted 1.5 × 1.5 m spacing. At Gumine and Tabibuga, the trial was replicated three times while it was replicated four times at Aiyura. At all sites, a randomised block design was used.

Diameter was measured 10 cm above the ground level using callipers. The tree heights were measured using a calibrated measuring stick. All measurements were collected at two-monthly intervals.

Alley cropping

Four-month-old *A. angustissima* seedlings were planted in an alley cropping trial to determine the optimum alley spacing. The trial was made up of four spacing treatments of 5, 4, 3 and 2 m, with 2 m guard rows in the outer boundaries. The trial uses systematic design and the treatments were replicated four times. The treatments were arranged in decreasing order down the slope in one replicate while the other replicate was set out in reverse order. Each replicate occupies an area of 22 × 18 m (396 m^2). Two of the replicates were located on a good deep clay loam soil while the other two were located on a shallow soil with high concentrations of iron/manganese concretions found below the shallow topsoil. The alley crop was sweet potato (*Ipomoea batatas*), variety Wan mun.

Sweet potato was planted in small 50 cm mounds at 1 × 1 m spacing in alleys. Sweet potato was harvested after recording six months of measurements, including total tuber, marketable tuber, non-marketable tuber (<100 g) and sweet potato vines.

The *A. angustissima* hedge was cut at 50 cm above ground at three-month intervals while growing sweet potato. The measurements include total biomass, foliar leaf biomass and wood yield. Subsamples were obtained to collect dry weight and for foliar chemical analysis.

Soil samples were collected for chemical analysis before planting the trial and at every harvest of sweet potato.

Results and Discussion

Acacia evaluation

The 11-month growth data in Table 2 show highly variable growth performance at three different altitudes. Although the data are insufficient to make a fair judgement of their ability to grow at the respective altitudes, they show that *A. angustissima* performed well at Aiyura, followed by Tabibuga, while the performance at Gumine was not convincing. The other acacias grew slowly at the three sites. Turnbull (1986) pointed out that *A. auriculiformis* and *A. mangium* performed better at humid tropical lowland sites. With limited information available at that time, these species were tested to identify those that can grow better at highland altitudes. Physical observation of these species several years later shows that they were performing better at Tabibuga followed by Aiyura while at Gumine they were not growing and/or were stunted. At Tabibuga *A. auriculiformis* and *A. mangium* were flowering which did not happen for *A. mangium* at Aiyura. *A. angustissima* was seeding prolifically six months after planting at all sites. At all sites, *A. angustissima* had much higher growth rate (Table 2) than the other *Acacia* species. This is a desirable attribute when the species is used in systems where biomass is cut back and applied to the soil as mulch.

Although soil conditions at all sites are suitable for their growth, the main limitation could be the altitude. It can be said that these species cannot perform well at higher altitudes.

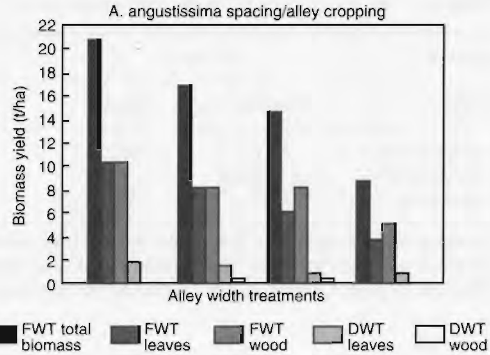

Figure 1. Hedgerow biomass yield at deeper soil site.

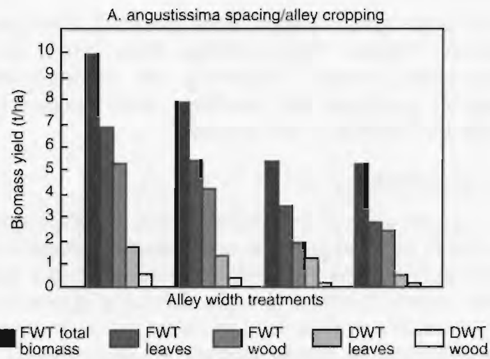

Figure 2. Hedgerow biomass yield at shallow soil site.

FWT — Fresh weight
DWT — Dry weight

Alley cropping

Hedgerow biomass production

Two replicates located on deeper clay loam produced more than 20 t/ha total biomass (Fig. 1), while the other two replicates located on shallow soil containing large numbers of iron/manganese concretions produced only up to 10 t/ha (Fig. 2). Iron/manganese concretions form a hard pan just below the surface, making the root penetration difficult and affecting the performance of plants grown on this soil. This indicates that on better soil, the productivity of this species is high.

The hedgerows with 5 m alley width treatment gave the highest biomass yield. The biomass yield appears to decrease in line with decreasing alley width. Sunlight and to a lesser extent competition could have contributed to the amount of biomass produced by hedgerows of different alley widths.

Sweet potato production

Sweet potato yield was analysed according to sweet potato rows and by proximity to the hedgerows. It appears that there was little difference in sweet potato yield between rows closer to the hedgerows and those from the centre of the alleys. This could be attributed to the frequent cutting of the hedgerows during cropping. Sweet potato marketable tubers (>100 g) from all alley width treatments ranged from 8 to 11 t/ha. However, the general trend appears to be that higher sweet potato productivity was obtained from higher alley widths and decreases with decreasing alley widths (Figs. 3 and 4). Sweet potato has a high requirement for potassium and according to the soil analysis two years after planting hedgerows (Table 4) and the amount of K being returned to the soil in hedgerow biomass, there is no deficiency in K and the soil could support more sweet potato production. The initial soil analysis (Table 1) also shows high K levels in the soil.

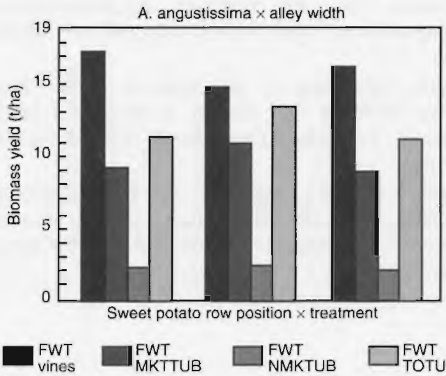

Figure 3. Sweet potato yield from centre rows in the alley.

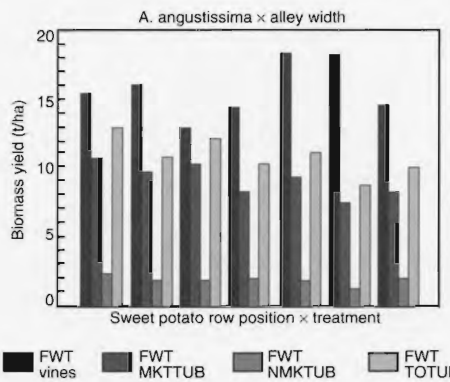

Figure 4. Sweet potato yield from rows closer to the hedgerows.

FWT — Fresh weight, DWT — Dry weight
R — Row number, T — Treatment number
MKTTUB — Marketable tubers
NMKTTUB — Non marketable tubers
TOTUB — Total tubers
T1 — 2 m alley width, T2 — 3 m alley width
T3 — 4 m alley width, T4 — 5 m alley width

Tables 1 and 4 show that although the initial soil analysis shows high soil fertility, two years after planting the hedgerows and growing food crops the fertility appears to decline. This would be the expected trend, but with regular input of cut hedge biomass and other crop residues in alleys, the fertility level in the soil should be maintained for sustainable crop production. The amount of nutrients returned to the soil in the hedge biomass depends on the density of the hedgerow species (Table 3).

Over all, 5 m was the alley width that produced higher biomass and sweet potato yield, making this treatment the best prospect.

Table 3. Main nutrient inputs in leaves of *A. angustissima* hedgerows.

Alley width	Stems/ha	N kg/ha	P kg/ha	K kg/ha	Ca kg/ha
2	5000	29.67	1.69	11.12	6.11
3	3333	19.78	1.13	7.41	4.07
4	2500	14.83	0.85	5.56	3.05
5	2000	11.87	0.68	4.45	2.44

Table 4. Soil chemical analysis results two years after planting the trial.

Nutrient	Topsoil	Subsoil	Critical level
Total N%	0.33	0.34	medium
P mg/kg	4.33	4.07	low
K me%	0.31	0.34	medium
Ca me%	4.71	5.0	low
pH	4.7	4.5	strongly acid

Conclusion

A. angustissima showed good promise in terms of vigorous growth and higher biomass production. It could be an ideal candidate in intercropping systems where biomass can be cut and applied as mulch. However, further studies are needed on it's prolific seeding behaviour and whether it poses a threat as a weed.

A. auriculiformis and *A. mangium*, though they can be grown in the highlands, appear to be more productive at lower altitudes.

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References

Department of Agriculture and Livestock (DAL), and the International Board for Soil Research and Management (IBSRAM) 1989. Training workshop on management of sloping land for smallholder agriculture in the Pacific-PACIFICLAND, Aiyura, Papua New Guinea.

Garrity, D.P. 1996. Tree-soil-crop interactions on slopes. In: Ong, C.K. and Huxley, P., ed., Tree–Crop Interactions. CAB International, 299–317.

Gutteridge, J.R. 1994. Other species of multipurpose forage tree legumes. In: Gutteridge, R.C. and Shelton, H.M., ed., Forage Tree Legumes in Tropical Agriculture. CAB International, 97–108.

Lundgren, B. 1989. The potential of agroforestry. In: Kilewe, A.M., Kealey, K.M. and Kebaara, K.K., ed., Agroforestry development in Kenya. Proceedings of the second Kenya national seminar on agroforestry, ICRAF, Nairobi, Kenya, 29–38.

MacDicken, G.K. 1994. Selection and Management of Nitrogen Fixing Trees. Winrock International, Arkansas, USA.

McAlpine, J.R., Keig, G. and Short, K. 1975. Climatic Tables of Papua New Guinea. Division of Land Use Research, Technology Paper No. 37. CSIRO, Australia, 177 p.

Turnbull, J.W. 1986. Australian Acacias in Developing Countries. ACIAR Proceedings No. 16. Australian Centre for International Agricultural Research, Canberra, Australia, 196 p.

Performance of Australian Temperate Acacias on Subtropical Highlands of Vietnam

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Abstract

Twenty-four *Acacia* species originating in temperate southeastern Australia represented by a total of 67 seedlots, were tested in two trials located in the subtropical highlands of Vietnam. The Bavi site is located in the north of Vietnam and the Dalat site is located in the south of Vietnam. The objective of the study was to identify and characterise acacia species with potential for soil improvement and commercial planting on the highly degraded, low fertility soils of the subtropical highlands.

Trial assessments carried out at age 16 months showed that several species were growing significantly better than the control *A. auriculiformis* at the high elevation. Marked differences in survival and growth rate between species and provenances were also observed.

In relation to both growth and survival, most *A. mearnsii* seedlots ranked at the top of both trials, followed by provenances of *A. irrorata* and *A. leucoclada* then *A. dealbata, A. binervata* and *A. melanoxylon.* The last three species performed well only at the Dalat trial.

OVER the last 50 years nearly 6 million hectares of natural forest in Vietnam has been lost and barren lands have expanded to 10 million hectares (Nguyen Ngoc Lung 1994), large areas of which are located in the subtropical highland regions. Most of this barren land is highly degraded and the soils are seriously eroded and poor in nutrients, causing serious environmental problems and adversely affecting socioeconomic rural development. Therefore, many large, ambitious reforestation programs were started by the Vietnam Government to restore this barren degraded land and convert it, step by step, into more productive land.

Due to their pioneering character, fast growth and tolerance of poor soils as well as their multiple uses for fuelwood, timber, pulp, tannin and soil amelioration, acacias are often the preferred species for many forest growers. For the lowland areas of Vietnam, tropical acacia species such as *A. auriculiformis* and *A. mangium* were successfully introduced and widely planted throughout the country. But for subtropical highland areas, normally located at altitudes above 600 m in the north and above 1000 m in the south (Nguyen Ngoc Binh 1997), less effort has been made until now to identify the most valuable and fastest growing acacia species/provenances adapted to the prevailing harsh conditions of cold winters, moist, hot summers and poor soils with low pH.

Experience in other countries showed some species of temperate acacias naturally found in southeastern Australia are promising for planting on poor and degraded soils in subtropical highland regions. Examples are *A. mearnsii* and *A. melanoxylon*, which are well known as high tannin yielders and quality timber producers respectively and are widely grown as plantation species in many countries, such as Brazil and South Africa. *A. deabata, A. decurrens* and *A. glaucocarpa* have also been introduced to a lesser extent in some countries (Vivekanandan 1993). In the subtropical highlands of southern China where conditions are quite similar to that of Vietnam, *A. dealbata, A. filicifolia, A. fulva, A. glaucocarpa* and *A. mearnsii* have proved quite promising, with height growth at 18 months above 5 m (Yang et al. 1991).

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Table 1. Provenance details for *Acacia* species tested at Bavi and Dalat.

Acacia species	CSIRO seedlot	Provenance		Latitude		Longitude		Altitude
				Deg	Min	Deg	Min	(m)
auriculiformis	local	Dong Nai	VN	11	15N	107	06	50
binervata	17260	Springbrook	Qld	28	12	153	16	500
"	16245	Kiama	NSW	34	40	150	43	240
binervia	15845	Springwood	NSW	33	38	150	40	15
chrysotricha	18620	Newry S.F.	NSW	30	32	152	55	50
cincinnata	17634	Mossman	Qld	16	35	145	25	410
"	19005	Finch Hatton	Qld	21	04	148	37	160
"	19289	Tuan S. F.	Qld	25	44	152	44	3
"	19302	N Qld, Seed Orchard	Fiji	18	00	178	00	—
dangarensis	18608	Mt Dangar	NSW	32	20	150	28	600
dealbata	16267	32 Mile Rd	Vic	37	25	148	37	350
"	16271	Errinundra	Vic	37	11	148	52	960
"	16376	Bemboka	NSW	36	37	149	26	1035
"	18973	Kandos	NSW	32	56	149	54	600
deanei	15470	Goondiwindi	NSW	28	49	150	43	260
decurrens	14726	SW of Goulburn	NSW	34	53	149	17	685
"	14768	Goulburn	NSW	34	38	150	09	660
"	15847	Picton	NSW	34	17	150	35	380
elata	18251	Gloucester	NSW	32	05	151	38	1000
"	18252	Mt Wilson	NSW	33	30	150	21	650
"	18253	Blackheath	NSW	33	37	150	18	700
"	18243	Mt Boss	NSW	31	14	152	22	800
falciformis	16253	Narooma	NSW	36	11	150	11	150
"	15502	Warwick	Qld	28	32	151	58	900
filicifolia	15841	Singleton	NSW	32	41	151	1	150
"	17893	Yadboro Flat	NSW	35	19	150	14	60
fulva	15843	Howes Valley	NSW	32	52	150	52	240
"	18861	Howes Valley	NSW	32	52	150	51	300
"	18972	Mt Yengo	NSW	32	59	150	51	600
glaucocarpa	15473	Gaynda	Qld	25	32	151	29	390
"	18065	Cadagar	Qld	26	07	150	55	350
"	18092	Baralaba	Qld	23	30	140	49	200
implexa	18611	Sofala	NSW	33	11	149	41	850
"	18019	Pyalong	Vic	37	08	144	53	200
"	18859	Moonan Flat	NSW	31	56	151	11	350
"	18978	Glenmaggie	Vic	37	53	146	45	120
irrorata	18623	Cogarinni S.F.	NSW	30	41	152	53	60
"	18622	Newry S.F.	NSW	30	31	152	59	10
"	18619	Bodalla	NSW	36	08	150	02	20
"	17145	Mt Mee	Qld	27	07	152	45	250
"	18626	Gloucester	NSW	31	59	151	47	650
leucoclada	18621	Inverell	NSW	29	44	150	57	700
mearnsii	17927	Tantanoola	SA	37	41	140	28	30
"	17933	Omeo Hwy	Vic	37	27	147	50	200
"	18607	Berrima	NSW	34	30	150	20	750
"	15329	Apsley River	Tas	41	56	148	14	10
"	17937	Cooma	NSW	36	14	149	5	1000
"	17928	Tarpeena	SA	37	36	140	58	70
mearnsii	16246	Nowra	NSW	34	59	150	36	10
"	16380	Nowa Nowa	Vic	37	45	148	12	31
"	16621	Bodalla	NSW	36	11	149	58	15
"	18975	Bungendore	NSW	35	11	149	32	760
"	18979	Blackhill Res.Kyneton	Vic	37	12	144	29	520
"	local	Lam Dong	VN	21	06N	105	26	1500

Table 1. (continued)

Acacia species	CSIRO seedlot	Provenance		Latitude		Longitude		Altitude
				Deg	Min	Deg	Min	(m)
melanoxylon	15863	Blackwood	Tas	40	57	145	10	250
"	17263	Mt Mee	Qld	27	06	152	44	500
"	16526	Mt Gambier	SA	37	57	141	56	40
"	15821	Ravenshoe	Qld	17	35	145	32	100
"	19001	Mt Linsay S.F.	NSW	28	21	152	39	600
"	19322	Crawford R.	Vic	37	56	141	30	—
"	19350	Otways	Vic	38	41	143	33	300
"	19494	Kannunah	Tas	41	08	144	59	100
nanodealbata	17940	Lavers Hill	Vic	38	45	143	15	200
obliquinervia	16273	Bemboka	NSW	36	36	149	25	960
parramattensis	17711	Tarago	NSW	35	10	149	35	740
"	18610	Windsor	NSW	33	8	150	41	400
"	14723	Bungendore	NSW	35	19	149	25	730
parvipinnula	15842	Howes Valley	NSW	32	52	150	52	240
silvestris	16254	Narooma	NSW	36	11	150	01	130
"	15852	Deua River	NSW	35	58	149	45	420
"	17939	Bruthen	Vic	37	35	147	54	200
trachyphloia	14229	Monga S.F.	NSW	35	36	149	55	710
"	17894	Currowan Ck.	NSW	35	35	150	3	100

Materials and Methods

Seed sources and seedling production

The trial consisted of 24 acacia species plus a control (*A. auriculiformis* at Bavi and a land race of *A. mearnsii* at Dalat) represented by 67 seedlots (Table 1). The seven phyllodinous species included were *A. binervata, A. cincinnata, A. falciformis, A. implexa, A. melanoxylon, A. obliquinervia* and the control *A. auriculiformis*. The other 18 species were bipinnate species belonging to the Botrycephalae section of *Acacia* and most of them are relatively unknown and inadequately tested in trials. Some species such as *A. fulva, A. chrysotricha* and *A. dangarensis* are classified as rare and endangered (Tame 1992). With the exception of the controls, the acacia species tested originated from southeastern Australia, from southeast Queensland to southern Tasmania.

Prior to sowing, seeds were pretreated in boiling water for 1 minute. Three days later geminated seeds were transplanted into 9 × 12 cm PE tubes containing a mixture of 84% fine nursery soil, 15% well composted organic manure and 1% superphosphate. Due to great variation in seedling growth between seedlots, 3-month-old seedlings raised at Bavi nursery were then transplanted into bigger pots (15 × 20 cm PE tubes) containing the same mixture.

Trial locations, design and establishment

The two sites selected for trial establishment represent the two main subtropical climate types in Vietnam. Bavi National Park (21°06′N, 105°26′E, 600 m asl) is located north of Hanoi and the other located north of Ho Chi Minh is at FSIV's Regional Research Centre for Silviculture at Dalat (11°57′N, 108°26′E, 1600 m asl). Climatic data and site descriptions and trial design for both trial sites are presented in Table 2. Forty-two seedlots were arranged in incomplete block designs in six replicates.

In addition to the two species elimination trials, one smaller test planting was established at Bavi nursery (altitude: 50 m asl) using surplus seedlings of 42 seedlots included in the trial at Bavi National Park to explore the reaction and tolerance of temperate acacias to temperatures and increased water availability at a lower altitude. This test planting was designed as a RCB with three replicates, each plot included five trees and planting spacing was 50 × 50 cm.

Data collection and analysis

Germination rate, seedling growth and vigour were closely and continuously monitored at the nursery stage and the survival and growth were assessed 3, 6, 12 and 16 months after planting. Survival rate was recorded on each occasion, total tree height and diameter at ground level was measured at age 6, 12 and 16 months.

Data was analysed using DATACHAIN and GENSTAT software (Williams and Matheson 1994). Results of variance analyses for survival, tree height and diameter at ground level presented in this paper are from data collected at 16 months of age. To enable comparison at the species level, the average survival of each species was also calculated.

Table 2. Site characteristics and trial establishment.

Site characteristics	Bavi National Park	Dalat, Lam Dong province.
Climatic data:		
Altitude (m):	600	1600
Mean annual rainfall (mm):	2190	1730
Average max. temp. (°C):	20.9	23.3
Average min. temp. (°C):	15.9	14.3
Site description:		
Local relief:	SE exposed steep slope (20–25°)	SE exposed steep slope
Parent material:	Schist/sandstone	Magma acid
Soil type:	Light yellow ferrallitic	Red yellow ferrallitic
Soil pH:	4.3–4.8	4.5–5.0
Dominant vegetation:	Imperata grass of 1.5–2.0 m	Fern and shrub of 1.0–1.5 m
Trial establishment:		
Site preparation:	Vegetation clearing, manual hole digging (40 × 40 × 40 cm)	Vegetation clearing, burning and kept on site, manual ploughing and hole digging (40 × 40 × 40 cm)
Trial design:	ICB with 42 seedlots in 6 blocks and 4 replicates, 8 trees/plot	ICB with 42 seedlots in 6 block and 4 replicates, 20 trees/plot
Planting date:	End of April, 1996	Early May, 1996
Planting spacing:	1.5 × 2.0 m	1.5 x 2.0 m
Seedling age at planting:	5 months old	3 months old
Fertilising:	200 g NPK/hole before planting	0.5 kg Bio-organic manure/hole

Results

Trial at Bavi National Park

A set of 40 provenances from 22 species plus two control treatments (local seedlots of *A. auriculiformis* and *A. mearnsii*) were included in this trial. Seedlot means for survival, height and diameter (gl) are presented in Table 3. Species summaries of survival, height and diameter at ground level of each seedlot are presented in Table 4.

Initial establishment of the trial was successful, with an overall survival rate of 81.4% recorded at the age of 6 months (Table 4). However, one year after planting, significant differences in survival rate between seedlots and species had emerged. By age 16 months, the survival of 11 of the 23 tested species had fallen below 30%, and the worst examples were *A. obliquinervia* (all dead), *A. chysotricha* and *A. nanodealbata* (3.1%), *A. falciformis* (12.5%), *A. elata* and *A. fulva* (15.6%) and *A. dangarensis* (18.7%) (Table 4).

In terms of height growth, all phyllodinous species including *A. auriculiformis* (H = 0.84 m) were slower growing, reaching only 0.70–1.13 m in 16 months (Table 3).

Considering height and diameter growth as well as survival and stem form development, *A. mearnsii* is the most promising species among the 16 bipinnate acacias tested in the trial. The two top-ranked seedlots of *A. mearnsii* are from Victoria (17933: survival 84.4%, height 2.08 m and diameter at ground level 1.89 cm) and South Australia (17928: survival 87.5%, height 1.97 m and diameter at ground level 1.72 cm), followed by *A. irrorata* from Newry S.F. NSW (18622: survival 46.8%, height 1.78 m and dgl 1.54 cm) (Table 3).

Test planting at Bavi Nursery

As expected, very low survival was observed for 15 of the 23 species tested at Bavi nursery. Only a few seedlots of *A. binervia, A. decurrens, A. filicifolia, A. implexa, A. irrorata, A. mearnsi, A. melanoxyloni* as well as the control *A. auriculiformis could* survive well at lower elevation (Table 5).

Data presented in Table 5 show furthermore that in addition to the control *A. auriculiformis,* the height and diameter growth of *A. binervata* and *A. mearnsii* on the fertile alluvial soils of Bavi nursery was relatively high. In extreme cases, tree height of both species at age 16 months is similar to that of *A. auriculiformis* and could reach a height of more than 5 m, much greater than on the poor and highly degraded site of Bavi National Park. This indicated that on the deep and moist soils, some temperate acacias could tolerate the higher summer temperatures of lowland areas.

Trial at Dalat

This trial comprised of 42 seedlots from an original 47 seedlots representing 14 temperate acacia species sown at Dalat nursery (Table 6). *A. cincinnata*

Table 3. Growth and survival of *Acacia* species at age 16 months tested at Bavi National Park.

Acacia species	CSIRO seedlot no.	Surv. (%)	H (m)	Acacia species	CSIRO seedlot no.	Dgl (cm)
mearnsii	17933	84.4	2.08	*mearnsii*	17933	1.89
mearnsii	17928	87.5	1.97	*mearnsii*	17928	1.72
irrorata	18622	46.8	1.78	*irrorata*	18622	1.54
glaucocarpa	18065	40.6	1.54	*parramattensis*	17711	1.32
mearnsii	18607	58.2	1.53	*trachyphloia*	14229	1.30
leucoclada	18621	59.4	1.52	*implexa*	18611	1.29
mearnsii	Dalat	65.6	1.51	*mearnsii*	18607	1.29
deanei	15470	53.1	1.48	*mearnsii*	17927	1.28
mearnsii	17927	75.0	1.43	*elata*	18252	1.24
mearnsii	17937	78.1	1.41	*leucoclada*	18621	1.24
filicifolia	17893	21.8	1.37	*mearnsii*	17937	1.24
elata	18252	21.8	1.36	*glaucocarpa*	18065	1.21
chrysotricha	18620	3.10	1.35	*mearnsii*	15329	1.19
implexa	18611	43.7	1.33	*elata*	18251	1.14
mearnsii	15329	59.4	1.31	*irrorata*	18619	1.14
decurrens	14726	31.2	1.28	*deanei*	15470	1.10
parvipinnula	15842	21.8	1.28	*parvipinnula*	15842	1.09
parramattensis	18610	34.4	1.25	*parramattensis*	18610	1.05
parramattensis	17711	50.0	1.20	*elata*	18243	1.02
glaucocarpa	15473	68.7	1.19	*trachyphloia*	17894	1.01
irrorata	18619	31.2	1.19	*melanoxylon*	17263	1.00
trachyphloia	14229	21.8	1.17	*irrorata*	18623	0.93
melanoxylon	17263	75.0	1.13	*falciformis*	15502	0.91
fulva	15843	15.6	1.10	*mearnsii*	Dalat	0.91
falciformis	15502	43.7	1.09	*filicifolia*	17893	0.90
trachyphloia	17894	12.5	1.09	*decurrens*	14726	0.89
elata	18251	18.7	1.06	*falciformis*	16253	0.88
falciformis	16253	12.5	1.06	*glaucocarpa*	15473	0.86
filicifolia	15841	34.4	1.03	*implexa*	18019	0.81
irrorata	18623	59.4	1.01	*binervata*	17260	0.75
silvestris	15852	12.5	1.00	*chrysotricha*	18620	0.74
melanoxylon	15863	25.0	0.87	*silvestris*	15852	0.74
silvestris	17939	18.7	0.85	*filicifolia*	15841	0.71
binervata	17260	6.25	0.84	*melanoxylon*	15863	0.70
dangarensis	18608	6.20	0.84	*auriculiformis*	local	0.67
elata	18243	18.7	0.84	*silvestris*	17939	0.61
implexa	18019	21.8	0.83	*binervia*	15845	0.58
auriculiformis	local	75.0	0.82	*nanodealbata*	17940	0.57
binervia	15845	21.8	0.70	*fulva*	15843	0.52
nanodealbata	17940	3.1	0.53	*dangarensis*	18608	0.46
melanoxylon	16526	0	—	*melanoxylon*	16526	—
obliquinervia	16273	0	—	*obliquinervia*	16273	—
Overall mean:		**36.7**	**1.19**			**1.01**
F probability:		**<001**	**<001**			**<001**
LSD:		**18.4**	**0.43**			**0.46**

Table 4. Survival at different ages of *Acacia* species tested at Bavi National Park.

No.	*Acacia* species	Number of seedlots tested	Species mean survival (%)			Species mean height (m)		Species mean Dgl (cm)
			Time after planting (month):					
			6	12	16	12	16	16
1	***auriculiformis***	1	93.7	93.7	75.0	0.42	0.82	0.67
2	***binervata***	1	84.4	75.0	62.0	0.49	0.84	0.75
3	***binervia***	1	100	78.1	61.8	0.57	0.70	0.58
4	*chrysotricha*	1	78.1	9.4	3.1	0.69	1.35	0.74
5	*dangarensis*	1	37.5	25.0	18.7	0.55	0.84	0.46
6	*deanei*	1	78.1	65.6	53.1	1.16	1.48	1.10
7	*decurrens*	1	93.7	50.0	21.8	1.01	1.28	0.89
8	*elata*	3	74.0	33.3	15.6	0.74	1.09	1.13
9	***falciformis***	2	20.0	25.0	12.5	0.78	1.08	0.89
10	*filicifolia*	2	97.7	70.3	28.1	0.85	1.20	0.80
11	*fulva*	1	53.1	37.5	15.6	0.91	1.10	0.52
12	*glaucocarpa*	2	70.0	48.5	35.9	1.05	1.37	1.04
13	***implexa***	2	89.0	76.6	59.4	0.74	1.08	1.05
14	*irrorata*	3	96.9	83.3	58.3	1.01	1.33	1.20
15	*leucoclada*	1	75.0	62.5	59.4	1.01	1.52	1.24
16	*mearnsii*	7	94.0	85.3	72.5	1.09	1.61	1.36
17	***melanoxylon***	3	60.3	41.7	33.3	0.50	1.00	0.85
18	*nanodealbata*	1	12.5	12.5	3.1	0.53	0.53	0.57
19	***bliquinervia***	1	0	0	0	—	—	—
20	*parramattensis*	2	93.7	81.2	42.2	0.85	1.23	1.18
21	*parvipinnula*	1	87.5	78.1	31.2	0.93	1.28	1.09
22	*silvestris*	2	92.0	45.3	15.6	0.71	92.5	0.68
23	*trachyphloia*	2	82.8	56.2	32.8	0.87	1.13	1.15
	Overall mean	**42**	**81.4**	**58.7**	**36.7**	**0.84**	**1.19**	**1.01**

Bold = phyllodinous species

Table 5. Growth and survival of temperate *Acacia* species at Bavi nursery (16 months).

Acacia species	CSIRO seedlot	Survival (%)		Dgl (cm)	Tree height (m)		
		Time after planting (months):					
		6	16	16	6	16	H (max)
auriculiformis	Local	73.4	73.4	3.97	1.19	4.46	5.9
binervia	15845	100	73.4	3.89	1.54	3.82	5.1
mearnsii	16246	93.3	80.0	2.94	1.19	3.22	4.0
mearnsii	18607	93.3	46.6	2.36	1.40	3.14	5.6
mearnsii	15329	93.3	53.4	2.92	1.31	2.96	4.7
mearnsii	17933	86.7	66.7	2.46	1.58	2.92	4.5
mearnsii	Local	93.3	66.7	2.56	1.34	2.91	3.5
implexa	18611	93.3	73.4	2.12	1.45	2.61	4.0
irrorata	18626	80.0	60.0	1.96	1.15	2.42	3.9
filicifolia	15841	80.0	73.4	1.67	1.65	2.30	3.7
decurrens	14726	66.7	40.0	2.41	1.34	2.28	3.3
melanoxylon	17263	73.4	66.6	1.85	0.96	2.26	2.9
filicifolia	17893	100	66.7	1.53	1.15	2.23	3.4
irrorata	18619	86.7	66.7	1.46	1.06	1.94	2.7
irrorata	18623	86.7	46.6	1.52	1.02	1.86	3.2

Table 6. Growth and survival of *Acacia* species at age 16 months tested at Dalat, Lam Dong.

Acacia species	CSIRO seedlot	Sur. (%)	H (m)	*Acacia* species	CSIRO seedlot	Dgl (cm)
mearnsii	16246	76.3	3.00	*mearnsii*	16621	2.57
mearnsii	18979	62.5	2.86	*mearnsii*	18979	2.43
mearnsii	18607	63.8	2.83	*mearnsii*	16246	2.42
mearnsii	16621	62.5	2.79	*mearnsii*	18607	2.40
irrorata	18619	67.5	2.45	*mearnsii*	16380	2.24
irrorata	17145	60.0	2.42	*mearnsii*	18975	2.17
mearnsii	18975	61.3	2.36	*irrorata*	18619	2.09
dealbata	16267	63.8	2.35	*irrorata*	17145	2.08
mearnsii	16380	65.0	2.33	*melanoxylon*	17263	2.08
melanoxylon	17263	68.8	2.30	*binervata*	17260	2.05
binervata	17260	63.8	2.30	*dealbata*	16267	2.01
melanoxylon	19350	65.0	2.24	*dealbata*	18973	1.95
fulva	18861	48.8	2.13	*melanoxylon*	19350	1.95
dealbata	18973	45.0	2.10	*fulva*	18861	1.86
implexa	18978	52.5	2.05	*dealbata*	16376	1.85
dealbata	16376	52.5	2.03	*glaucocarpa*	18092	1.83
implexa	18611	68.8	2.03	*silvestris*	16254	1.80
melanoxylon	19494	65.0	2.03	*implexa*	18978	1.80
fulva	18972	50.0	2.01	*fulva*	18972	1.78
silvestris	16254	51.1	1.96	*implexa*	18611	1.76
dealbata	16271	57.5	1.86	*melanoxylon*	19494	1.76
melanoxylon	19001	57.5	1.85	*dealbata*	16271	1.70
irrorata	18626	60.0	1.84	*melanoxylon*	19001	1.70
parramattensis	17711	60.0	1.81	*irrorata*	18626	1.68
glaucocarpa	18092	58.8	1.80	*parramattensis*	17711	1.63
glaucocarpa	18065	60.0	1.74	*glaucocarpa*	18065	1.62
melanoxylon	18521	57.5	1.73	*decurrens*	15847	1.61
parramattensis	14723	63.2	1.72	*parramattensis*	14723	1.60
decurrens	15847	40.0	1.69	*melanoxylon*	18521	1.59
implexa	18859	60.0	1.64	*implexa*	18859	1.59
decurrens	14768	52.5	1.64	*glaucocarpa*	15473	1.54
glaucocarpa	15473	62.6	1.59	*cincinnata*	19302	1.47
elata	18251	52.5	1.47	*cincinnata*	19289	1.47
mearnsii	Local	62.5	1.41	*decurrens*	14768	1.45
elata	18252	37.5	1.36	*melanoxylon*	19322	1.35
melanoxylon	19322	31.3	1.33	*elata*	18251	1.34
chrysotricha	18620	42.5	1.30	*mearnsii*	Local	1.33
elata	18253	37.5	1.02	*chrysotricha*	18620	1.14
cincinnata	17634	43.8	0.73	*elata*	18252	1.13
cincinnata	19302	37.5	0.71	*cincinnata*	17634	0.98
cincinnata	19005	38.8	0.63	*elata*	18253	0.91
cincinnata	19289	35.0	0.62	*cincinnata*	19005	0.83
Overall mean		**55.8**	**1.85**			**1.77**
F-probability		**<001**	**<001**			**<001**
Average LSD.		**0.46**	**0.62**			**0.46**

(18250) and *A. silvestris* (15852), failed to germinate, and the three seedlots of *A. neriifolia* (14735, 14759 and 169290) from Queensland performed poorly (2–5 cm after 3 months) and gradually died out at the nursery stage. Nursery observations showed that in contrast to seedlings at Bavi, both bipinnate and phyllodinous species were growing well, with *A. melanoxylon* the most vigorous. Except for *A. cincinnata*, which grew very slowly at the nursery stage (only 5–10 cm), seedlings of the remaining seedlots were 40–50 cm high and ready for planting out at 3 months.

Trial assessment at age 6, 12 and 16 months suggested that temperate acacias are better adapted to the conditions at Dalat than at Bavi. Survival, height and diameter growth of all species planted were significantly higher than at Bavi (Table 7). The most promising species were *A. mearnsii, A. irrorata* and the phyllodinous *A. binervata* and *A. melanoxylon*. As in the Bavi trial, *A. cincinnata* and *A. elata* (which appear to require high moisture) and the narrowly distributed *A. chrysotricha* and *A. fulva* did not adapt to planting on these barren degraded sites.

Table 7. Survival at different ages of *Acacia* species tested at Dalat, Lam Dong.

Acacia species	Number of seedlots tested	Species mean survival (%)			Species mean height (m)	Species mean Dgl (cm)
		Time after planting (months):				
		6	12	16	16	16
1 *binervata*	1	85.0	75.0	63.8	2.30	2.05
2 *chrysotricha*	1	61.2	51.0	42.5	1.30	1.14
3 *cincinnata*	4	68.7	51.0	38.8	0.67	1.18
4 *dealbata*	4	76.2	69.1	54.7	2.09	1.88
5 *decurrens*	2	73.8	53.8	46.3	1.67	1.53
6 *elata*	3	65.8	45.9	33.3	1.28	1.13
7 *fulva*	2	76.9	71.9	49.4	2.07	1.82
8 *glaucocarpa*	3	85.4	76.0	60.3	1.71	1.66
9 *implexa*	3	84.1	75.5	60.4	1.91	1.72
10 *irrorata*	3	87.5	80	62.5	2.24	1.95
11 *mearnsii*	7	84.0	78.7	64.8	2.51	2.23
12 *melanoxylon*	6	78.9	70.5	62.5	1.92	1.74
13 *parramattensis*	2	87.0	74.2	61.6	1.77	1.62
14 *silvestris*	1	72.5	70	51.1	1.96	1.80
Overall mean	**42**	**78.6**	**68.6**	**55.8**	**1.85**	**1.77**

Results from the variance analysis carried out for data collected at age 16 months (Table 6) showed that growth rate of the 42 seedlots tested differed significantly from each other. Except for the local *A. mearnsii*, which was planted 1.5 months later, all six provenances of *A. mearnsii* belonged to the top-ranking group and their height (2.4–3.0 m after 16 months), diameter growth (2.2–2.6 cm) and survival rate (61–76%) were significantly higher than the other species. In terms of survival and diameter growth, there was no significant difference between the six *A. mearnsii* provenances, but the height growth of seedlots 16246 (Nowra NSW), 18979 (Blackhill Reserve, Kyneton, Vic.), 18607 (Berrima, NSW) and 16621 (Bodalla, NSW) was slightly higher than 18975 (Bungendore, NSW) and 16380 (Nowa Nowa, Victoria).

A. irrorata seedlots 18619 (Bodalla, NSW) and 17145 (Mt Mee Qld) are also promising with height (2.42–2.45 m) and diameter growth (2.08–2.09 cm) ranking them in the top group with *A. mearnsii.*

The well known high quality timber producer *A. melanoxylon* is growing well and is relatively homogeneous at Dalat in contrast to its performance at Bavi. At the nursery stage and 6 months after planting in the field, survival and growth of all six *A. melanoxylon* seedlots placed them in the top-ranking group. Some seedlots of *A. melanoxylon* such as 19494 (Kannunah, Tasmania) and 19350 (Otways, Victoria) were growing faster than *A. mearnsii.* Despite the fact that growth of *A. melanoxylon* is slightly less than that of *A. mearnsii* and *A. irrorata* at age 16 months, this species has still proved adaptable to the Dalat area. Considering tree growth, survival and stem form, the most promising provenances of this species are 17263 (Mt Mee, Qld), 19350 and 19494. Their survival was above 65% and tree height at 16 months more than 2 m.

Discussion and Conclusions

It is not feasible to draw final conclusions about the most promising species and provenances at age 16 months, but preliminary results indicate that some Australian temperate *Acacia* species are quite adaptable and show promise for planting on barren and degraded subtropical highland sites of Vietnam where tropical acacia species such as *A. auriculiformis* (Bavi trial) and *A. cincinnata* (Dalat trial) perform poorly.

Poor performers were narrowly distributed species such as *A. dangarensis, A. fulva* and *A. chrysotricha.* And the high altitude *A. obliquinervia* (960 m asl), *A. binervata, A. cincinnata, A. nanodealbata, A. elata, A. silvestris* and *A. trachyphloia,* which grow in either moist eucalypt or rain forests and near watercourses in their native habitats (Tame 1992) were also poor performers in these trials.

Based on survival and growth, *A. mearnsii* is the most promising species at both trial sites. Provenances of this species were always in the top ranking, but there was no clear geographical pattern to the survival and growth of the provenances tested. At Bavi, the most promising provenances of *A. mearnsii* were from Victoria (17933) and South Australia (17928) and their survival and growth were significantly higher than provenances from NSW and Tasmania. However differences between *A. mearnsii* provenances tested at Dalat were not significant and the two top-ranked provenances were from NSW (16246) and Victoria (18979). It is interesting to note that provenances 17933 (Omeo Highway, Victoria) and 18979 (Blackhill Reserve, Kyneton, Victoria) are regarded as amongst the most promising at different sites in the subtropical highlands of southern China such as at Ganzhou, Nandan and Nanping (Gao and Li 1991) and also at Longdouxie, Guangdong (Yang et al. 1991). Results of the test planting at Bavi nursery also indicate that *A. mearnsii* could tolerate sites at lower elevation.

The other species which also performed quite well were *A. irrorata* (18622), *A. glaucocarpa* (18065) and *A. leucoclada* (18621) at Bavi in the north and *A. irrorata* (18619 and 17145), *A. dealbata* (16267) and *A. binervata* (17260) at Dalat in the south.

In the case of *A. melanoxylon,* a long-lived species of great interest for quality timber production, eight provenances were included in both trials and their performance at Dalat trial is very promising. Three seedlots (17263, 19350 and 19494) were the best of the six tested at Dalat. They had a survival rate of 65–69%, were homogeneous in their performance, had good stem form, and reached a mean height of 2.0–2.3 m after 16 months.

References

Gao Chuan Bi and Li Ji Yuan 1991. *Acacia mearnsii* provenance trials in Southern China. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. ACIAR, Canberra, 209–214.

Nguyen Ngoc Binh 1997. Forest Land of Vietnam. Agriculture Publishing House, Hanoi, 156 p. (in Vietnamese).

Nguyen Ngoc Lung 1994. Present status of reforestation in Vietnam. In: National Workshop, Strengthening Reafforestation Programmes in Vietnam. UNDP/FAO Project RAS/91/004 and Ministry of Forestry Vietnam, 9–12.

Tame, T. 1992. Acacias of Southeast Australia. Kangaroo Press, 206 p.

Vivekanandan, K. 1993. Experience with acacias in Sri Lanka. In: Kamis Awang and Taylor, D.A., ed., Acacias for Rural, Industrial and Environmental Development. Winrock International and FAO, Bangkok, Thailand. 73–79.

Williams, E.R. and Matheson, A.C. 1994. Experimental Design and Analysis for Use in Tree Improvement. CSIRO and ACIAR, Melbourne, 174 p.

Yang Minquan, Searle S.D. and Zeng Yutian 1991. Growth of Australian acacias in species/provenance trials in subtropical Guangdong, China. In Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. ACIAR, Canberra, 219–223.

Acacias for Saltland in Southern Pakistan

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Abstract

Salinity is a serious threat to agricultural production in Pakistan. Engineering efforts to lower ground water levels and reduce salinity have not been very successful. However, salt-affected farmland may be productively utilised and even reclaimed under certain conditions by growing trees and shrubs.

This paper summarises early (21 and 36 months) results from a species evaluation trial conducted on moderately to severely saline land near Hyderabad (Sindh province) in Pakistan. Some acacias, including *Acacia ampliceps* and *A. stenophylla*, were found to be more salt-tolerant than several *Casuarina* and *Eucalyptus* species. *A.. stenophylla* and *A. nilotica* survived well and continued to grow after two months of flooding and thus demonstrated their tolerance of combined waterlogging and salinity.

IN Pakistan, approximately 6.5 million ha of agricultural land are salt-affected (Anon. 1996). Development of shallow, saline water tables and root-zone waterlogging, the main causes of the upward flux of salts, is due to intensive and continuous use of surface irrigation. Seepage of water to the water table has altered the hydrological balance of the Indus Basin where ground water following monsoons often rises to within 1.5 m of the soil surface over 25% of the cultivated area. Expensive drainage efforts over the years have not substantially improved the situation.

Therefore, salinity will be a long term problem and suitable land utilisation choices will need to be made. Use of salt-tolerant crops is likely to be feasible only for slightly to moderately saline soil (Maas and Grieve 1994). Planting trees and shrubs should to be a logical choice for salt-affected land because many species are moderately to highly salt-tolerant (Marcar et al. 1995). Farm forestry is also becoming of increasing importance in many parts of Pakistan for the provision of various wood and non-wood products, shade and shelter, and more recently, as an option for managing high water tables and utilising saltland (e.g. Nizamani and Shah 1997).

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Australian, other exotic and local tree species, including acacias, have been evaluated on saline, sodic and waterlogged land in Pakistan in a number of trials over a ten year period (e.g. Marcar et al. 1991; Ansari et al. 1993; Hussain and Gul 1993). This paper reports on the performance of several *Acacia* species included in a species evaluation trial conducted on saline land at Tando Jam, near Hyderabad (Sindh province) in Pakistan.

Materials and Methods

A species evaluation trial was planted on highly saline land, underlain by a shallow (less than 2 m) saline watertable, at the Atomic Energy Agricultural Research Centre (AEARC) field station, Tando Jam (lat. 23°35′N, long. 28°00′E, alt. 35 m), near Hyderabad (Sindh province), Pakistan, in November 1990. Annual average rainfall at the site is less than 350 mm, the majority falling during July and August. The area has long hot summers and mild winters with mean minimum/maximum temperatures of 26/40°C and 12/30°C for summer and winter respectively. Soils are generally clay loam to clay, low in nitrogen, moderately high in total phosphorus (P) (but low in available P) with a pH range of 7.5 to 8.2. Depth to water table varies from 2 to 3 m from the soil surface; there was no sub-surface drainage under this trial.

Soil salinity is variable (estimated EC_e range in the root-zone (0–60 cm) is 5–40 dS m^{-1}), but mostly high (greater than 15 dS m^{-1}).

Rapid assessments of soil salinity across the experimental site and under individual trees were conducted using a hand-held electromagnetic induction device (EM model 38). Using this device, apparent conductivity (EC_a) values calculated for the 0–60 cm horizon (or similar depth) were converted to EC_e after determination of soil texture, water content and $EC_{1:5}$ for specific profiles spanning the range of salinity levels across the site (Slavich and Petterson 1990).

Twenty-four seedlots, including 12 from seven *Acacia* species (Table 1), were included. A randomised complete block design was used with four replicates, each replicate having a rectangular plot of 10 (2 × 5) trees per seedlot and with 2 m between trees and rows. Dead plants were replaced at one and three weeks after transplanting. Irrigation with good quality canal water (concentration of total dissolved solids c. 600 ppm) was applied only during the early phase of establishment (up to 2 months) and subsequently no more water was applied.

Observations of survival, growth (height, crown diameter and basal and/or breast height stem diameter) and tree health were recorded at 9, 12, 15, 21 and 36 months after planting. For some species, individual tree growth and EC_e data were correlated in order to determine response to salinity. Severe flooding due to heavy monsoonal rains occurred in July/August 1992 (c. 21 months from planting). This resulted in the death of the majority of trees of most seedlots. Above-ground biomass of dead plants was harvested at this stage: stems and leaves were separated for weighing and stem diameter recorded. Surviving trees were allowed to grow for another year when they were also harvested (ie at c. 36 months after planting).

Species differences in growth response to salinity were assessed by fitting linear regression lines using the Genstat 5 statistical package (Williams and Matheson 1994) after removing data points corresponding with EC_e of less than 5 or greater than 28 dS m^{-1}. This then gave the same range of EC_e for all three species.

Results

Significant differences were observed between seedlots for survival, height and diameter at breast height at 21 months after planting, i.e. before flooding (Table 2). *Acacia ampliceps* demonstrated better survival and growth than other species except *Atriplex lentiformis*, a halophytic forage shrub (Table 2). *Acacia auriculiformis* and *A. salicina* did not survive. *Acacia ampliceps* was the most productive species followed by *A. stenophylla*, *A. machonochieana*, *A. nilotica* and *A. victoriae*.

Table 2. Mean squares for analyses of variance based on plot means for survival (arc sin transformed), height, stem diameter at 10 cm above the ground and at 1.3 m (breast height) and crown diameter of nine *Acacia* seedlots (five species) at 21 months on a moderately to highly saline site near Hyderabad, Pakistan.

Source of variation	Survival	Height	Diameter (at 10 cm)	Diameter (breast ht)	Crown diameter
Seedlot	0.56***	1.22*	14.67 ns	13.10*	4885ns
Residual	0.10	0.50	6.15	4.64	2758

Note: * indicates the factor (i.e. source of variation) proved to have a significant effect (p 0.05) in an analysis of variance
'ns' indicates the factor did not to have a significant effect ($p > 0.05$).

Table 1. *Acacia* seedlots used in a species evaluation trial at Tando Jam, Pakistan, with details of seed origin. Except for *A. nilotica*, all acacias are of Australian origin (CSIRO Forestry and Forest Products, Australian Tree Seed Centre, seedlot numbers provided).

Species	CSIRO seedlot number	Origin (latitude, longitude, altitude)
Acacia ampliceps	15741	Wolf Creek Crater, WA (19°10′S, 127°48′E, 360 m)
Acacia ampliceps	14668	40 km E Hall's Creek, WA (18°26′, 127°51′, 400 m)
Acacia ampliceps	15734	70 km NW Wave Hill, NT (17°00′, 130°34′, 250 m)
Acacia ampliceps	15769	Karratha, WA (20°43′, 116°51′, 1 m)
Acacia auriculiformis	16484	Morehead River, Qld (15°03′, 143°40′, 50 m)
Acacia maconochieana	14676	44 km SW Lake Gregory, WA (20°17′, 127°19′, 260 m)
Acacia nilotica	n/a	seed supplied by Sindh Forest Department, Hyderabad
Acacia salicina	16648	near Moura, Qld (24°35′, 149°55′, 109 m)
Acaciab stenophylla	14670	Cow Creek, WA (18°41′, 126°21′, 340 m)
Acaciab stenophylla	15736	Lake Nongra, NT (18°11′, 129°44′, 300 m)
Acacia victoriae	17209	Lake Josceline, WA (18°06′, 124°24′, 65 m)

WA is Western Australia, NT is Northern Territory, Qld is Queensland

Inter-provenance differences were also noted for *A. ampliceps*, where provenance 15741 (Wolfe Creek Crater, WA) had the best survival and growth of the four provenances studied, and for *A. stenophylla*, where provenance 15736 (Lake Nongra, NT) had better growth and survival than provenance 14670 (Cow Creek, WA).

Some trees survived the two months of flooding (Table 3) and these were destructively harvested after a year. Surviving trees of *A. stenophylla* and *A. nilotica* continued to grow well during the year following flooding. Surviving trees of *A. ampliceps* (15769) grew relatively slowly following flooding.

Data shown in Table 3 are means of four replicates. But because soil salinity is very variable spatially as well as temporally, it was desirable to compare species' response to salinity. EC_a measurements for each tree have enabled this to be done for several species with high survival, prior to flooding. Figure 1 shows the response in height growth for *A. ampliceps* (all provenances combined), *A. stenophylla* (both provenances combined) and *A. nilotica* to increasing soil salinity, represented as estimated EC_e in the root-zone. Reductions in growth due to salinity were similar for the three species. The equations for the fitted linear regression lines are: *A. ampliceps* $Y = -0.11x + 5.6$, *A. nilotica* $Y = -0.11x + 4.55$, *A. stenophylla* $Y = -0.11x + 4.50$.

Discussion

Before the devastating floods, several acacias performed very well in this trial, both by the virtue of their high growth rates and their relative tolerance to soil salinity. *Acacia ampliceps* was the best followed by *A. stenophylla*, *A. maconochieana* and *A. nilotica*. The good performance of these species has been demonstrated in previous trials conducted at Tando Jam and at other experimental sites in Pakistan (e.g. Marcar et al. 1991; Hussain and Gul 1993). Marcar reports that *A. ampliceps* has also performed quite well on moderately to highly saline soils in Thailand, except where soils are acidic, seasonally waterlogged or too dry. In Australia he found that *A. stenophylla* has survived well and suffered little growth reduction where root-zone soil salinities (EC_e) are 10–15 dS m^{-1}. These species performed considerably better than *Eucalyptus microtheca* and *E. camaldulensis*, and also better than *Casuarina glauca* in this trial. Use of the EM38 technique afforded a good opportunity to provide an integrated measure of the root-zone salinity of individual trees and plots. This in turn enabled relationships to be developed between soil salinity and tree growth. This technique has been used to compare tree performance in several trials (e.g. Dunn et al. 1995).

Significant between-provenance variation for growth and survival was found for *A. ampliceps* in

Table 3. Growth performance (at 21 and 36 months) of several *Acacia* species and provenances, in comparison with *Eucalyptus*, *Casuarina* and *Atriplex* species, included in a species evaluation on moderately to highly saline land near Tando Jam, Sindh province, Pakistan. Note: Ht refers to height, D10 refers to stem diameter at 10 cm, DBH refers to stem diameter at breast height and CD refers to crown diameter. *Acacia auriculiformis* (16484) and *A. salicina* (16648) were also planted but trees did not survive.

Acacia species and provenance	Surv %	Ht m	D 10 cm	DBH cm	CD cm	Surv %	Ht cm	D 10 cm	DBH cm	CD cm
	.... 21 months				....	.... 36 months				....
nilotica	55	2.73	6.4	4.0	192	45	3.53	9.4	6.2	229
ampliceps (15741)	98	3.70	9.7	7.9	154	0	0	0	0	0
ampliceps (15769)	80	2.67	6.9	4.2	146	18	2.60	5.6	2.9	146
ampliceps (14668)	78	3.27	9.7	5.3	159	0	0	0	0	0
ampliceps (15734)	78	2.88	9.1	5.8	168	0	0	0	0	0
stenophylla (14670)	38	2.67	5.6	3.8	166	35	3.47	10.7	5.9	305
stenophylla (15736)	65	3.13	7.0	3.9	173	55	4.05	10.3	7.1	222
maconochieana (14676)	58	2.24	4.4	1.7	94	0	0	0	0	0
victoriae (17209)	23	2.45	5.7	3.1	110	0	0	0	0	0
Standard error of difference between means (sed)	15	0.50	1.75 ns	1.52	37 ns	nc[1]	nc	nc	nc	nc
Atriplex lentiformis	100	2.64	6.7	2.8	220	18	293	9.0	3.8	287
Casuarina glauca (15929)	70	1.44	2.0	1.2	43	35	217	3.2	1.1	113
Eucalyptus microtheca (15068)	45	2.28	3.4	1.7	94	23	329	6.1	3.8	156
E. camaldulensis (15441)	13	2.90	4.4	2.2	101	0	0	0	0	0

[1] nc = analysis of variance not conducted for this data because of poor tree survival

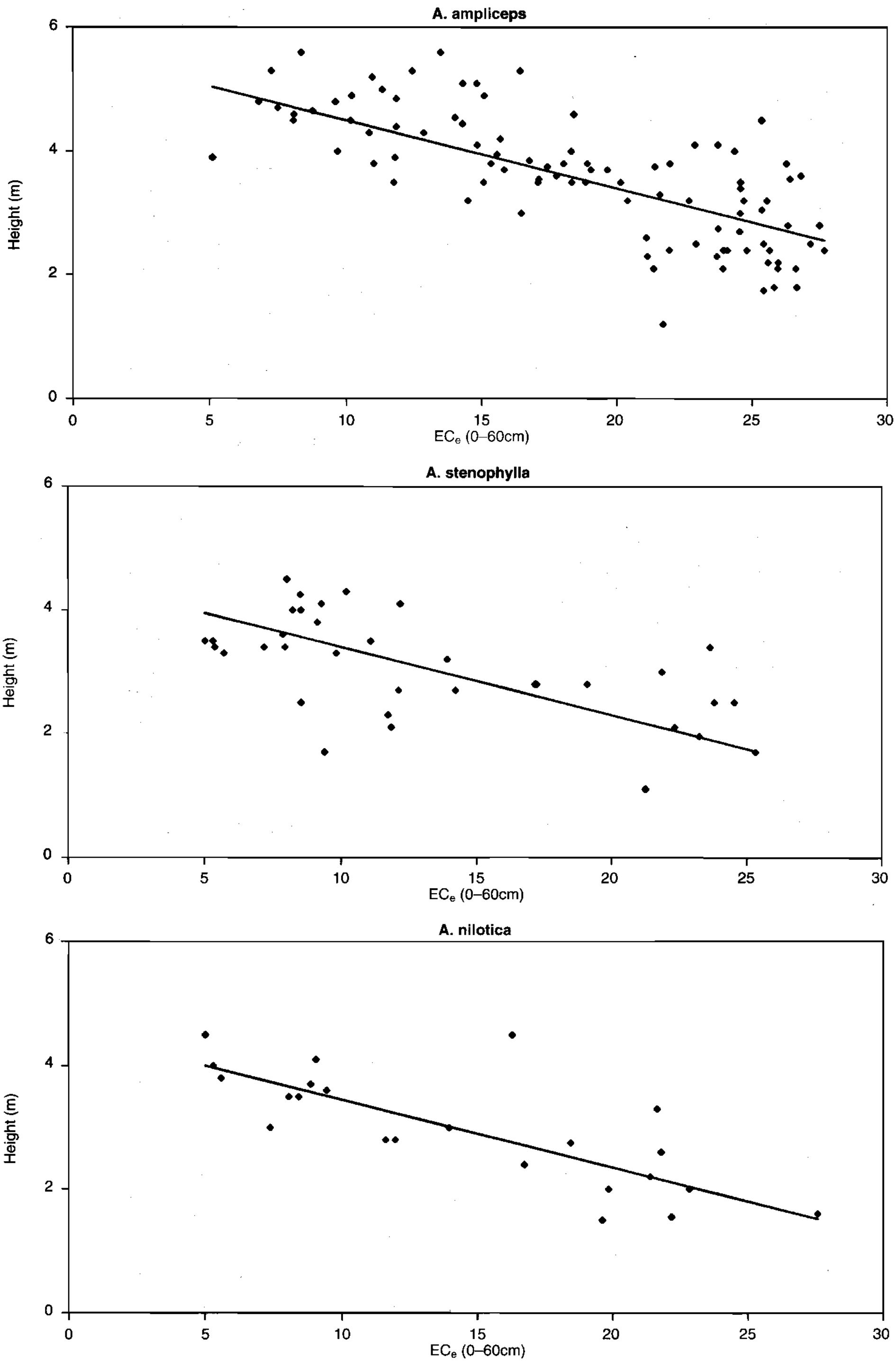

Figure 1. Effect of root-zone salinity on height growth of *A. ampliceps* (for provenances combined), *A. stenophylla* (two provenances combined) and *A. nilotica* at 21 months of age, as part of a species evaluation trial near Tando Jam, Pakistan.

this trial. Consistent rankings for the performance of different provenances have been made from several trials within Pakistan. The provenance from Wolf Creek Crater, WA (15741) had the best performance in this trial. This provenance has also performed well in trials on sandy soils irrigated with saline water near Karachi (Pakistan) though not as well as the provenance from Wave Hill, NT (14631) (S. Ismail, pers. comm.). The provenance from Wave Hill, NT, also had the best performance in a provenance-family trial near Faisalabad, Punjab province (Marcar et al. these Proceedings). The provenance from Karratha (WA, 15769) was the least productive. Marcar et al. (these Proceedings) also showed that this provenance was the least productive. In addition, the provenance from 80 Mile Beach, WA (15762) was also shown to perform relatively poorly (Marcar et al. these Proceedings; S. Ismail, pers. comm.).

Differences in the salt tolerance of *Acacia* species are probably due to several physiological, morphological and other mechanisms acting in a complex but integrated manner. Ansari reports that at 24 months the more salt-tolerant species had lower concentrations of sodium (Na) and chloride (Cl) in leaves sampled from trees in this trial. Evidence from glasshouse studies also suggests that uptake rates and distribution of Na and Cl within the plant is related to differential salt tolerance in acacias (Marcar et al. 1994).

When waterlogged conditions occurred for up to 2 months during the hot months of July and August 1992, as a result of heavy monsoonal rains and restricted drainage, survival of most species was drastically reduced. *A. nilotica* and *A. stenophylla* managed to retain good survival under these conditions. Marcar found these species tolerated these conditions in other trials within Pakistan and Australia. The physiological reasons for the good performance of these species under these conditions has not been explored but warrants investigation. Presumably roots of these species were able to continue growing and restrict the uptake of salts better than sensitive species (e.g. for *Eucalyptus* species of varying salt and waterlogging tolerance (Marcar 1993)).

Recent studies with acacias in Pakistan (Khanzada et al. 1997) and with eucalypts in Australia have shown that water use of trees is directly related to their growth rate and size (specifically leaf area), even under saline conditions. Thus, although *A. nilotica* and *A. ampliceps* were shown to differ in their water use rates per tree, rates per sapwood area were similar (Khanzada et al. 1997). Higher water use is desirable in order to increase opportunities for tree plantings to reduce water table depths and therefore assist with salinity control. Therefore correct species choice is essential to ensure best growth. Ansari also reports that in a trial at Tando Jam the application of mulch around seedling trees at planting has improved survival and growth of both *A. ampliceps* and *A. nilotica*.

Several new trials involving acacias were established at AEARC (Tando Jam) during 1995. These trials comprised (i) evaluation of six *Acacia* species, (ii) impact of salt-tolerant strains of *Rhizobium* on growth of *A. ampliceps* and *A. stenophylla* and (iii) evaluation of several provenances of *A. ampliceps* and *A. stenophylla*. Preliminary data indicate significant species and provenance differences as well as positive impacts of salt-tolerant *Rhizobium* on growth.

These and other trials involving *Acacia* species in Pakistan have provided valuable information on possible uses of trees on saline farmland in Pakistan. Within-species variation is now being thoroughly investigated for *A. ampliceps* in a provenance-family trial near Faisalabad (Marcar et al. these Proceedings). Provenances of other species (e.g. *A. stenophylla*) are also being investigated. It would also be desirable to evaluate the degree of interspecific variation for growth and salt tolerance within non-Australian acacias such as *A. nilotica*. The local *A. nilotica* deserves special mention because it is already established as a very useful tree in Pakistan and the present study has only further substantiated earlier contentions (FAO 1989; Ansari et al. 1993). Farmers in the Sindh are familiar with planting *A. nilotica* in the 'hurries' system in order to gain benefits of improved fertility and also reductions in soil pH and salinity (Keerio 1993). Glasshouse experimentation at the University of Bangor (UK) has revealed some significant variation between families of *A. nilotica* (C. Cahalan, pers. comm.) suggesting that field evaluations would be very useful.

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References

Anon. 1996. Agricultural Statistics of Pakistan, 1994–95 Government of Pakistan, Ministry of Food, Agriculture and Live Stock, Islamabad.

Ansari, R., Khanzada, A.N. and Khan, M.A. 1993. Acacias for rural, industrial and environmental development in Pakistan. In: Awang, K. and Taylor, D.A., ed., Acacias for Rural Industrial and Environmental Development. Winrock International and FAO, Bangkok, Thailand. 63–70.

Dunn, G.M., Taylor, D.W., Nester, M.R. and Beetson, T.B. 1995. Performance of twelve selected Australian tree species on a saline site in southeast Queensland. Forest Ecology and Management 70, 255–260.

FAO, 1989. *Acacia nilotica* (L.) Willd. ex. Del.: Its Production, Management and Utilization in Pakistan. Field Document No. 20. FAO-RAPA, Bangkok, Thailand.

Hussain, A. and Gul, P. 1993. Selection of tree species for saline and waterlogged areas in Pakistan. In: Davidson, N. and Galloway, R., ed., Productive Use of Saline Land. ACIAR Proceedings No. 42. Canberra, Australia, 53–55.

Keerio, G.R. 1993. Soil fertility and economic studies of *Acacia nilotica* hurries agroforestry system in Sindh, Pakistan. PhD Thesis, University of Idaho. 82 p.

Khanzada, A.N., Morris, J.D., Ansari, R., Slavich, P.G. and Collopy, J.J. 1997. Groundwater uptake and sustainability of *Acacia* and *Prosopis* plantations in southern Pakistan. Agriculture and Water Management (submitted).

Maas, E.V. and Grieve, C.M. 1994. Salt tolerance of plants at different stages of growth. In: Naqvi, S.S. M., Ansari, R., Flowers, T.J. and Azmi, A.R., ed., Current Developments in Salinity and Drought Tolerance of Plants. AEARC, Tando Jam, Pakistan, 181–197.

Marcar, N.E. 1993. Waterlogging modifies growth, water use and ion concentrations in seedlings of salt-treated *Eucalyptus camaldulensis, E. tereticornis, E. robusta* and *E. globulus*. Australian Journal of Plant Physiology, 20, 1–13.

Marcar, N.E., Hussain, R.W., Arunin, S. and Beetson, T. 1991. Trials with Australian and other *Acacia* species on salt-affected land in Pakistan, Thailand and Australia. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 229–232.

Marcar, N.E., Crawford, D., Aswathappa, N. and Thomson, L.A.J. 1994. Salt and waterlogging tolerance of subtropical and tropical leguminous Australian native trees: a review. In: Naqvi, S.S.M., Ansari, R., Flowers, T.J. and Azmi, A.R., ed., Current Developments in Salinity and Drought Tolerance of Plants. AEARC, Tando Jam, Pakistan, 375–388.

Marcar, N., D. Crawford, D., Leppert, P., Jovanovic, T. Floyd, R. and Farrow, R. 1995. Trees for Saltland: a Guide to Selecting Native Species for Australia. CSIRO Press, Melbourne, Australia.

Nizamani, A. and Shah, I. 1997. Real problems, real solutions. The Way Ahead (IUCN, Pakistan) 4: 25–27.

Slavich, P. and Petterson, G.H. 1990. Estimating average root-zone salinity from electromagnetic induction (EM 38) measurements. Australian Journal of Soil Research, 38, 453–463.

Williams, E.R. and Matheson, A.C. 1994. Experimental Design and Analysis for Use in Tree Improvement. CSIRO, Canberra, 169 p.

Growth and Form of 25 Temperate *Acacia* Species in Two Trials near Canberra, Australia

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Abstract

This paper presents results from two field trials at Kowen and Uriarra near Canberra, Australia for the growth (height, diameter, volume, stem number, stem form, branching characteristics, root suckering and impact of bird attack) of 25 acacia species at 32 months after planting. Frost, with minimum temperatures falling to –6°C, was the most limiting factor at these sites, and seriously affected the survival and growth of provenances of *A. binervata*, *A. cangaiensis*, *A. elata*, *A. falciformis*, *A. implexa* and *A. melanoxylon*.

The largest trees in trial at Kowen, based on a volume index using diameter at ground level (10 cm), were provenances of *A. decurrens* (from Picton-Mittagong and Goulburn NSW and *A. mearnsii* (Tarpeena South Australia, Kyneton Victoria, and Bodalla NSW). At Uriarra the largest trees were the same provenances of *A. mearnsii* that had performed well at Kowen as well as a provenance from Bungendore NSW, *Eucalyptus nitens* (Badja State Forest NSW), *A. dealbata* from Errinundera Plateau, Victoria and *A. fulva* from Mt Yengo NSW.

TWO field trials were established near Canberra, Australia as part of an international series of temperate acacia species elimination trials supported by the Australian Centre for International Agricultural Research (ACIAR) through the project 'Australian acacias for sustainable development in China, Australia and Vietnam'. These trials continue the exploration by CSIRO Forestry and Forest Products of the potential of Australian acacia tree species related to commercially successful *Acacia mearnsii*. This species is used in several countries to produce tannin for leather tanning and waterproof wood adhesives, and wood for paper, rayon, charcoal, fuelwood, firing ceramics, marine posts and mushroom media (Searle 1996). This research aimed to identify the most productive acacia species for farm forestry and plantation uses in temperate Australia. In particular the Canberra trials focused on identifying suitable species for firewood plantations to supply the Canberra market, which consumes c. 80 000 tonnes of fuelwood per year. It also aimed to expand the currently limited choice of climatically adapted, nitrogen-fixing, woody species for domestic and industrial use in mountainous regions of the tropics and subtropics.

The taxonomic focus of the trials was on bipinnate acacias closely related to *A. mearnsii.* These belong to the subgenus *Phyllodineaea* section Botrycephalae (42 species with adult bipinnate foliage) (Maslin and McDonald 1996) which includes some of the largest acacia species in temperate Australia. Nineteen tree-form Botrycephalae species, including rare and little-known species such as *A. blayana*, *A. cangaiensis*, *A. chrysotricha*, *A. dangarensis* and *A. fulva* were selected for trial together with six phyllodinous species which either had valuable timber, frost or drought tolerance, good form and size. All species, with the exception of *A. deanei*, reach 10 m or more in their natural habitat.

These trials follow up promising field trials established in northern Guangdong province China at 250–480 m asl at c. 25°N planted as part of a previous ACIAR project (Yang et al. 1991). Nineteen Australian species (14 bipinnate; five phyllodinous) showed excellent growth and form until a one-in-50 year cold event at the end of 1991 (Yang et al. 1994) seriously damaged a number of the species. Bipinnate acacias have also performed well in Sri Lanka at a high altitude (1160 m asl) site at 30 months of age

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with *A. glaucocarpa*, *A. mearnsii* and *A. parramattensis* having potential for reforestation of degraded lands at high elevation (Weerawardane and Vivekanandan 1991).

This paper describes the growth (height, diameter (diameter at ground level (dgl) and diameter at breast height (dbh)), volume, stem number, stem form, branch size and density, root suckering and impact of bird attack) of 25 acacia species at 32 months after planting. Frost tolerance of the species/provenances in trial is described in Searle (these proceedings).

Materials and Methods

Species and trial sites

The 25 acacia and one eucalypt species in trial were represented by 64 seedlots. The collection locations of these are mapped in Figure 1 and briefly described in Table 4. All the acacia species in trial, with the exception of phyllodinous *A. binervata*, *A. binervia*, *A. falciformis*, *A. implexa*, *A. melanoxylon* and *A. obliquinervia*, have bipinnate adult foliage. The eucalypt in trial, *Eucalyptus nitens*, was included for comparison as it was one of the best performers in earlier species elimination trials in the region and is one of the primary paper pulp plantation species in southeastern Australia.

The trial was replicated at two sites near Canberra within the Australian Capital Territory (ACT) with 2560 trees at each site. The Kowen trial site, 12 km ESE Canberra City (35°20′S, 149°15′E, 585 m asl) was planted on a red podsolic soil derived from old river terrace gravels over Ordovician sediments. The Uriarra trial site, 19 km W of Canberra City (35°18′S, 148°56′E, 618 m asl) was located across two soil types; a red podsolic soil (replicates 2, 3 and 4) and a deep yellow earth (replicate 1) derived from Paddys River volcanics laid down in the Middle Silurian. At both sites the organic carbon, nitrogen and available phosphorus were low. Surface soil pH (0–20 cm) was 4.6 at Kowen and 4.8–5.0 at Uriarra (Snowdon 1996).

Climate

Canberra has a continental climate with a marked variation in temperature from winter to summer. The city experiences very warm to hot days during summer and cold nights with widespread frosts during winter. Temperatures recorded by Canberra Airport Observing Office (35°19′S, 149°12′E, 571 m asl) range from a low of −10.0°C to a high of 43°C (Pearce and Smith 1984). Frosts occur on about 100 days each year.

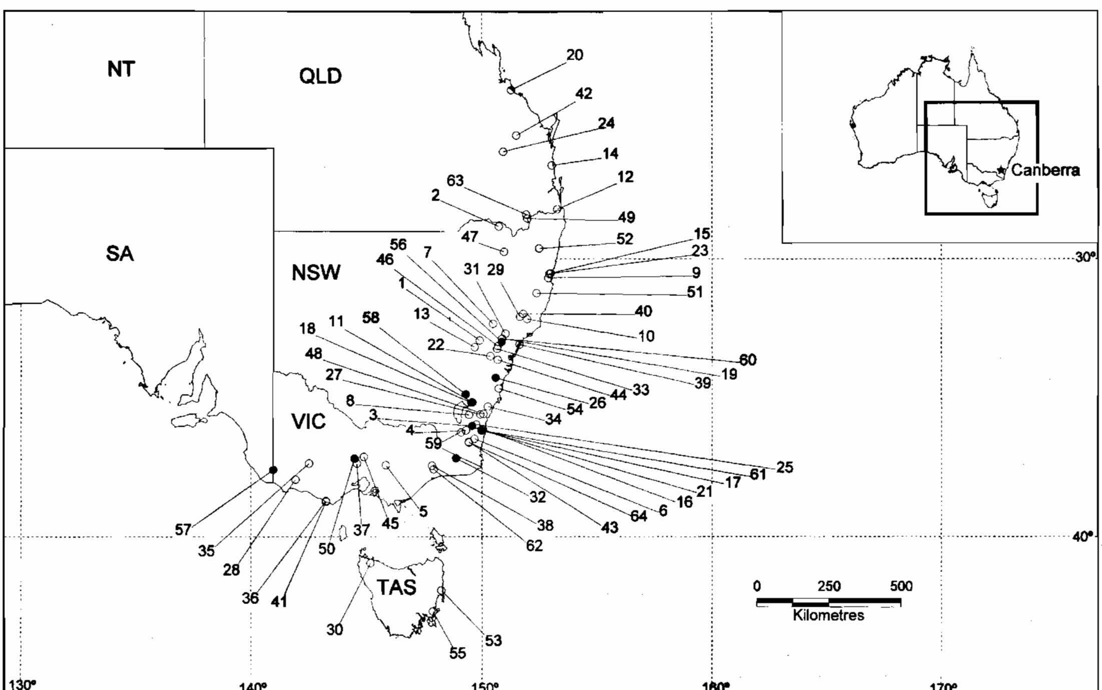

Figure 1. Map showing origin of seedlots used in two field trials near Canberra. The largest (in terms of volume index) species/provenances across both trials are indicated by ●.

Rainfall is fairly evenly distributed throughout the year, averaging about 40 mm per month during winter and increasing to 50–60 mm per month for the rest of the year. The average annual rainfall for Canberra is about 630 mm. Kowen is located c. 6 km E of the Canberra Airport Observing Office and has a similar average annual rainfall. Kowen is the drier of the two trial sites and in 1995 and 1996 annual rainfalls of 688 and 601 mm were recorded respectively. Uriarra, c. 25 km W of the Canberra Airport Observing Office received 1039 mm and 870 mm in 1995 and 1996 respectively and has an annual average rainfall of 824 mm. In 1995, the Canberra Airport Observing Office recorded 89 frosts; in 1996 there were 77, with most occurring between April and October.

Nursery

The seedlings for both trials were raised in glasshouses during winter at the Yarralumla Nursery (ACT Parks and Conservation Service) for sowing in spring. The seed was manually scarified in a sand-paper lined, manually turned drum and soaked in hot water which was left to cool overnight. Two to four seeds were sown in each pot (rigid plastic, black pots 12 cm in length; 5 cm × 5 cm at the top tapering to 4 cm × 4 cm at the base with a semi-open base to ensure root pruning). The seedlings were thinned to 1–2 seedlings per pot at c. 4 weeks of age. The potting mix was composed of composted bark fines, graded sand and composted hardwood dust in a ratio of 5:2:1 plus a number of different fertilisers including a general purpose fertiliser. A liquid fertiliser (20 N:7.4P:16.6K) was sprayed on the foliage two and three months after sowing. At planting the seedlings were healthy and there was considerable variation in size between the seedlings, which ranged from 3 to 30 cm in height. Their subsequent survival in the field, apart from insect attack at Kowen, was excellent.

Trial design

The field trials were arranged in a square lattice (8 × 8) with four replicates. Each plot consisted of 10 trees arranged in two rows of five trees (2.5 m between trees within rows × 3.0 m spacing between rows) and thus each seedlot was represented by 40 trees in each trial. Both trials were surrounded by two rows of buffer trees to minimise the impact of edge effects upon the trees in trial; the outer row was a species/provenance which was expected to grow well (*A. mearnsii* 18975–Bungendore NSW) and its purpose was to provide some measure of protection against winds and cold air drainage. The inner row was an extension of the plots adjacent to the edge of the trial.

Site preparation

Six months before planting, rows were ripped and mounded. This is a standard practice used by ACT Forests to alleviate moisture stress in *Pinus radiata* plantations in this relatively low rainfall region. This practice also raised the roots of the seedlings out of any high water table; provided an easier site to hand plant; provided a temporarily weed-free environment around the seedling; combined well with the water conservation technique of pattern ripping, and returned some soil back into the ripline after the ripper tyne had created a trench. The ripping depth was approximately 60 cm and the mounds varied between 30 and 50 cm in height. Both sites were fenced with vermin-proof fencing to prevent any rabbit or other grazing damage to the seedlings.

Trial management

The trials were planted during a drought and therefore it was not feasible to conduct any chemical weed control prior to planting or to fertilise at planting as had been planned. All trees were watered-in with c. 3 litres of water per tree. The trials were generally kept free of weeds using both knockdown and residual herbicides (Roundup (glyphosate)), a non- selective, non-residual control; Goal, a residual for control of annual grasses and broad-leaved weeds and Pulse, a penetrant) and manual chipping. The trials were fertilised 12 and 24 months after planting with 400 g/tree single superphosphate (NPKS 0:9:0:11% w/w) in 1995 and 250 g/tree Starter 15 (NPKS 13.9:12.7:0:11% w/w) in 1996. Due to a deficiency in the soil and foliage, boron was added in the first year at a rate that had been used for *A. mearnsii*, *Pinus radiata* and eucalypt species (30 g of sodium tetraborate/ tree). This caused boron toxicity in all species with the possible exception of *A. nano-dealbata*. The resulting leaf desiccation and leaf shed was particularly evident during the winter of 1996.

Insecticide (a mixture of Carbaryl, Rogor and Chemspread) was used to control a scale (*Eriococcus* sp.) insect which was killing *Eucalyptus nitens* at both Kowen (five trees killed) and Uriarra (one tree killed).

Measurement

Results are presented from the annual measurement conducted in June (winter) 1997 when the trees were 32 months old. At this time of year, tree growth was minimal. All trees except those classed as runts were measured. These were defined as being equal to or less than one-third the height of the next smallest tree in the same 10-tree plot. These trees were not destroyed as they may have a genetic outcome and it would be important to know what fraction of the population consisted of inferior trees.

Trees known to have been dead for more than 2 months were not measured. A number of trees, particularly *A. dealbata* provenances at Kowen, had dead foliage in the winter months just prior to measurement. This was believed to be the result of drought conditions in the first half of 1997. It was decided to measure these because their growth was still indicative of their performance over the growing season and it was not possible to discern if the trees were dead.

Height

Only one height measurement was taken for each tree in trial. This was defined as total stem length from the ground to the base of the apical growing point of the tallest stem and expressed in metres. In the case of double or multiple-stemmed trees this was the height or length of the tallest (longest) stem. This was measured to the nearest 10 cm if the trees were 1.5 m or taller, or to the nearest 1 cm if the trees were shorter than 1.5 m. Some of the trees at Uriarra were leaning, due to the effect of wind when the trees were less than 8 months old. Their length was measured as it is the custom in Australia to measure the length of the leaning stem rather than calculate the vertical height of such trees.

For trees that showed damage, the height of the green crown was measured and the cause of damage recorded. For example *A. implexa* trees grew coppice stems from the original stem base when the central stem(s) died following damaging frosts. It was the tallest of these that was measured and recorded as a coppice stem.

Diameter

Diameter measurements at ground level and, if the trees were tall enough, at breast height (1.3 m) were taken for each tree in trial. Diameter at ground level (dgl) was defined as 10 cm above the ground surface. A branch was measured as a stem if it originated below 1.3 m (or 10 cm dgl if that was the point of diameter measurement) and at the point of measure (1.3 m or 0.10 m) was at least ≥ 75% of the diameter of the largest stem at the same point. Diameter at breast height was measured for all trees that were ≥ 3.0 m in height. Diameter was measured to the nearest millimetre and expressed in centimetres. A maximum of six stems per plant were measured at ground level and breast height.

For analysis the combined stem diameter was calculated using the following formula (MacDicken et al. 1991):

$$D_{combined} = \sqrt{d_1^2 + d_2^2 + d_3^2 + \ldots + d_6^2}$$

For comparative purposes, it was assumed the trees in trial were all shaped like cones and the following formula was used to combine height and diameter in a volume index:

$$\text{Volume (dm}^3) = \pi \times \text{diameter}^2 \text{ (cm)} \times \text{height (m)} \times 0.00833$$

Form assessment

A form assessment was developed for the trees >3.0 m in height. Trees averaged heights of 3.5 m and 4.1 m at Kowen and Uriarra respectively. The assessment was based on the straightest dominant or co-dominant stem growing in each tree. The index is shown in Table 1.

Table 1. Categories used to assess stem form for trees >3.0 m in height.

Category	Form description of straightest dominant or codominant stem
1	Straight to very slightly crooked; has one minor fault which may be: • a bend or curve in the stem which deviates <5° from stem axis and occurs over a length ≤50 cm • a minor kink or bow which occurs at the base of the stem up to 70 cm above ground level. NB: 1) form assessment ignores zig-zagging of the stem which can occur between the branch nodes. This is prominent in species such as *A. decurrens* and *A. glaucocarpa* 2) form assessment ignores drooping of the apical shoot associated with current season's growth (prominent in species such as *A. fulva* and *A. trachyphloia*)
2	Slightly crooked; has up to two faults which may be: • one fork at any height along the stem • up to two slight bends or bows along the stem which deviate 5–20° from stem axis and occur over a distance of 50–75 cm • one major kink which deviates 30–45° from the stem axis and occurs over a distance ≤30 cm
3	Crooked; has three faults which may be: • one fork at any height along the stem • continuous minor sweeping or bowing along the entire length of the stem which deviates ≤10% from the stem axis • one–two major kinks, which deviate 30–45° from the stem axis and each occurs over a distance of ≤50 cm
4	Very crooked; has four or more faults which may be: • multiple forks along the length of the dominant stem • continuous bowing along the entire length of the stem which deviates >10° from the stem axis • multiple sharp kinks which deviate >45° from the stem axis

Branching assessment

Average branch size and density was assessed for both dominant and codominant stems in each tree ≥3.0 m. Branch size was assessed as an average for the entire tree using a simple three-point index which related the average diameter of a branch at its junction with the stem as a percentage of the diameter of the stem. Branch density was assessed using a simple three-point index based on the average distance (in cm) between branch nodes from the ground level to the terminal bud(s) of the tree. Both indices are shown in Table 2.

Table 2. Categories used to assess tree branching characteristics.

Index value	Branch density—distance between branch nodes (cm)	Index value	Relative branch diameter at junction with stem
1 Light	30–40 cm	1 Light	<25% stem
2 Moderate	20–<30 cm	2 Moderate	25%–≥40% stem
3 Heavy	0–<20 cm	3 Heavy	>40% stem

Number of stems per tree

For all trees ≥3.0 m high, the number of stems was assessed using a simple four-point index. Coppice and regeneration were not assessed. A branch was counted as a stem for this assessment if its diameter at breast height was ≥50% of the diameter of the largest stem at breast height. The index is shown in Table 3.

Table 3. Categories used to assess the number of stems at diameter at breast height (dbh).

Index	No. of stems with dbh ≥50% dbh of largest stem
1	one stem
2	two stems
3	three stems
4	four or more stems

Root suckering

The appearance of root suckers for the seedlots in trial was recorded. This is valuable information for those who wish to either minimise the weedy potential of acacia introductions by choosing non-suckering species or conversely reduce the cost of establishment by selecting species which once successfully introduced will spread of their own accord.

Data analysis

Plot means for survival, height, diameter, volume, branching characteristics and number of stems were analysed using Residual Maximum Likelihood (REML) in GENSTAT version 5.2 (GENSTAT 5 Committee 1990).

Results and Discussion

There were highly significant differences at both sites between seedlots ($P < 0.001$) for all the characteristics measured and assessed. Generally the average seedlot survival, height and diameter (dgl and dbh) was greater at Uriarra than Kowen. However the number of stems per tree was generally higher and the branch density generally greater at Kowen.

Genotype × site interactions

There were highly significant ($P < 0.001$) genotype × site interactions for height which implied seedlots were growing differently on each site. For example three seedlots grew taller at Kowen than Uriarra because at Uriarra their height had been reduced by birds (cockatoos): *A. dealbata* from Bemboka NSW (16376) suffered from serious bird attack (c. 60% of trees at Uriarra were damaged) and to a lesser extent so did *A. parvipinnula* (15844 Colo Heights-Putty Rd NSW) and *A. trachyphloia* (17894 Currowan Ck NSW).

Diameter at ground level was larger at Kowen than Uriarra for seedlots such as *A. silvestris* (17939 Bruthen Vic), *A. parramattensis* (18610 Windsor NSW) and *A. dangarensis* (18608 Mt Dangar NSW). Similarly diameter at breast height was larger at Kowen than Uriarra for *A. melanoxylon* (18981 Grampians Vic.), and multistemmed species such as *A. binervia* (15845 Richmond-Springwood NSW) and *A. obliquinervia* (16273 Bemboka NSW). With reference to stem form, some species grew straighter at Kowen; others at Uriarra. For example *A. melanoxylon* (16526 Mt Gambier SA) and *A. chrysotricha* (18620 Newry S.F. NSW) had significantly better form at Kowen than Uriarra while *A. binervia* (15845 Richmond-Springwood NSW) had significantly poorer form at Kowen. In terms of branch density, trees at Uriarra generally had as many or fewer branches. The shrubby *A. deanei* (15470 Goondiwindi Qld) was an exception, with more branches at Uriarra. There were no significant genotype × site interactions for branch size or stem number.

Survival

At 32 months of age the average survival was 72% at Kowen (range 0–100%) and 89% at Uriarra (range

14–100%). There were no significant differences between the four replicates at either site.

At Kowen the initial survival 4 months after planting was 89%; 8% of the deaths had been caused by a root-chewing, white-fringed weevil (*Graphognathus leucoloma*) which attacked the seedlings within three weeks of planting. This same insect is believed to have caused the death of 3.1% of the trees in trial at Uriarra. Subsequent deaths at Kowen were due to a combination of frost, patches of uncontrolled couch grass in replicate 3 and 4 of the trial and root and collar rot caused by *Phytophthora* sp. (near *P. drechsleri*) and *Fusarium* species (Mark Dudzinski CSIRO FFP 1997 pers. comm.) in replicate 1. Those species affected by the fungal rots were *A. obliquinervia* (18070 Ruoaks Rd. Blue Range Vic. and 16273 Bemboka NSW), *A. falciformis* (16253 Narooma NSW), *A. dealbata* (16376 Bemboka NSW) and *A. nano-dealbata* (17940 Lavers Hill Vic.).

Species severely affected by frost at Kowen were the two provenances of *A. binervata* (16245 Kiama NSW and 17260 Springbrook Qld), *A. cangaiensis* (18862 Jackadgery NSW), all three *A. elata* provenances from NSW (18251, 18252 and 18243), *A. falciformis* (17740 Gladstone Qld), all three *A. implexa* provenances from NSW and Victoria (18611, 18019 and 15832) and *A. melanoxylon* (16358) from Bli Bli Qld.

Frost and waterlogging were the principal causes of the small number of deaths at Uriarra. Only the Queensland provenances of *A. binervata* and *A. falciformis* were severely damaged by frost. Survival for each seedlot is presented in Table 4.

Table 4. Provenance details and survival at Kowen and Uriarra—32 months after planting (June 1997).

Treat. No.	*Acacia* species	CSIRO Seedlot	Provenance	Latitude ° ′ S	Longitude ° ′ E	Altitude (m asl)	Survival % Kowen	Survival % Uriarra
54	*binervata*	16245	7 km W Kiama NSW	34 40	150 43	240	49.1	92.7
12	*binervata*	17260	Springbrook Qld	28 12	153 16	500	12.1	50.7
44	*binervia*	15845	Richmond–Springwood NSW	33 38	150 40	15	87.6	94.3
6	*blayana*	18068	Brogo NSW	36 29	149 40	500	54.6	80.6
52	*cangaiensis*	18862	Cangai S.F. W Jackadgery NSW	29 37	152 29	600	36.4	87.4
23	*chrysotricha*	18620	Newry S.F. NSW	30 32	152 55	50	57.9	85.2
7	*dangarensis*	18608	Mt Dangar NSW	32 20	150 28	600	98.0	100.0
8	*dealbata*	18024	Captains Flat NSW	35 37	149 26	700	93.8	97.8
64	*dealbata*	16376	22–18 km WNW Bemboka NSW	36 37	149 26	1035	87.3	92.4
1	*dealbata*	18973	Kandos, 4 km E Lithgow NSW	32 56	149 54	600	84.2	93.8
32	*dealbata*	16271	Errinundera Plateau Vic	37 11	148 52	960	82.7	94.4
55	*dealbata*	16384	18.6 km S Orford Tas	42 41	147 52	120	79.8	95.5
2	*deanei*	15470	Goondiwindi NSW	28 49	150 43	260	30.8	70.8
58	*decurrens*	14726	SW Goulburn NSW	34 53	149 17	685	92.7	100.0
26	*decurrens*	15847	Picton–Mittagong NSW	34 17	150 35	380	89.0	99.2
22	*elata*	18252	Mt Wilson NSW	33 30	150 21	650	42.0	61.4
29	*elata*	18251	Gloucester Tops NSW	32 05	151 38	1000	40.7	87.9
51	*elata*	18243	Mt Boss S.F. NSW	31 14	152 22	800	28.4	60.8
3	*Eucalyptus nitens*	14438	Badja S.F. NSW	36 01	149 34	1050	68.5	98.0
49	*falciformis*	15502	S. Warwick Qld	28 32	151 58	900	72.3	89.9
61	*falciformis*	16253	11 km WNW Narooma NSW	36 11	150 01	150	59.6	76.7
20	*falciformis*	17740	S. Gladstone Qld	23 53	151 16	50	0.0	14.3
34	*filicifolia*	17893	Yadboro Flat NSW	35 19	150 14	60	95.3	95.3
31	*filicifolia*	15841	19 km SW Singleton NSW	32 41	151 01	150	82.2	85.7
56	*fulva*	18972	Mt Yengo NSW	32 59	150 51	600	95.7	96.1
60	*fulva*	15843	Howes Valley NSW	32 52	150 52	240	85.1	89.6
42	*glaucocarpa*	15473	c. 20 km NW Gayndah Qld	25 32	151 29	390	82.3	94.8
24	*glaucocarpa*	18065	Cadarga Qld	26 07	150 55	350	78.1	94.7
13	*implexa*	18611	Sofala NSW	33 11	149 41	850	30.4	100.0
45	*implexa*	18019	Pyalong Vic	37 08	144 53	200	13.6	90.3
39	*implexa*	15832	Swansea NSW	33 05	151 37	10	4.1	77.4
16	*irrorata*	18619	Bodalla NSW	36 08	150 02	20	100.0	98.8
40	*irrorata*	18626	Gloucester NSW	31 59	151 47	650	90.2	88.3
10	*irrorata*	15840	Craven–Stroud NSW	32 10	151 57	110	79.8	93.3
9	*irrorata* ssp. *velutinella*	18623	Congarinni S.F. NSW	30 41	152 53	60	88.8	90.5
15	*irrorata* ssp. *velutinella*	18622	Newry StateForest NSW	30 31	152 59	10	87.7	95.2

Table 4. (continued)

Treat. No.	*Acacia* species	CSIRO Seedlot	Provenance	Latitude ° ′ S	Longitude ° ′ E	Altitude (m asl)	Survival % Kowen	Survival % Uriarra
63	*leucoclada* ssp. *argentifolia*	18067	Dalveen–Warwick Rd Qld	28 23	151 55	750	56.1	91.9
47	*leucoclada* ssp. *leucoclada*	18621	Inverell NSW	29 44	150 57	700	98.2	100.0
57	*mearnsii*	17928	Tarpeena SA	37 36	140 58	70	97.7	95.2
50	*mearnsii*	18979	Blackhill Reserve, NE Kyneton Vic	37 12	144 29	520	92.5	98.2
18	*mearnsii*	18975	N Bungendore NSW	35 11	149 32	760	92.2	72.4
17	*mearnsii*	16621	Tuross R. SW Bodalla NSW	36 11	149 58	15	90.0	97.8
38	*mearnsii*	17933	Wattle Circle Omeo Hwy Vic.	37 27	147 50	200	88.4	95.9
59	*mearnsii*	18977	Mt Gladstone, W Cooma NSW	36 15	149 05	1000	87.3	99.5
53	*mearnsii*	15329	Apsley R, W. Bicheno Tas	41 56	148 14	10	83.7	97.2
28	*melanoxylon*	16526	25 km SE Mt Gambier S.A.	37 57	141 56	40	88.4	95.5
35	*melanoxylon*	18981	Grampians NP Vic	37 22	142 31	300	83.6	95.7
36	*melanoxylon*	18980	Gellibrand R. Vic	38 43	143 15	50	82.3	98.6
30	*melanoxylon*	15863	Blackwood Park, Lileah Tas.	40 57	145 10	250	80.2	98.0
14	*melanoxylon*	16358	Bli Bli Qld	26 37	153 02	95	39.6	95.4
37	*nano-dealbata*	17195	Mt Macedon Vic	37 22	144 35	900	81.8	90.1
41	*nano-dealbata*	17940	Lavers Hill Vic	38 45	143 15	200	76.5	98.3
5	*obliquinervia*	18070	Ruoaks Rd Blue Range Vic	37 26	145 50	1200*	47.1	66.3
43	*obliquinervia*	16273	13 km WNW Bemboka NSW	36 36	149 25	960	44.7	75.0
11	*parramattensis*	17711	Tarago NSW	35 10	149 35	740	90.2	95.6
46	*parramattensis*	18610	N Windsor NSW	33 08	150 41	400	82.0	96.3
4	*parramattensis*	17925	Numeralla NSW	36 11	149 18	900	81.2	91.5
19	*parvipinnula*	15842	Howes Valley NSW	32 52	150 52	240	90.4	92.5
33	*parvipinnula*	15844	Colo Heights–Putty Rd NSW	33 14	150 39	360	78.8	81.9
25	*silvestris*	15852	Deua R. Deua National Park NSW	35 58	149 45	350	89.9	99.3
21	*silvestris*	16254	11 km WNW Narooma NSW	36 11	150 01	130	77.7	100.0
62	*silvestris*	17939	Bruthen Vic	37 35	147 54	200	68.6	93.7
48	*trachyphloia*	17894	Currowan Ck. NSW	35 35	150 03	100	93.5	85.5
27	*trachyphloia*	14229	Monga S.F. NSW	35 36	149 55	710	84.5	97.6

Height, diameters (dgl and dbh) and volume

The tallest seedlots in both trials were provenances of *A. dealbata*, *A. decurrens*, *A. filicifolia*, *A. irrorata* ssp. *velutinella*, *A. parvipinnula* and *A. trachyphloia* (Table 5). The average tree height at Kowen was 3.5 m with seedlot means ranging from 1.2 to 5.4 m. There were significant differences between the replicates; the best growth in replicate 1 and the poorest in replicate 3. At Uriarra the average height was 4.1 m with seedlot means ranging from 2.2 to 5.7 m but this was an underestimate, due to bird damage, of the potential of the trees in a relatively higher rainfall environment.

Table 5. Seedlot means at Kowen and Uriarra (June 1997 at 32 months after planting) for height, diameter (ground level (10 cm)) and breast height (1.3 m), volume, number of stems and fraction of trees damaged at Uriarra by bird attack. The table is arranged in descending order for volume at the Kowen site.

Treat. No.	*Acacia* species	Seedlot	Height (m) Kowen	Height (m) Uriarra	% trees bird-damaged Uriarra	Diam. (gl) (cm) Kowen	Diam. (gl) (cm) Uriarra	Vol. (dm^3) Kowen	Vol. (dm^3) Uriarra	Dbh (cm) Kowen	Dbh (cm) Uriarra	Stem no. Kowen	Stem no. Uriarra
26	*decurrens*	15847	5.4	5.7	55.4	8.6	9.3	9.9	12.3	6.1	6.6	1.4	1.4
58	*decurrens*	14726	4.8	5.0	32.5	8.5	8.5	8.4	9.0	6.0	6.0	1.7	1.5
57	*mearnsii*	17928	4.1	4.6	34.1	8.9	10.0	8.2	11.3	5.2	5.8	2.2	2.0
50	*mearnsii*	18979	4.4	4.9	53.5	8.7	9.6	7.9	11.1	5.6	6.3	1.6	1.4
17	*mearnsii*	16621	4.7	5.4	40.9	7.9	8.9	7.6	10.5	5.2	5.8	1.8	1.9
64	*dealbata*	16376	5.2	4.7	59.5	7.6	8.0	7.4	7.3	5.3	5.2	1.5	1.3
53	*mearnsii*	15329	4.2	4.5	46.3	8.3	8.9	7.2	9.2	4.7	5.0	1.6	1.7
59	*mearnsii*	18977	4.2	4.8	32.7	8.2	8.7	7.1	8.9	4.7	5.5	2.1	1.5
38	*mearnsii*	17933	4.3	5.0	46.9	8.0	8.9	7.0	9.8	5.0	5.7	2.0	1.8
18	*mearnsii*	18975	4.4	5.2	38.0	8.2	9.6	7.0	11.5	5.3	5.9	1.4	1.4

Table 5 (continued)

Treat. No.	*Acacia* species	Seedlot	Height (m) Kowen	Height (m) Uriarra	% trees bird-damaged Uriarra	Diam. (gl) (cm) Kowen	Diam. (gl) (cm) Uriarra	Vol. (dm³) Kowen	Vol. (dm³) Uriarra	Dbh (cm) Kowen	Dbh (cm) Uriarra	Stem no. Kowen	Stem no. Uriarra
1	*dealbata*	18973	5.0	5.0	56.0	7.9	8.5	6.8	9.0	5.7	6.0	1.4	1.6
32	*dealbata*	16271	4.7	5.2	82.1	7.7	9.0	6.7	10.4	5.2	5.7	1.3	1.5
33	*parvipinnula*	15844	4.6	4.3	12.2	7.6	6.8	6.6	4.9	5.6	4.5	3.5	2.8
55	*dealbata*	16384	4.7	5.0	44.5	7.8	8.6	6.3	9.1	5.8	6.0	1.7	1.5
3	*Eucalyptus nitens*	14438	4.2	4.8	0	7.9	9.4	6.1	10.5	5.2	5.9	1.3	1.1
60	*fulva*	15843	4.8	5.1	69.8	7.2	7.2	6.1	6.5	4.7	5.0	2.9	2.4
19	*parvipinnula*	15842	4.5	4.9	8.1	7.2	7.2	5.7	6.3	5.4	4.7	3.2	2.5
34	*filicifolia*	17893	4.7	5.2	15.7	7.1	7.8	5.7	7.9	4.7	5.1	2.3	1.8
16	*irrorata*	18619	3.6	4.3	15.2	7.9	8.4	5.6	7.5	5.1	5.0	3.5	2.9
24	*glaucocarpa*	18065	4.3	4.9	18.5	7.2	7.2	5.5	6.3	4.7	4.7	2.6	2.2
31	*filicifolia*	15841	5.0	5.0	52.5	6.7	7.1	5.5	6.2	5.0	5.1	1.4	1.2
62	*silvestris*	17939	4.5	4.5	13.3	6.9	6.2	5.3	4.5	4.1	3.6	1.9	1.9
46	*parramattensis*	18610	4.0	4.0	15.6	7.1	6.6	5.2	4.3	4.3	4.1	2.6	2.3
25	*silvestris*	15852	4.7	4.9	35.2	6.7	6.7	5.2	5.4	4.7	4.4	1.5	1.5
42	*glaucocarpa*	15473	4.2	4.8	7.9	7.0	7.4	5.1	6.4	4.6	4.9	2.3	2.0
56	*fulva*	18972	4.7	5.8	62.4	6.7	8.4	5.1	10.2	4.3	5.4	2.8	2.7
40	*irrorata*	18626	3.5	4.2	5.7	7.7	7.8	4.9	6.3	5.2	5.1	3.5	2.9
27	*trachyphloia*	14229	4.2	4.8	20.5	6.6	7.2	4.6	5.8	4.4	4.4	1.9	1.4
8	*dealbata*	18024	4.1	4.9	30.7	6.7	7.5	4.6	6.7	4.4	4.8	1.8	1.5
11	*parramattensis*	17711	4.0	4.1	15.7	6.7	6.9	4.5	4.6	4.2	4.3	2.0	2.1
15	*irrorata* ssp. *vel.*	18622	3.4	4.1	7.9	7.1	7.3	4.3	5.3	4.3	4.2	3.6	2.5
48	*trachyphloia*	17894	4.2	4.2	8.8	6.4	6.7	4.2	4.5	4.0	4.1	1.9	1.8
4	*parramattensis*	17925	3.8	3.9	21.9	6.7	6.5	4.1	3.8	4.3	4.0	2.7	2.2
21	*silvestris*	16254	4.5	5.1	47.5	6.2	6.6	4.1	5.5	4.2	4.4	1.5	1.4
10	*irrorata*	15840	3.4	4.0	5.4	7.1	7.3	3.8	4.9	4.8	4.6	3.3	2.5
47	*leucoclada*	18621	3.9	4.1	15.0	6.2	6.3	3.7	4.0	4.1	4.4	1.5	1.3
41	*nano-dealbata*	17940	3.8	4.6	20.3	6.2	7.2	3.5	5.9	4.0	4.6	2.7	2.3
9	*irrorata* ssp. *vel.*	18623	3.4	4.4	8.3	6.4	7.4	3.3	5.9	4.2	4.4	3.1	2.3
37	*nano-dealbata*	17195	3.3	4.4	8.3	6.4	7.0	3.3	5.3	4.0	4.1	3.1	2.6
5	*obliquinervia*	18070	3.0	3.3	0	6.4	6.8	3.1	3.6	3.2	3.7	2.4	1.2
49	*falciformis*	15502	3.2	3.9	0	6.3	6.9	3.1	4.6	4.3	4.3	1.8	1.9
7	*dangarensis*	18608	2.9	3.2	0	6.3	5.9	2.9	2.7	4.2	3.3	3.2	2.0
45	*implexa*	18019	2.6	2.6	0	5.7	5.4	2.3	1.7	4.0	3.6	1.6	1.5
44	*binervia*	15845	2.4	3.0	0	6.2	6.0	2.1	2.6	3.8	3.1	2.9	2.7
61	*falciformis*	16253	2.7	3.1	0	5.9	6.3	2.1	2.9	4.0	3.9	1.5	1.5
54	*binervata*	16245	2.1	3.7	0	6.1	8.1	1.9	6.0	3.9	4.4	3.0	2.0
63	*leucoclada* ssp. *arg.*	18067	3.4	3.5	2.7	4.7	5.2	1.8	2.3	3.1	3.7	1.2	1.6
2	*deanei*	15470	2.9	3.6	0	5.2	5.8	1.8	3.0	3.2	3.7	4.1	3.7
43	*obliquinervia*	16273	2.5	2.6	0	5.5	6.0	1.7	2.4	3.9	3.3	3.7	3.9
6	*blayana*	18068	3.0	4.2	15.5	5.2	6.4	1.6	4.1	4.2	4.2	1.8	1.7
35	*melanoxylon*	18981	2.2	2.7	2.6	5.2	6.3	1.5	2.7	3.8	3.0	1.2	1.3
36	*melanoxylon*	18980	2.3	3.3	5.1	5.3	6.4	1.5	3.1	4.0	4.0	1.0	1.6
13	*implexa*	18611	2.6	3.1	0	4.3	5.5	1.3	2.1	2.9	3.7	1.1	1.2
28	*melanoxylon*	16526	2.1	2.9	7.9	5.1	6.8	1.2	3.3	3.3	3.9	1.0	1.5
30	*melanoxylon*	15863	2.3	3.4	5.1	4.9	6.7	1.2	3.8	3.7	4.0	1.4	1.4
23	*chrysotricha*	18620	2.3	3.3	0	4.1	5.9	0.8	2.7	2.1	2.8	2.4	2.7
20	*falciformis*	17740	*	2.2	0	*	4.9	*	1.5	*	*	*	*
39	*implexa*	15832	1.8	2.2	0	4.0	5.2	*	1.3	*	3.1	*	1.5
22	*elata*	18252	1.8	2.3	0	5.3	5.8	*	1.6	*	3.0	*	2.4
12	*binervata*	17260	1.2	2.3	0	4.7	4.7	*	1.2	*	*	*	*
29	*elata*	18251	1.5	2.4	0	5.3	6.4	*	2.2	*	4.0	*	1.8
51	*elata*	18243	1.5	2.4	0	5.1	5.7	*	1.9	*	3.1	*	2.3
52	*cangaiensis*	18862	1.2	2.8	0	3.7	5.6	*	2.0	*	3.3	*	3.5
14	*melanoxylon*	16358	1.9	3.2	2.6	4.1	5.8	*	2.6	*	3.4	*	2.1
	Average standard error of differences		0.23	0.19		0.48	0.38	1.25	1.18	0.49	0.34	0.40	0.28

* Volume (dm³) = $\pi \times$ diameter² (cm) $\times$ height (m) $\times$ 0.00833 where diameter is $\sqrt{\sum_{i=1}^{n} (d_i)^2}$ and n = n⁰ stems ≥ 75% diameter of largest stem, and d_i is the diameter of the i^{th} stem

The trial at Uriarra was attacked by birds — yellow-tailed black cockatoos (*Calyptorhynchus funereus*) (September-October 1995 and 1996) and sulphur-crested cockatoos (*Cacatua galerita*) (February 1996). These birds landed on the tallest trees (Table 6) and chewed or snapped the stems to extract the phloem sap; in some cases causing loss of two metres of crown height. These damaged trees were recorded with the intention they would no longer be included in the trial measurement. However many recovered well, with branches below the damaged stems vigorously taking over apical dominance. As a result, these trees were included in the annual assessments but it was noted that the growth measurements were an underestimate of the potential of the trees and that their form may have been negatively affected. At the time of the 1997 annual assessment 17.7% of the trial had trees with stem form or growth damaged by bird attack. There was a trend with the damage increasing downslope from replicate 1 to 4; 10% of trees damaged in replicate 1, 15% in replicate 2, 20% in replicate 3 and 26% in replicate 4.

Seedlot means for combined diameters at ground level ranged from 3.7 to 8.9 at Kowen and 4.7 to 10.0 at Uriarra. The largest at Kowen were a provenances of *A. decurrens* (8.3–8.5 cm) and *A. mearnsii* (8.0–8.9 cm) and these did not differ significantly from each other. At Uriarra those with the largest ground diameters (9.4–10.0 cm dgl) were some of the same provenances of *A. decurrens* and *A. mearnsii* that had performed well at Kowen as well as *Eucalyptus nitens*.

At Kowen, diameters at breast height for trees greater than 3.0 m in height ranged from 2.1 to 6.1 cm. Six species had the largest diameters at breast height which did not differ significantly from each other: both provenances of *A. decurrens* (6.0–6.1 cm) followed by *A. dealbata* (16384 Orford Tasmania 5.8 cm; 18973 Lithgow NSW 5.7 cm; 16376 Bemboka NSW 5.3 cm; 16271 Errinundera Plateau Vic. 5.2 cm), *A. mearnsii* (18979 Kyneton Vic. 5.6 cm; 18975 Bungendore NSW 5.3 cm and 16621 Bodalla NSW 5.2 cm), *A. parvipinnula* (15844 Colo Heights-Putty Road NSW 5.6 cm; 15842 Howes Valley NSW 5.4 cm) , *E. nitens* (14438 Badja S.F. NSW 5.1 cm) and *A. irrorata* (18626 Gloucester NSW 5.2 cm; 18619 Bodalla NSW 5.1 cm) (Table 5).

At Uriarra, seedlot means ranged from 2.8 to 6.6 cm and those with the largest diameters at breast height were much the same as those at Kowen: provenances of *A. decurrens* (15847, 6.6 cm and 14726, 6.0 cm) and *A. mearnsii* (18979, 6.3 cm and 18975, 5.9 cm) and *A. dealbata* (16384 and 18973, both 6.0 cm) (Table 5).

Table 6. Table of average tree heights and percentage trees/seedlot damaged by birds at Uriarra. This table is arranged in ascending order for tree height.

Treat. No.	*Acacia* species	Seedlot	Height (m) Uriarra	% trees damaged by birds at Uriarra
20	*falciformis*	17740	2.2	0
39	*implexa*	15832	2.2	0
12	*binervata*	17260	2.3	0
22	*elata*	18252	2.3	0
29	*elata*	18251	2.4	0
51	*elata*	18243	2.4	0
45	*implexa*	18019	2.6	0
43	*obliquinervia*	16273	2.6	0
35	*melanoxylon*	18981	2.7	2.6
52	*cangaiensis*	18862	2.8	0
28	*melanoxylon*	16526	2.9	7.9
44	*binervia*	15845	3.0	0
61	*falciformis*	16253	3.1	0
13	*implexa*	18611	3.1	0
14	*melanoxylon*	16358	3.2	2.6
7	*dangarensis*	18608	3.2	0
36	*melanoxylon*	18980	3.3	5.1
23	*chrysotricha*	18620	3.3	0
5	*obliquinervia*	18070	3.3	0
30	*melanoxylon*	15863	3.4	5.1
63	*leucoclada* ssp. *arg.*	18067	3.5	2.7
2	*deanei*	15470	3.6	0
54	*binervata*	16245	3.7	0
4	*parramattensis*	17925	3.9	21.9
49	*falciformis*	15502	3.9	0
46	*parramattensis*	18610	4.0	15.6
10	*irrorata*	15840	4.0	5.4
11	*parramattensis*	17711	4.1	15.7
47	*leucoclada*	18621	4.1	15.0
15	*irrorata* ssp. *vel.*	18622	4.1	7.9
6	*blayana*	18068	4.2	15.5
48	*trachyphloia*	17894	4.2	8.8
40	*irrorata*	18626	4.2	5.7
16	*irrorata*	18619	4.3	15.2
33	*parvipinnula*	15844	4.3	12.2
9	*irrorata* ssp. *vel.*	18623	4.4	8.3
37	*nano-dealbata*	17195	4.4	8.3
53	*mearnsii*	15329	4.5	46.3
62	*silvestris*	17939	4.5	13.3
57	*mearnsii*	17928	4.6	34.1
41	*nano-dealbata*	17940	4.6	20.3
64	*dealbata*	16376	4.7	59.5
59	*mearnsii*	18977	4.8	32.7
27	*trachyphloia*	14229	4.8	20.5
42	*glaucocarpa*	15473	4.8	7.9
3	*Eucalyptus nitens*	14438	4.8	0
50	*mearnsii*	18979	4.9	53.5
25	*silvestris*	15852	4.9	35.2
8	*dealbata*	18024	4.9	30.7
24	*glaucocarpa*	18065	4.9	18.5
19	*parvipinnula*	15842	4.9	8.1
1	*dealbata*	18973	5.0	56.0
31	*filicifolia*	15841	5.0	52.5
38	*mearnsii*	17933	5.0	46.9
55	*dealbata*	16384	5.0	44.5
58	*decurrens*	14726	5.0	32.5
60	*fulva*	15843	5.1	69.8
21	*silvestris*	16254	5.1	47.5
32	*dealbata*	16271	5.2	82.1
18	*mearnsii*	18975	5.2	38.0
34	*filicifolia*	17893	5.2	15.7
17	*mearnsii*	16621	5.4	40.9
26	*decurrens*	15847	5.7	55.4
56	*fulva*	18972	5.8	62.4

In terms of the volume index, the range at Kowen was from 0.8 to 9.9 dm^3 with the best species ranked as follows: the two *A. decurrens* provenances (15847, 9.9 dm^3 and 14726, 8.4 dm^3) followed by *A. mearnsii* provenances from Tarpeena South Australia (S.A.) (17928, 8.2 dm^3), Kyneton Victoria (18979, 7.9 dm^3) and Bodalla NSW (16621, 7.6 dm^3). At Uriarra, seedlot means ranged between 1.2 and 12.3 dm^3. The largest were provenances of *A. decurrens* (15847, 12.3 dm^3 per tree), *A. mearnsii* (N Bungendore NSW, 18975, 11.5 dm^3; Tarpeena South Australia 17928, 11.4 dm^3; Kyneton Vic. 18979, 11.1 dm^3) *E. nitens* (14438, 10.5 dm^3) and *A. dealbata* (Errinundera Plateau Vic. 16271, 10.4 dm^3) and *A. fulva* (Mt Yengo NSW 18972, 10.2 dm^3) (Table 5).

Form characteristics

Number of stems

Two provenances of *A. melanoxylon* (16526 Mt Gambier S.A. and 18980 Gellibrand R. Vic.) at Kowen were the only seedlots across both trials to have, on average, single stems. At Kowen the overall mean was 2.2 stems; seedlot means ranged from 2.8 to 4.0 stems and there were significant replicate differences with the number of stems being the least in replicate 2 (2.0 stems) and the most in replicate 3 (2.4 stems). At Uriarra, seedlot means ranged from 1.1 to 3.9 stems, the overall mean was 2.0 stems and there were replicate differences with those seedlots in replicate 2 having the least (1.8 stems) and those in replicate 3 (2.1 stems) the most number of stems/seedlot. Although there was a highly significant correlation ($r = 0.875$ $P < 0.001$) between the number of stems produced by the same seedlot at both sites, with few exceptions there were similar or fewer stems per seedlot at Uriarra.

A. deanei was the shrubbiest species in trial across both sites with more than four dominant stems/tree. As this species suffered only slight frost damage, this was probably close to its true form (Table 5). However a number of species which have excellent form in their natural habitat were reduced to shrubs by frost at these sites and these included *A. binervata*, *A. elata*, *A. fulva*, *A. irrorata* ssp. *irrorata* and *A. irrorata* ssp. *velutinella*.

Stem form

The effect of bird attack on the stem form of trees at Uriarra was ignored during the form assessment, which was concerned only with the genetic potential of the trees. There was little difference in the stem form of the dominant stems of seedlots between the two trial sites (Table 7) with seedlot means ranging from 1.5 to 4.0 for Kowen and 1.7 to 4.0 for Uriarra. Those with the best form were similar for both sites. For example, at Kowen the straightest species were in descending order from the straightest, *E. nitens* (1.5), *A. melanoxylon* (16526 Mt Gambier S.A. 1.6) *A. dealbata* (16384 Orford Tas. 1.7; 16376 Bemboka NSW 1.7; 16271 Errinundera Plateau Vic.1.7), *A. fulva* (15843 Howes Valley NSW 1.8), *A. melanoxylon* (18980 Gellibrand R. Victoria 1.8), *A. decurrens* (14726 Goulburn NSW 1.9), *A. binervata* (16245 Kiama NSW 2.1) and *A. silvestris* (17939 Bruthen Vic. 2.1). At Uriarra they were again in descending order, Eucalyptus nitens (14438, 1.7), *A. dealbata* (16384, 1.7; 16376, 1.8; 16271, 1.8), *A. mearnsii* (18975, 2.0), *A. silvestris* (16254, 2.0), *A. fulva* (15843, 2.1), *A. melanoxylon* (18980, 2.1) and *A. trachyphloia* (14229, 2.1).

Table 7. (continued) Seedlot means for stem form, branch density and branch size at Kowen and Uriarra (June 1997 at 32 months after planting).

Treat. no.	*Acacia* species	Seedlot	Stem form Kowen	Stem form Uriarra	Branch density Kowen	Branch density Uriarra	Branch size Kowen	Branch size Uriarra
3	*Eucalyptus nitens*	14438	1.5	1.7	3.0	3.0	1.3	1.0
28	*melanoxylon*	16526	1.6	2.6	3.0	3.0	0.8	1.8
55	*dealbata*	16384	1.7	1.7	3.0	2.9	1.7	1.7
64	*dealbata*	16376	1.7	1.8	3.0	3.0	1.4	1.4
32	*dealbata*	16271	1.7	1.8	3.0	3.0	1.5	1.5
60	*fulva*	15843	1.8	2.1	1.9	1.5	1.9	1.8
36	*melanoxylon*	18980	1.8	2.1	3.0	3.1	1.8	1.8
58	*decurrens*	14726	1.9	2.8	3.0	2.9	1.2	1.3
54	*binervata*	16245	2.1	2.3	3.0	2.9	3.0	1.9
62	*silvestris*	17939	2.1	2.4	2.8	2.6	1.6	1.4
18	*mearnsii*	18975	2.2	2.0	3.0	3.0	1.7	1.6
56	*fulva*	18972	2.2	2.2	1.8	1.4	2.0	2.0
21	*silvestris*	16254	2.3	2.0	2.7	2.8	1.6	1.4
23	*chrysotricha*	18620	2.3	3.0	2.7	2.2	2.2	2.4

Table 7. (continued)

Treat. no.	*Acacia* species	Seedlot	Stem form Kowen	Stem form Uriarra	Branch density Kowen	Branch density Uriarra	Branch size Kowen	Branch size Uriarra
27	*trachyphloia*	14229	2.4	2.1	3.0	3.0	1.3	1.7
25	*silvestris*	15852	2.4	2.2	2.9	2.6	1.5	1.7
50	*mearnsii*	18979	2.4	2.4	3.0	2.9	1.9	1.7
53	*mearnsii*	15329	2.4	2.4	2.9	2.8	2.0	1.9
26	*decurrens*	15847	2.4	2.6	3.0	2.9	1.4	1.4
41	*nano-dealbata*	17940	2.4	2.6	3.0	2.7	1.9	1.7
31	*filicifolia*	15841	2.5	2.3	2.9	2.7	1.4	1.4
30	*melanoxylon*	15863	2.5	2.6	3.0	3.0	1.8	1.4
1	*dealbata*	18973	2.5	2.6	3.0	3.0	1.6	1.7
48	*trachyphloia*	17894	2.5	2.9	3.0	3.1	1.5	1.8
63	*leucoclada* ssp. *argent.*	18067	2.5	2.9	3.0	3.0	1.2	1.4
5	*obliquinervia*	18070	2.6	2.4	3.0	3.0	1.1	1.3
8	*dealbata*	18024	2.6	2.6	3.0	3.0	1.6	1.3
11	*parramattensis*	17711	2.6	3.0	2.9	3.0	1.8	2.1
42	*glaucocarpa*	15473	2.6	3.1	2.6	2.2	1.7	1.7
59	*mearnsii*	18977	2.7	2.4	2.9	2.9	1.8	1.6
17	*mearnsii*	16621	2.7	2.5	3.0	2.8	1.8	1.9
57	*mearnsii*	17928	2.7	2.7	3.0	2.9	2.0	1.6
13	*implexa*	18611	2.7	2.9	3.0	2.9	1.0	1.2
40	*irrorata*	18626	2.7	3.1	3.0	2.9	2.1	2.1
38	*mearnsii*	17933	2.8	2.6	3.0	2.8	1.8	1.6
37	*nano-dealbata*	17195	2.9	2.5	3.0	2.9	2.0	1.8
34	*filicifolia*	17893	2.9	2.6	2.9	2.5	1.9	1.6
46	*parramattensis*	18610	2.9	2.6	3.0	2.8	2.1	2.2
19	*parvipinnula*	15842	2.9	2.9	3.0	2.7	1.5	1.6
24	*glaucocarpa*	18065	2.9	3.0	2.4	1.8	1.8	2.0
44	*binervia*	15845	3.1	2.4	3.0	2.7	2.1	1.8
16	*irrorata*	18619	3.1	3.0	3.0	2.8	2.0	2.2
33	*parvipinnula*	15844	3.1	3.2	3.0	3.0	1.6	1.9
61	*falciformis*	16253	3.1	3.3	3.0	2.9	0.9	1.3
6	*blayana*	18068	3.2	2.3	2.9	2.8	0.9	1.3
35	*melanoxylon*	18981	3.2	2.6	3.0	3.0	1.0	1.9
49	*falciformis*	15502	3.2	3.0	3.0	2.7	1.5	1.4
47	*leucoclada*	18621	3.2	3.4	2.9	2.9	1.2	1.6
7	*dangarensis*	18608	3.2	3.6	3.0	2.9	1.8	1.7
15	*irrorata* ssp. *velutinella*	18622	3.3	2.7	2.9	2.8	2.2	2.0
4	*parramattensis*	17925	3.4	2.7	3.0	2.9	1.8	1.9
2	*deanei*	15470	3.4	3.3	2.8	3.0	2.1	2.1
9	*irrorata* ssp. *velutinella*	18623	3.5	2.8	3.0	2.8	1.9	1.8
43	*obliquinervia*	16273	3.6	2.9	3.0	3.0	2.4	1.9
10	*irrorata*	15840	3.6	3.4	3.0	2.9	2.1	2.1
45	*implexa*	18019	4.0	2.5	3.0	3.1	2.0	1.5
39	*implexa*	15832	*	2.4	*	3.0	*	1.7
14	*melanoxylon*	16358	*	2.8	*	2.9	*	1.9
29	*elata*	18251	*	3.8	*	2.6	*	2.4
52	*cangaiensis*	18862	*	3.8	*	2.4	*	2.2
22	*elata*	18252	*	3.9	*	2.2	*	2.4
51	*elata*	18243	*	4.0	*	2.5	*	2.3
12	*binervata*	17260	*	*	*	*	*	*
20	*falciformis*	17740	*	*	*	*	*	*
	Average standard error of differences		0.34	0.23	0.13	0.11	0.27	0.19

Branch density

Branch distribution at Kowen ranged from 1.8 to 3.0 with an overall average of 2.9. The two provenances of *A. fulva* were significantly different from any other species at both trial sites because they had the largest distance between branch nodes along the stems (index values of 1.8–1.9 at Kowen and 1.4–1.5 at Uriarra) (Table 7). At Uriarra the range across species was 1.4–3.0 with an overall mean of 2.8.

Branch size

At Kowen the average branch size index value was 1.7, ranging from 0.8 to 3.0 with significant differences between the replicates. The trees in replicate 2 (1.5) had the smallest branches and those in replicate 3 had the largest (1.8). At Uriarra the overall branch size was also 1.7 but the range was narrower (1.0–2.4) with replicate 2 (1.6) having branches significantly smaller than those in the other three replicates; the largest branching occurred in replicate 4 (1.9) (Table 7).

The seedlots with the relatively smallest branch size at Kowen were, in ascending order *A. melanoxylon* (16526 Mt Gambier S.A. 0.8), *A. falciformis* (16253 Narooma NSW 0.9), *A. blayana* (18068 Brogo NSW 0.9), *A. melanoxylon* (18981 Grampians Vic. 1.0), *A. implexa* (18611 Sofala NSW 1.0), *A. obliquinervia* (18070 Blue Range Vic. 1.1), *A. decurrens* 14726 (Goulburn NSW 1.2), *A. leucoclada* ssp. *argentifolia* (18067 Dalveen–Warwick NSW 1.2), *A. leucoclada* (18621 Inverell NSW 1.2), *E. nitens* (14438 Badja S.F. NSW 1.3) and *A. trachyphloia* (14429 Monga S.F. NSW 1.3). At Uriarra the seedlots with the relatively smallest branches were in ascending order *E. nitens* (14438, 1.0), *A. implexa* (18611, 1.2), *A. decurrens* (14726, 1.3), *A. blayana* (18068, 1.3), *A. dealbata* (18024 Captains Flat NSW 1.3), *A. falciformis* (16253, 1.3), *A. obliquinervia* (18070 1.3), *A. silvestris* (16254 Narooma NSW 1.4), *A. falciformis* (15502 Warwick NSW 1.4), *A. leucoclada* ssp. *argentifolia* (18067 1.4), *A. decurrens* (15847 Picton–Mittagong NSW 1.4), *A. dealbata* (16376 Bemboka NSW 1.4), *A. filicifolia* (15841 Singleton NSW 1.4) and *A. silvestris* (17939 Bruthen Vic. 1.4) (see Table 7).

At both sites the same provenances of *A. blayana*, *A. decurrens* (14726), *A. falciformis* (16253), *A. implexa* (18611), *A. leucoclada* ssp. *argentifolia* (18067), *A. obliquinervia* (18070) and *E. nitens* had the smallest branches (see Table 7).

Acacia species that produced root suckers

Nine of the 25 species in trial produced root suckers within 2.5 years of planting (Table 8).

Table 8. Species/provenances that developed root suckers.

Acacia species	Seedlot	Provenance
A. binervata	17260	Springbrook Qld
A. dealbata	18024	Captains Flat NSW
A. dealbata	18973	Kandos, 4 km E Lithgow NSW
A. falciformis	15502	S Warwick Qld
A. falciformis	16253	11 km WNW Narooma NSW
A. implexa	15832	Swansea NSW
A. irrorata ssp. *velutinella*	18622	Newry State Forest NSW
A. leucoclada	18621	Inverell NSW
A. leucoclada ssp. *argentifolia*	18067	Dalveen-Warwick Rd Qld
A. melanoxylon	16358	Bli Bli Qld
A. obliquinervia	16273	13 km WNW Bemboka NSW
A. parramattensis	17711	Tarago NSW

Conclusion

This paper presents preliminary results from two field trials for the survival, growth and form characteristics of 25 temperate acacia species at 32 months of age. Frost with minimum temperatures falling to −6°C was the most limiting factor at these sites, and seriously affected the survival and growth of provenances of *A. binervata*, *A. cangaiensis*, *A. elata*, *A. falciformis*, *A. implexa* and *A. melanoxylon*. Generally species had better survival and growth at Uriarra, despite the effect of bird attack on the height of the taller trees. This better growth was probably due to the relatively higher rainfall at this site compared with Kowen: in 1995 Uriarra received 351 mm more rainfall than Kowen and 269 mm more in 1996).

Acacia decurrens from Picton-Mittagong NSW was ranked the largest seedlot, based on a volume index, at both trials. It also had light branch distribution, relatively small branch size and slightly crooked form. This species is one of several temperate acacia species including *A. mearnsii*, *A. dealbata*, *A. melanoxylon*, *A. parramattensis* and *A. silvestris*, reported by Clark et al. (1994) to have kraft pulp yields within the range of commercial pulpwoods. These promising early growth and form results for *A. decurrens* call for further investigation which should logically begin with range-wide provenance seed collections and trials.

It is also interesting to note the good performance of the *A. mearnsii* provenances in trial; including the Victorian seedlot from Blackhill Reserve, NE of Kyneton Victoria (18979). This was one of five *A. mearnsii* provenances selected by Fang et al. (1994) from 22 Australian provenances at 5 years of age as the most suitable provenance to form the basis of large-scale plantation establishment in China. *A. mearnsii* has been planted overseas principally for its high tannin-yielding bark but these trials show that for short-rotation wood production it competes very well with other closely-related, fast-growing species.

A. filicifolia is one of the lesser-known species which showed early promise. Across the two sites the two provenances of this species had good height growth (4.7–5.2 m), a small number of stems (1.2–2.3) and good form (2.3–2.9). Its relatively small diameter at ground level (6.7–7.8 cm) excluded it from the top volume grouping.

The rare species in trial, *A. blayana*, *A. cangaiensis*, *A. chrysotricha*, *A. dangarensis* and *A. fulva* were, with the exception of *A. dangarensis*, too frost-prone to show their full potential. *A. dangarensis* however appears generally well adapted to the climate and soil conditions of the region and has attractive foliage for amenity plantings.

Two provenances of *A. melanoxylon* at Kowen were the only acacia seedlots across both trials to have, on average, single stems. At Kowen the overall mean number of stems across seedlots was 2.2 and at Uriarra the overall mean was 2.0 stems. *A. deanei* was the shrubbiest species in trial across both sites with more than four dominant stems/tree. A number of species with excellent form in their natural habitat were reduced to shrubs by frost at these sites. These included *A. binervata*, *A. elata*, *A. fulva*, *A. irrorata* ssp. *irrorata* and *A. irrorata* ssp. *velutinella*.

Those seedlots with the best form of the straightest dominant or codominant stem for trees taller than 3.0 m were similar for both sites. These included *E. nitens* and provenances of *A. binervata*, *A. dealbata*, *A. decurrens*, *A. fulva*, *A. mearnsii*, *A. melanoxylon*, *A. silvestris* and *A. trachyphloia*. In terms of branch density, *A. fulva* had significantly wider-spaced branches than all other species in trial and there were provenances of 12 species which carried relatively small branches. Nine of the 25 acacia species produced root suckers within 2.5 years after planting.

The results indicated that at 32 months of age, provenances of *A. decurrens* and *A. mearnsii* were the most productive in terms of wood volume and were well adapted to relatively dry (630–820 mm/annum) and frost-prone (winter minima of –6°C) conditions. However these results are preliminary and should be treated with caution. For example since the annual assessment (June 1997) reported in this paper, drought conditions in the first half of that year and frosts falling to –7°C during the winter of 1997 affected the survival and growth of species such as *A. dealbata* and *A. fulva* at Kowen. The trials were designed to yield information for a total of c. four years without thinning and changes in ranking could continue over the next 12–18 months.

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References

Clark, N.B., Balodis, V., Fang, G. and Wang, J. 1994. Pulpwood potential of acacias. In: Brown, A.G., ed., Australian Tree Species Research in China. ACIAR Proceedings No. 48, Australian Centre for International Agricultural Research, Canberra, 196–202.

Fang, Y., Gao, C., Zheng F., Ren, H., Li, J., Liu, S. and Zhang Q. 1994. Field evaluation and selection of *Acacia mearnsii* provenances. In: Brown, A.G., ed., Australian Tree Species Research in China. ACIAR Proceedings No. 48, Australian Centre for International Agricultural Research, Canberra, 149–157.

GENSTAT 5 Committee 1990. GENSTAT 5, Release 2 Reference Manual Supplement. NAG Ltd, Lawes Agricultural Trust (Rothamsted Experimental Station).

MacDicken, K.G., Wolf, G.V. and Briscoe, C.B. 1991. Standard research methods for multipurpose trees and shrubs. Multipurpose Tree Species Network Research Series; Manual No. 5. A research study cosponsored by the International Council for Research in Agroforestry (ICRAF) and the Winrock International Institute for Agricultural Development.

Maslin, B.R. and McDonald, M.W. 1996. A Key to Useful Acacias for the Seasonally Dry Tropics. CSIRO Australia, 80 p.

Pearce, E.A. and Smith, C.G. 1984. The World Weather Guide. Hutchinson, London. 480 p.

Searle, S. 1996. Wood and non-wood uses of temperate Australian acacias In: Proceedings of 1996 Australian Forest Growers Conference — Farm Forestry and Plantations Investing in Future Wood Supply. Mount Gambier South Australia, 9–12 September 1996, 256–266.

Snowdon, P. 1996. Site descriptions and chemical analyses for ACIAR Project 9227 acacia species elimination trials. In: Brown, A.G., ed., ACIAR Project 9227 Second Annual Report 1 January–31 December 1995. CSIRO Forestry and Forest Products, Canberra, 137–162.

Weerawardane, N.D.R. and Vivekanandan, K. 1991. *Acacia* species and provenance trials in uplands of Sri Lanka. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research: ACIAR Proceedings No. 35, Australian Centre for International Agricultural Research, Canberra, 166–169.

Yang, M., Searle, S. and Zeng Y. 1991. Growth of Australian acacias in species/provenance trials in subtropical Guangdong, China. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research: ACIAR Proceedings No. 35, Australian Centre for International Agricultural Research, Canberra, 219–223.

Yang, M., Zheng, Y., Zhang, X. and Zhang, M. 1994. Effect of low temperatures on *Acacia*. In: Brown, A.G., ed., Australian Tree Species Research in China. ACIAR Proceedings No. 48, Australian Centre for International Agricultural Research, Canberra, 176–179.

Frost Tolerance of 25 Temperate *Acacia* Species in Two Field Trials near Canberra, Australia

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Abstract

This paper describes the relative frost tolerance of 25 *Acacia* species grown in two field trials near Canberra. Frosts limit tree growth in the region and it was important to identify those species which are best adapted to this aspect of the climate. Observations of damage caused by frost were made over the first two winters after planting. A number of *Acacia* species/provenances were minimally damaged by winter temperatures as low as –6°C and would therefore be suitable candidates for commercial planting in the Canberra region. These were *Acacia dealbata, A. decurrens, A. filicifolia, A. leucoclada, A. parramattensis, A. mearnsii, A. nano-dealbata* and *A. trachyphloia*. Irrespective of provenance, *A. dealbata* was the most frost-tolerant species in trial. There were significant differences in frost tolerance between provenances of a number of species including *A. decurrens, A. fulva, A. implexa, A. glaucocarpa, A. mearnsii, A. melanoxylon, A. silvestris* and *A. trachyphloia*.

TWO field trials near Canberra, Australia were established as part of an international series of temperate *Acacia* trials supported by the Australian Centre for International Agricultural Research (ACIAR) through the project 'Australian acacias for sustainable development in China, Vietnam and Australia'. This aimed to identify and characterise temperate Australian acacias with potential for soil amelioration and commercial planting across a wide range of sites in three countries. In particular the Canberra trials focused on identifying species suitable for firewood plantations to supply the Canberra market which consumes c. 80 000 tonnes of fuelwood per year. Frost limits tree growth in the region and it was important to identify the most frost-tolerant species. Data on growth are presented in a complementary paper (Searle et al. these Proceedings)

Materials and Methods

Trial sites

The 25 acacia and one eucalypt species in trial were represented by 64 seedlots (Table 1 and Figure 1) which were planted at two sites near Canberra within the Australian Capital Territory (ACT). The Kowen trial site, 12 km ESE Canberra City (35°20′S 149°15′E, 585 m asl), was planted on a red podsolic soil derived from old river terrace gravels over Ordovician sediments. The Uriarra trial site, 19 km W of Canberra (35°18′S, 148°56′E, 618 m asl), was located across two soil types; a red podsolic soil (replicates 2, 3 and 4) and a deep yellow earth (replicate 1) derived from Paddys River volcanics laid down in the Middle Silurian.

Climate

Canberra has a continental climate with marked variation in temperature from winter to summer. The city experiences very warm to hot days during summer and cold nights with widespread frosts during winter. Temperatures recorded by the Canberra Airport Observing Office (35°19′S 149°12′E, 571 m asl) range from a low of –10.0°C to a high of 43°C (Pearce and Smith 1984). Frosts occur on about 100 days each year.

Rainfall is fairly evenly distributed throughout the year, averaging about 40 mm per month during winter and increasing to 50–60 mm per month for the rest of the year. The average annual rainfall for Canberra is 631 mm. Kowen is located within 6 km of the Canberra Airport Observing Office and has a similar average annual rainfall. Kowen is the drier of the two trial sites and in 1995 and 1996 annual rainfalls of 688

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and 601 mm were recorded respectively. Uriarra, c. 25 km W of the Canberra Airport Observing Office received 1039 mm and 870 mm in 1995 and 1996 respectively and has an annual average rainfall of 824 mm. In 1995, 89 frosts were recorded by the Canberra Airport Observing Office; 1996 there were 77 with most occurring between April and October.

Nursery, site preparation and trial management

The seed pretreatment, nursery practice, site preparation and trial management for these trials is described by Searle et al. 1997 (these proceedings). It is worth noting that while the health of the seedlings at planting was excellent they were subsequently affected to an unknown degree by boron toxicity, induced by fertilisation (30 g of sodium tetraborate/ tree) intended to correct a soil deficiency. This may have interacted with frost and drought to affect the frost tolerance of the trees. All species, with the exception of *A. nano-dealbata*, showed leaf dessication and leaf shed during the winter of 1996 as a result of boron toxicity.

Table 1. Seedlots in trial at Kowen and Uriarra near Canberra (ACT).

Treat. no.	*Acacia* species	Common name	Seedlot*	Location	Lat. ° ′ E	Long. ° ′ S	Alt. (m asl)
12	*binervata*	Two-veined hickory	17260	Springbrook Qld	28 12	153 16	500
54	*binervata*	"	16245	7 km W Kiama NSW	34 40	150 43	240
44	*binervia*	Coast myall	15845	Richmond-Springwood NSW	33 38	150 40	15
6	*blayana*	Blay's wattle	18068	Brogo NSW	36 29	149 40	500
52	*cangaiensis*	None	18862	Cangai State Forest, W Jackadgery NSW	29 37	152 29	600
23	*chrysotricha*	Bellinger river wattle	18620	Newry S. F. Bellinger R Valley NSW	30 32	152 55	50
7	*dangarensis*	None	18608	Mt Dangar NSW	32 20	150 28	600
8	*dealbata*	Silver wattle	18024	Captains Flat NSW	35 37	149 26	700
64	*dealbata*	"	16376	22-18 km WNW Bemboka NSW	36 37	149 26	1035
55	*dealbata*	"	16384	18.6 km S Orford Tas	42 41	147 52	120
32	*dealbata*	"	16271	Errinundera Plateau Vic	37 11	148 52	960
1	*dealbata*	"	18973	Kandos, 4 km E Lithgow NSW	32 56	149 54	600
2	*deanei*	Deane's wattle, Green wattle	15470	Goondiwindi NSW	28 49	150 43	260
58	*decurrens*	Black wattle, Green wattle	14726	SW Goulburn NSW	34 53	149 17	685
26	*decurrens*	"	15847	Picton-Mittagong NSW	34 17	150 35	380
22	*elata*	Cedar wattle	18252	Mt Wilson NSW	33 30	150 21	650
51	*elata*	"	18243	Mt Boss S.F. NSW	31 14	152 22	800
29	*elata*	"	18251	Gloucester Tops NSW	32 05	151 38	1000
20	*falciformis*	Broad-leaf hickory	17740	S. Gladstone Qld	23 53	151 16	50
61	*falciformis*	"	16253	11 km WNW Narooma NSW	36 11	150 01	150
49	*falciformis*	"	15502	S. Warwick Qld	28 32	151 58	900
31	*filicifolia*	Fern-leaf wattle	15841	19 km SW Singleton NSW	32 41	151 01	150
34	*filicifolia*	"	17893	Yadboro Flat NSW	35 19	150 14	60
60	*fulva*	Soft wattle	15843	Howes Valley NSW	32 52	150 52	240
56	*fulva*	"	18972	Mt Yengo NSW	32 59	50 51	600
42	*glaucocarpa*	None	15473	c. 20 km NW Gayndah Qld	25 32	151 29	390
24	*glaucocarpa*	"	18065	Cadarga Qld	26 07	150 55	350
39	*implexa*	Hickory wattle, Lightwood, Broad-leaf wattle	15832	Swansea NSW	33 05	151 37	10
45	*implexa*	"	18019	Pyalong Vic	37 08	144 53	200
13	*implexa*	"	18611	Sofala NSW	33 11	149 41	850
10	*irrorata*	Green wattle, Blueskin	15840	Craven-Stroud NSW	32 10	151 57	110
40	*irrorata*	"	18626	Gloucester NSW	31 59	151 47	650
16	*irrorata*	"	18619	Bodalla NSW	36 08	150 02	20
9	*irrorata* ssp. *velutinella*	None	18623	Congarinni S.F. NSW	30 41	152 53	60
15	*irrorata* ssp. *velutinella*	"	18622	Newry S.F. NSW	30 31	152 59	10
47	*leucoclada*	Northern silver wattle	18621	Inverell NSW	29 44	150 57	700
63	*leucoclada* ssp. *argent.*	None	18067	Dalveen-Warwick Rd Qld	28 23	151 55	750
59	*mearnsii*	Black wattle, Green wattle	18977	Mt Gladstone, W Cooma NSW	39 15	149 05	1000
53	*mearnsii*	"	15329	Apsley R, W. Bicheno Tas	41 56	148 14	10
38	*mearnsii*	"	17933	Wattle Circle, Omeo Hwy Vic	37 27	147 50	200
50	*mearnsii*	"	18979	Blackhill Reserve, NE Kyneton Vic	37 12	144 29	520
18	*mearnsii*	"	18975	N Bungendore NSW	35 11	149 32	760
17	*mearnsii*	"	16621	Tuross R. SW Bodalla NSW	36 11	149 58	15
57	*mearnsii*	"	17928	Tarpeena SA	37 36	140 58	70

Table 1. (continued)

Treat. no.	*Acacia* species	Common name	Seedlot*	Location	Lat. ° ′ E	Long. ° ′ S	Alt. (m asl)
14	*melanoxylon*	Blackwood	16358	Bli Bli Qld	26 37	153 02	95
35	*melanoxylon*	"	18981	Grampians National Park Vic	37 22	142 31	300
36	*melanoxylon*	"	18980	Gellibrand R. Vic	38 43	143 15	50
28	*melanoxylon*	"	16526	25 km SE Mt Gambier SA	37 57	141 56	40
30	*melanoxylon*	"	15863	Blackwood Park, Lileah Tas	40 57	145 10	250
37	*nano-dealbata*	Dwarf silver wattle	17195	Mt Macedon Vic.	37 22	144 35	900
41	*nano-dealbata*	"	17940	Lavers Hill Vic	38 45	143 15	200
43	*obliquinervia*	Mountain hickory wattle	16273	13 km WNW Bemboka NSW	36 36	149 25	960
5	*obliquinervia*	Mountain hickory wattle	18070	Ruoaks Rd Blue Range Vic	37 26	145 50	1200*
4	*parramattensis*	Sydney green wattle, Parramatta wattle	17925	Numeralla NSW	36 11	149 18	900
46	*parramattensis*	"	18610	N. Windsor NSW	33 08	150 41	400
11	*parramattensis*	"	17711	Tarago NSW	35 10	149 35	740
33	*parvipinnula*	Silver-stemmed wattle	15844	Colo Heights-Putty Road NSW	33 14	150 39	360
19	*parvipinnula*	"	15842	Howes Valley NSW	32 52	150 52	240
62	*silvestris*	Red wattle, Bodalla silver wattle	17939	Bruthen Vic	37 35	147 54	200
21	*silvestris*	"	16254	11 km WNW Narooma NSW	36 11	150 01	130
25	*silvestris*	"	15852	Deua R. Deua National Park NSW	35 58	149 45	350
27	*trachyphloia*	Golden feather wattle	14229	Monga S.F. NSW	35 36	149 55	710
48	*trachyphloia*	"	17894	Currowan Ck. NSW	35 35	150 03	100
3	*Eucalyptus nitens*	Shining gum	14438	Badja S.F. NSW	36 01	149 34	1050

* These seedlot numbers are usually prefixed with an S, but this component has been omitted in this paper

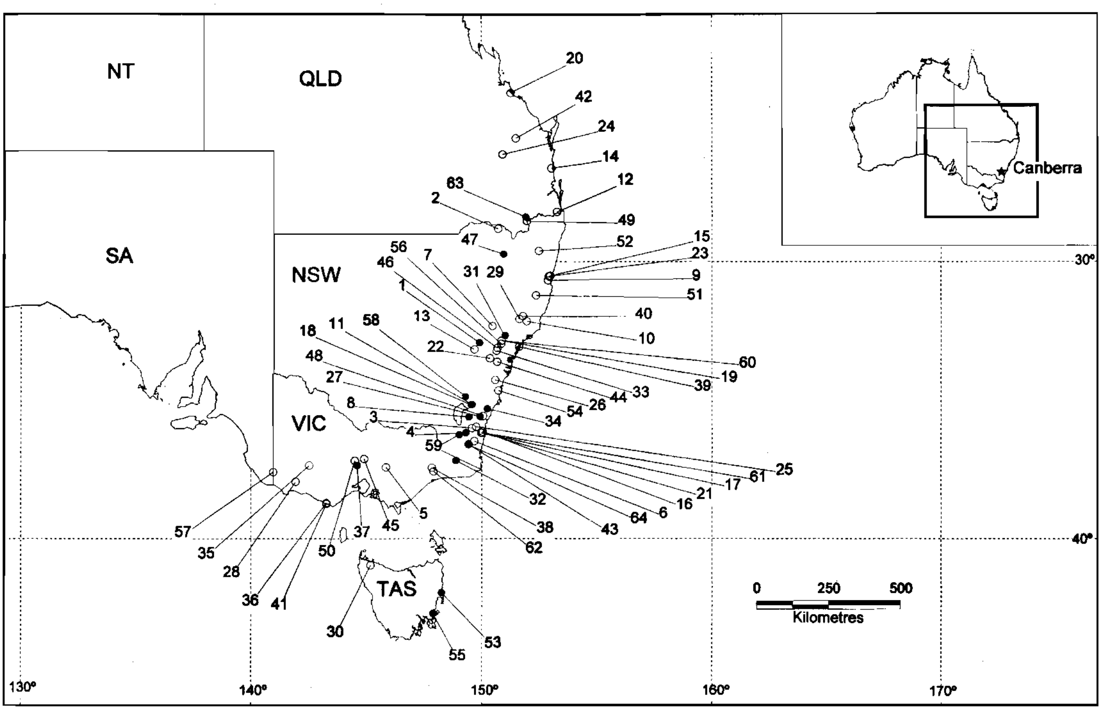

Figure 1. Map showing origin of seedlots used in two field trials near Canberra. The most frost-tolerant species/provenances are indicated by ●.

Trial design

The field trials were arranged in a square lattice (8 × 8) with four replicates. Each plot consisted of 10 trees arranged in two rows of five trees (2.5 m between trees within rows × 3.0 m between rows) and thus each seedlot was represented by 40 trees in each trial. Both trials were surrounded by two rows of buffer trees to minimise the impact of edge effects upon the trees in trial. The outer row was a species/provenance which was expected to grow well (*A. mearnsii* 18975, Bungendore NSW) and its purpose was to provide some measure of protection against wind and cold air drainage; the inner row was an extension of the plots adjacent to the edge of the trial.

Frost damage assessments

Seedlots were sown in May 1994; the trials were planted in October (spring) 1994 and assessed for frost tolerance over the subsequent winters of 1995 and 1996. Frost assessments were conducted monthly over four months (July–October inclusive) in 1995 and over five months (June–September inclusive) in 1996.

A simple six-point index was devised and used to assess damage to terminal buds and leaves of each tree in trial (Table 2). Damage to the terminal buds and subsequent potential to alter the form of the trees was regarded as being more serious than desiccation of the leaves. However two species (*A. elata* and *A. glaucocarpa*) were treated as exceptions (see Table 2) because their terminal buds, usually the most frost sensitive of plant parts, did not appear to be damaged before leaf desiccation occurred. *A. elata* exhibited this trait most clearly, with *A. glaucocarpa* showing relatively less leaf damage.

A. melanoxylon was a difficult species to assess visually for slight to moderate damage because the terminal buds were very small and often naturally reddish-brown in colour. Attempts to feel the bud for desiccation could end with the bud being damaged. When in doubt as to whether the bud was alive or dead, it was recorded as alive. Discolouration of the leaves and buds prior to desiccation was assessed as damage.

Temperature recordings

Maximum and minimum temperatures at each site were recorded on a weekly basis using manually read and reset maximum/minimum thermometers placed in Stevenson screens adjacent to the trials. When calibrated with each other the thermometers were found to be ±0.5°C of each other, with the thermometer at Kowen reading 0.5°C higher than the thermometer at Uriarra. The readings at both Kowen and Uriarra were within a degree of the official temperature weekly minima recorded at the Canberra Airport Observing Office. Minimum temperatures are presented for the months April–October in Table 3.

Table 2. Frost assessment index.

Index	Description	Impact on tree growth
1	No visible signs of damage	No damage
2	<10% expanded (mature) + unexpanded leaves burnt/desiccated (terminal buds undamaged)	Minimal
3	10%–25% expanded (mature) + unexpanded leaves desiccated and terminal bud of dominant stem(s) is dead or *A. elata*/*A. glaucocarpa* terminal bud(s) is alive but <25% foliage is dessicated	Slight
3.5	*A. elata*/*A.glaucocarpa* terminal bud(s) is dead but <25% foliage is dessicated	Slight
4.0	25%–75% mature foliage desiccated, terminal bud of dominant stem(s) is dead or *A. elata*/*A. glaucocarpa* terminal bud(s) is alive but 25%–75% foliage is dessicated	Moderate
4.5	*A. elata*/*A. glaucocarpa* terminal bud(s) is dead but 25%–75% foliage is dessicated	Moderate
5	75%–95% mature foliage desiccated, terminal bud of dominant stem(s) is dead or *A. elata*/*A. glaucocarpa* terminal bud(s) is alive but 75%–95% foliage is dessicated	Severe
5.5	*A. elata*/*A. glaucocarpa* terminal bud(s) is dead but 75%–95% foliage is dessicated	Severe
6	>95% foliage desiccated/brown, terminal bud(s) dead	Very severe

Analysis

For each tree the maximum frost score recorded in each year was taken as the measure of frost damage to be analysed. The frost damage score was treated as a quantitative scale and plot means were calculated for each year. The data were analysed by REML using Genstat (Genstat 5 Committee 1990). An initial analysis showed that the one eucalypt in trial, *Eucalyptus nitens*, which had been selected as one of the best performers from an earlier series of eucalypt-dominated fuelwood trials in the ACT, was significantly more frost tolerant than any of the

Table 3. Monthly means, minima and cumulative frost temperatures (°C) for Kowen and Uriarra trial sites for the months April–October 1995 and 1996.

Month	1995				1996			
	Kowen average	Kowen minimum	Uriarra average	Uriarra minimum	Kowen average	Kowen minimum	Uriarra average	Uriarra minimum
April	+0.2	−1.0	+0.2	−2.0	+1.8	−0.5	+0.6	−2.0
May	+1.2	0.0	+1.9	+3.5	−0.5	−4.0	−0.5	−5.5
June	−2.9	−4.5	−4.2	−5.0	−3.5	−5.5	−2.9	−6.0
July	−3.4	−5.0	−1.4	−5.5	−3.7	−6.0	−3.8	−6.0
August	−3.0	−4.5	−0.1	−2.0	−1.9	−4.5	−3.5	−6.0
September	+0.1	−3.0	−0.9	−5.0	+1.6	0.0	+1.9	+1.0
October	+4.4	+1.5	+3.5	+3.0	+2.9	+1.0	+2.9	−1.0
Mean	−0.5	−2.5	−0.1	−1.9	−0.5	−2.8	−0.8	−3.6
Absolute min. monthly temp. recorded at trial sites		−5.0		−5.5		−6.0		−6.0
Absolute min. monthly temp. for study months recorded by Canberra Airport Observing Office			−5.2				−6.8	
		Kowen		Uriarra		Kowen		Uriarra
Cumulative values for weekly min. temperatures <0°C		−47.0		−29.5		−60.0		−53.5

acacias in trial, showing no frost damage. This and the acacia from the most northerly location represented in trial (*A. falciformis* 17740 collected south of Gladstone Queensland (23°53′S 50 m asl)) were eliminated from the final analysis as the latter was, with the exception of a few individuals, killed outright during the first winter.

To examine the relationship between frost damage and height growth, the 1996 damage assessments and 1997 height measurements for Kowen were used. (Uriarra could not be used because the height of c.18% of trees has been reduced by bird (cockatoo) attack in spring in 1995 and 1996). Correlation at the species and provenance level was carried out using covariance and variance components from an analysis of cross products of provenance means for height and frost damage as in Williams and Matheson (1994).

Results and Discussion

Variation between sites, years and species

Both sites experienced temperatures as low as −6°C (Table 3) during the winter months and, in both years of observation, the trees showed more frost damage at Kowen than at Uriarra (Table 4). These weekly records of minimum temperatures, the absolute minimum monthly temperature and the cumulative values for weekly temperatures <0°C for the study periods did not distinguish between the two sites, except that the cumulative value for Kowen in 1995 was significantly greater than for Uriarra (Table 3). These readings were found inadequate, especially in 1996, for explaining the more severe frost damage observed at Kowen.

There were highly significant (P = 0.001) differences for frost damage between species/provenances at each site and significant differences between the two sites. The overall damage to trees at Kowen was significantly greater than at Uriarra in both years and was most severe in 1996 (Kowen — mean trial score 3.07 in 1995 and 3.20 in 1996; average standard error of difference = 0.060).

The frost damage recorded for each provenance was generally consistent from site to site and from year to year. For example at Uriarra (mean trial score 2.70 in 1995 and 2.60 in 1996; average standard error of difference = 0.060) only eight of the 64 seedlots showed significantly different damage from year to year. Of these, five showed significantly more damage in 1995 than 1996 and were as follows: *A. binervata* (17260 Springbrook Qld), *A. chrysotricha* (18620 Newry S.F. NSW), *A. glaucocarpa* (18065 Cadarga Qld and 15473 Gayndah Qld), *A. irrorata* (18626 Gloucester NSW), *A. parvipinnula* (15842 Howes Valley NSW). Conversely, *A. cangaiensis* (18862 Jackadgery NSW), *A. implexa* (18611 Sofala NSW) and *A. melanoxylon* (16358 Bli Bli Qld) showing significantly more damage in 1996 than 1995.

At Kowen there was again a general consistency between damage assessments from one year to the next. The exceptions were three seedlots that were significantly more damaged in 1995 than 1996 (*A. cangaiensis* (18862 Jackadgery NSW); *A. deanei* (15470 Goondiwindi NSW); *A. glaucocarpa* (15473 NW Gayndah Qld)) and seven significantly more damaged in the second year than the first. These were all three provenances of *A. implexa* (18611, 18019 and 15832) *A. irrorata* (18619 Bodalla NSW and 15840 Craven-Stroud NSW) and *A. melanoxylon* (18981 Grampians Vic. and 16358 Bli Bli Qld).

Table 4 shows rankings by mean scores for each seedlot and scores at each site in each year. These range from 1.98 (no damage) for *A. dealbata* to 5.03 (severe damage) for *A. elata* which died back each year with frost damage. In terms of ranking across sites, the most frost tolerant acacia seedlot was *A. dealbata* (18973) collected at Kandos, 4 km E Lithgow NSW (32°56'S 600 m asl). However there were 16 seedlots representing eight other acacia species (*A. decurrens*, *A. filicifolia*, *A. leucoclada*, *A. mearnsii*, *A. nano-dealbata*, *A. parramattensis*, silvestris, *A. trachyphloia*) which were not significantly different. The most severely damaged seedlots were the three NSW provenances of *A. elata* collected between 650 and 1000 m asl. Together with *A. cangaiensis*, *A. binervata* and *A. implexa*, this species showed severe branch and/or stem death and was reduced to a shrub.

These results are in accord with damage to c. 30-month old acacias in a species elimination trial reported by Yang et al. (1994). They were planted at Longdouxie in northern Guangdong province which experienced unusually severe winter temperatures down to −7.6°C. A number of the seedlots were identical to those subsequently planted in the Canberra trials. Yang et al. (1994) assessed the trees c. 4 months after the damage occurred and found *A. dealbata* was the most frost tolerant species in trial, followed by *A. parramattensis* (Bungendore and Marulan provenances NSW), *A. trachyphloia* (14229 Monga S.F. NSW), *A. deanei* (Queensland provenance) and most surprisingly, a provenance of *A. elata* (15848 Buxton-Hilltop NSW 34°17'S, 410 m asl). In the Canberra trials all three provenances of *A. elata* were seriously damaged. Amongst the *A. dealbata* provenances in common with the Canberra trials, the Bemboka NSW (16376) and Errinundera Plateau Vic. (16271) were the least damaged and the Orford Tasmania (16384) was the most damaged (Yang et al. 1994).

Table 4. Means score for frost damage sustained at Kowen and Uriarra trial sites in 1995 and 1996 by each seedlot ranked in decreasing order of frost tolerance by the overall mean across years and sites.*

Treat. no.	*Acacia* species	CSIRO Seedlot	Height (m) Kowen 1997	Frost damage score ** Overall mean	1995 + 1996 Kowen	1995 + 1996 Uriarra	Kowen 1995	Kowen 1996	Uriarra 1995	Uriarra 1996
1	*dealbata*	18973	5.19	1.98	2.05	1.92	2.04	2.05	2.00	1.84
8	*dealbata*	18024	4.96	1.99	2.04	1.93	2.02	2.06	2.02	1.85
11	*parramattensis*	17711	4.04	2.03	2.02	2.05	1.96	2.08	2.01	2.09
27	*trachyphloia*	14229	4.23	2.03	2.06	2.00	2.08	2.05	2.02	1.97
59	*mearnsii*	18977	4.40	2.03	2.07	2.00	2.04	2.10	1.98	2.01
4	*parramattensis*	17925	3.96	2.08	2.15	2.00	2.12	2.18	2.03	1.97
32	*dealbata*	16271	4.69	2.08	2.14	2.02	2.10	2.17	2.04	2.01
64	*dealbata*	16376	4.70	2.08	2.12	2.04	2.06	2.17	2.03	2.06
34	*filicifolia*	17893	5.00	2.08	2.07	2.09	2.01	2.14	2.10	2.08
47	*leucoclada*	18621	3.37	2.10	2.18	2.02	2.14	2.21	2.03	2.00
53	*mearnsii*	15329	4.40	2.10	2.15	2.05	2.05	2.25	2.09	2.02
63	*leucoclada* ssp. *argentifolia*	18067	3.92	2.12	2.14	2.10	2.20	2.09	2.05	2.16
58	*decurrens*	14726	5.36	2.12	2.02	2.21	2.02	2.02	2.39	2.03
31	*filicifolia*	15841	4.66	2.13	2.06	2.20	2.11	2.02	2.39	2.01
37	*nano-dealbata*	17195	3.82	2.14	2.23	2.06	2.25	2.20	1.97	2.14
55	*dealbata*	16384	4.12	2.15	2.19	2.11	2.20	2.18	2.18	2.04

Table 4. (continued)

Treat. no.	*Acacia* species	CSIRO Seedlot	Height (m) Kowen 1997	Frost damage score ** Overall mean	1995 + 1996 Kowen	1995 + 1996 Uriarra	Kowen 1995	Kowen 1996	Uriarra 1995	Uriarra 1996
18	*mearnsii*	18975	4.74	2.17	2.31	2.03	2.13	2.49	1.99	2.07
62	*silvestris*	17939	4.71	2.21	2.21	2.21	2.29	2.14	2.33	2.10
30	*melanoxylon*	15863	2.33	2.23	2.25	2.19	2.05	2.46	2.09	2.30
25	*silvestris*	15852	4.53	2.24	2.02	2.46	2.01	2.03	2.54	2.38
38	*mearnsii*	17933	4.35	2.25	2.42	2.07	2.40	2.44	2.11	2.04
28	*melanoxylon*	16526	2.26	2.26	2.27	2.25	2.15	2.40	2.06	2.44
17	*mearnsii*	16621	4.19	2.26	2.47	2.05	2.40	2.54	2.07	2.03
36	*melanoxylon*	18980	2.23	2.27	2.33	2.20	2.19	2.47	2.10	2.31
5	*obliquinervia*	18070	3.01	2.28	2.26	2.31	2.29	2.23	2.34	2.27
35	*melanoxylon*	18981	2.11	2.35	2.52	2.18	2.19	2.85	2.08	2.29
41	*nano-dealbata*	17940	3.29	2.35	2.54	2.16	2.48	2.59	2.00	2.32
50	*mearnsii*	18979	4.16	2.39	2.67	2.12	2.53	2.82	2.20	2.03
48	*trachyphloia*	17894	4.20	2.40	2.61	2.18	2.54	2.69	2.23	2.14
57	*mearnsii*	17928	4.06	2.46	2.82	2.10	2.68	2.96	2.06	2.15
7	*dangarensis*	18608	2.94	2.53	2.67	2.39	2.45	2.88	2.26	2.52
26	*decurrens*	15847	4.80	2.56	2.76	2.37	2.60	2.91	2.46	2.28
46	*parramattensis*	18610	3.77	2.69	2.87	2.50	2.74	3.00	2.48	2.52
43	*obliquinervia*	16273	2.50	2.70	3.00	2.41	2.41	3.59	2.34	2.47
44	*binervia*	15845	2.37	2.74	2.97	2.51	2.92	3.02	2.70	2.32
2	*deanei*	15470	2.92	2.79	3.16	2.42	3.39	2.92	2.27	2.57
33	*parvipinnula*	15844	4.58	2.80	2.94	2.66	2.86	3.02	2.54	2.79
16	*irrorata*	18619	3.35	2.82	3.13	2.50	2.90	3.36	2.60	2.41
19	*parvipinnula*	15842	4.47	2.84	2.89	2.78	2.93	2.85	3.19	2.38
56	*fulva*	18972	4.75	3.12	3.35	2.90	3.32	3.38	2.97	2.82
21	*silvestris*	16254	4.46	3.17	3.78	2.57	4.00	3.56	2.63	2.51
40	*irrorata*	18626	3.43	3.30	3.49	3.12	3.40	3.58	3.53	2.70
6	*blayana*	18068	2.96	3.35	3.87	2.84	4.09	3.64	2.78	2.89
60	*fulva*	15843	4.66	3.36	3.73	2.98	3.86	3.60	3.00	2.97
9	*irrorata* ssp. *velutinella*	18623	3.51	3.39	3.90	2.89	3.85	3.96	3.14	2.64
15	*irrorata* ssp. *velutinella*	18622	3.60	3.39	3.98	2.81	4.01	3.95	3.20	2.42
24	*glaucocarpa*	18065	4.33	3.46	3.71	3.21	3.85	3.57	3.75	2.67
10	*irrorata*	15840	3.41	3.51	3.97	3.04	3.72	4.23	3.24	2.85
23	*chrysotricha*	18620	2.35	3.57	4.04	3.09	4.07	4.02	3.61	2.57
14	*melanoxylon*	16358	1.88	3.63	4.04	3.22	3.79	4.28	2.74	3.71
13	*implexa*	18611	2.63	3.66	4.54	2.79	3.61	5.47	2.24	3.33
49	*falciformis*	15502	3.19	3.74	4.22	3.25	4.13	4.31	3.31	3.18
20	*falciformis*	16253	2.71	3.90	4.35	3.45	4.37	4.34	3.37	3.53
42	*glaucocarpa*	15473	4.22	3.96	4.17	3.75	4.42	3.93	4.07	3.42
45	*implexa*	18019	2.61	4.21	5.24	3.19	4.93	5.54	3.07	3.31
54	*binervata*	16245	2.07	4.25	4.66	3.85	4.69	4.62	4.08	3.62
39	*implexa*	15832	1.82	4.30	5.07	3.53	4.43	5.71	3.32	3.74
12	*binervata*	17260	1.22	4.67	5.03	4.31	5.26	4.80	4.69	3.94
52	*cangaiensis*	18862	1.18	4.69	5.10	4.29	5.39	4.81	3.96	4.62
22	*elata*	18252	1.76	4.78	5.19	4.38	5.18	5.20	4.68	4.08
29	*elata*	18251	1.51	4.97	5.47	4.46	5.38	5.57	4.59	4.34
51	*elata*	18243	1.46	5.03	5.55	4.52	5.53	5.56	4.80	4.23
	Standard error difference			0.11	0.17	0.17	0.21	0.21	0.21	0.21

* *Eucalyptus nitens* and *Acacia falciformis* (17740 S of Gladstone Qld) have not been included in this table. *E. nitens* received minimal damage and most of the *A. falciformis* was killed by frost in the first year.
** As per Table 2

Provenance variation

Three species were represented by five to seven provenances. *A. dealbata* was represented by five provenances from New South Wales (NSW), Victoria and Tasmania and all were ranked within the most frost-tolerant grouping with no significant differences between them. In descending order of frost tolerance they were 18973 (Lithgow NSW 32°56′S 600 m asl), 18024 (Captains Flat NSW 35°37′S 700 m asl), 16376 (Bemboka NSW 36°37′S 1035 m asl), 16271 (Errinundera Plateau Victoria 37°11′S 960 m asl) and 16384 (Orford Tasmania 42°41′S 120 m asl).

There were five *A. melanoxyon* provenances in trial; the highest ranked provenance for frost tolerance originated from northwest Tasmania (15863 Blackwood Park Lileah 40°57′S 250 m asl) but this did not differ significantly in frost tolerance from the other Victorian and South Australian provenances in trial. Significantly less frost tolerant was the south-eastern Queensland provenance (16358 Bli Bli 26°37′95 m asl).

Several authors have reported provenance variation in frost tolerance for *Acacia melanoxylon*. Campbell (1989) noted that the best sawlog provenance from the blackwood swamps of northwest Tasmania (altitude less than 10 m asl) suffered considerable frost damage when planted on other sites. On the other hand, seed from the Midlands area of central Tasmania (altitude 400–900 m asl, rainfall 400 mm) was quite frost tolerant, used extensively for amenity plantings but with little timber value. Brown and Jennings (1996) found no consistent trend in frost tolerance in a blackwood trial planted in 1992 (RP 266/6) that tested a small number of Tasmanian provenances and families: four provenances each represented by 2–6 individual tree seedlots. High-altitude seedlots from northwest Tasmania were the most frost tolerant and had better survival than other Tasmanian provenances but were also slower growing. High-altitude seedlots from the northeast were no more frost tolerant than low-altitude seedlots. Confirming Campbell's observations, low-altitude, northwest seedlots were the least frost resistant, together with high-altitude northeast seedlots. Frost tolerance and altitude were positively correlated. The authors concluded that although further research may identify frost-tolerant provenances, at that stage local provenances would still be recommended for planting in Tasmania (Brown and Jennings1996).

Franklin (1987) reported on a trial of 30 blackwood seedlots (Tasmania (6), Victoria (2), NSW (1), NZ (6), Chile (1), South Africa (2 bulk and 12 individual tree collections)), that was assessed at c. 2 years of age in late 1986 when the screen temperature was down to c. –7°C. The most frost resistant provenances (from Tasmania, Smithton (2), Scottsdale, Zeehan, Zudbury, Huon Valley) and high-altitude NSW (Boyd Plateau)) had below-average height growth. The South African seedlots, that on the whole grew faster than average, generally had much lower than average frost resistance. However the 30 seedlots included a number of frost-resistant individuals with fast growth and good form which could profitably be used in breeding programs. Franklin (1987) concluded that although the trials were still far too young to give definitive results, it did appear that where frost was likely to be a problem in blackwood establishment, there were provenances that would give better than random results.

A. mearnsii was represented by seven provenances. These were ranked in order of decreasing frost tolerance as follows: Mt Gladstone, Cooma NSW (18977); Apsley River Tasmania (15329); Bungendore NSW (18975); Omeo Hwy, Victoria (17933); Bodalla NSW (16621); Blackhill Reserve, NE Kyneton Victoria (18979); Tarpeena South Australia (17928). The Cooma, Apsley River and Bungendore provenances were equally frost tolerant and ranked amongst the most tolerant in trial. The Kyneton and Tarpeena provenances were significantly less frost tolerant. This field ranking of provenances duplicated the laboratory results of Searle et al. (1994) who ranked identical or similar provenances in order of decreasing frost tolerance as follows: Bungendore NSW (14725) Mt Gladstone, Cooma NSW (17937), Apsley River Tasmania (15329), Blackhill Reserve, NE Kyneton Victoria (14925), Bodalla NSW (16967), Tambo Crossing, Omeo Highway Victoria (16381). As with the field ranking there was no significant difference between the Cooma, Apsley River and Bungendore provenances (Searle et al.1994).

Acacia silvestris was represented by three provenances with the most coastal, lower altitude provenance from Narooma NSW (16254 36°11′S 130 m asl) being significantly less tolerant than the Deua River (15852 35°58′S 350 m asl) and Bruthen Vic. (17939 37°35′S 200 m asl) provenances. *A. parramattensis* was represented by three NSW provenances; the two most frost tolerant were high altitude provenances (17711 Tarago 35°10′S 740 m asl and 17925 Numeralla 36°11′S 900 m asl) and these were significantly more frost tolerant than the lower altitude and more northerly Windsor provenance (18610 33°08′S 400 m asl).

A. implexa, represented by three provenances from very different altitudes, showed significant provenance variation in frost tolerance. The most northerly, coastal provenance was from Swansea

NSW (15832 33°05′S 151°37′E 10 m asl); the most southerly, inland was from Pyalong Victoria (18019 37°08′S 144°53′E 200 m asl) and the highest altitude provenance was from Sofala NSW (18611 33°11′S 149°41′E 850 m asl). The most frost-tolerant provenance was the high altitude Sofala seedlot which showed slight to moderate damage, while the Pyalong and Swansea provenances were significantly less tolerant and showed moderate to severe damage. The severe damage to the two higher altitude provenances at Kowen in 1996 is difficult to explain, although Pollock et al. (1986) report that *A. implexa* from inland and medium altitude Dubbo NSW (32°15′S 148°37′E 560 m asl) was less frost tolerant than expected.

The more inland provenance of *A. glaucocarpa* from Cadarga Qld (18065 26°07′S 150°55′E 350 m asl) was significantly more frost tolerant than the Gayndah Qld provenance (15473 25°32′S 151°29′E 390 m asl). The higher altitude *A. trachyphloia* provenance from Monga State Forest NSW (14229 35°36′S 149°55′E 710 m asl) was significantly more frost tolerant than the coastal provenance (17894 Currowan Ck NSW 35°35′S 150°03′E 100 m asl). Similarly the higher altitude, more southerly provenance of *A. decurrens* (14726 SW Goulburn NSW 34°53′S 149°17′E 685 m asl) was significantly more frost tolerant than the *A. decurrens* (15847 Picton-Mittagong NSW 34°17′S 150°35′E 380 m asl). This same relationship existed for *A. fulva* with the provenance at 600 m asl (18972 Mt Yengo NSW 32°59′S 150°51′E) being more frost tolerant than the provenance at 240 m asl (15843 32°52′S 150°52′E).

Across species there was no significant correlation between the frost damage incurred and either the latitude or altitude of the collection site; such a correlation is confounded by inherent species differences in frost tolerance. The origin of the most frost-tolerant seedlots is shown in Figure 1; these range from Queensland to Tasmania and from coastal to high altitude locations. These results have some link to those based on 18 acacia species reported by Pollock et al. (1986) who stated that in *Acacia* the potential for frost tolerance was likely to associated with the origin (e.g. altitude, latitude and distance from the sea) of the seedlots examined and there was a tendency for seedlots with greater frost tolerance to originate from higher altitudes, higher latitudes or greater distance from the sea. Examples of seedlots that did not have such direct associations, were the frost tolerant *A. mearnsii* from high latitude, low altitude Tasmania (15329 Apsley River, W of Bicheno Tasmania 41°56′S 148°14′E 10 m asl), the lower latitude, inland Queensland provenance of *A. glaucocarpa* (18065 Cadarga 26°07′S 150°55′E 350 m asl) which showed slight to moderate damage and the higher latitude, moderate altitude, inland provenance of *A. implexa* (18019 Pyalong Victoria 37°08′S 144°53′E 200 m asl) which showed moderate–severe frost damage.

General trends, proposed by Pollock et al. (1986), for frost tolerance in acacias to be linked to their origin (altitude, latitude and distance from the sea), were best found within species, rather than between species in this study. Examples were found of higher altitude provenances being more frost tolerant than lower altitude provenances, i.e. in *A. decurrens*, *A. implexa*, *A. fulva*, *A. parramattensis*, *A. trachyphloia*; more southerly provenances being more frost tolerant than more northerly, i.e. *A. silvestris* and more inland provenances being more frost tolerant than coastal provenances, i.e. *A. glaucocarpa*. However, there appears to be a limit to the predictive accuracy of frost tolerance based on geographic or climatic analyses because these do not take into account the effects of the microclimate characteristics of a site, such as cold air drainage and exposure.

A highly significant ($P = 0.001$) negative correlation was found between tree height at Kowen in 1997 and frost damage during the winter of 1996 ($r = -0.67$). The tallest trees were the least damaged by frost while the shortest were the most frost-prone. This correlation was due to differences between species ($r = -0.74$ $P = 0.001$), not the effect of provenances within species ($r = -0.21$ n.s.). The species most damaged by frost were reduced by branch dieback or stem death to stunted shrubs, i.e. *A. elata*, or to coppice, i.e. *A. implexa* and *A. cangaiensis*.

Some species which had terminal shoot damage caused by frost, such as *A. fulva* and *A. blayana*, were subsequently attacked by fungi which caused stem cankers. This secondary attack by fungi is apparently not unusual but without the initial record of shoot death by frost it would not have been possible to determine if the fungi were the primary or secondary cause of death. In a small number of trees, these fungal cankers were also beginning to attract boring insects. These were examples of frost not only limiting height growth but also damaging the long-term health and viability of frost-prone species.

Conclusion

This research identified a number of *Acacia* species/provenances that were minimally damaged by winter temperatures down to –6°C and would therefore be suitable candidates for fuelwood plantations in the Canberra region and other areas subjected to similar damaging winter temperatures. Most promising were provenances of *A. dealbata*, *A. decurrens*, *A. filicifolia*, *A. leucoclada*, *A. parramattensis*, *A. mearnsii*, *A. nano-dealbata* and *A. trachyphloia*. Irrespective of provenance, *A. dealbata* was the most frost-tolerant species in trial. There were significant differences in frost-tolerance between provenances for a number of *Acacia* species including *A. decurrens*, *A. fulva*, *A. implexa*, *A. glaucocarpa*, *A. mearnsii*, *A. melanoxylon*, *A. silvestris* and *A. trachyphloia*.

These results indicated that local provenances were not necessarily the most frost-tolerant for the Canberra region and that selection of potentially frost-tolerant provenances on the basis of either latitude or altitude alone will not be successful. A useful approach to identifying the provenances best adapted to frost would a climatic analysis of seedlot origin, which would combine the effects of latitude and altitude.

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References

Brown, D. and Jennings, S.1996. Blackwood provenance frost trial Meunna plantation RP 266/6. In: Neilsen, W.A. and Brown, D.R., ed., *Acacia melanoxylon* Plantations in Tasmania. Forestry Tasmania Forests and Forest Industry Council, 75–84.

Campbell, G.D. 1989. Blackwood growing on private property in Tasmania. In: Proceedings Third Agroforestry Conference, Farm Trees for Productivity and Profit. 27–28 April 1989. Morwell Vic. 100–112.

Franklin, D. 1987. Resistance of Tasmanian blackwood to frost damage. New Zealand Tree Grower August 1987. 74–75.

GENSTAT 5 Committee 1990. GENSTAT 5, Release 2 Reference Manual Supplement. NAG Ltd, Lawes Agricultural Trust (Rothamsted Experimental Station).

Pearce, E.A. and Smith, C.G. 1984. The World Weather Guide. Hutchinson, London 480 p.

Pollock, K.M., Greer, D.H. and Bulloch, B.T. 1986 Frost tolerance of acacia seedlings. Australian Forest Research, 16, 337–46.

Searle, S.D., Owen, J. and Snowdon, P. 1994. Frost tolerance variation amongst 25 provenances of *Acacia mearnsii* De Wild. In: Brown, A.G., ed. Australian Tree Species Research in China. Proceedings of an international workshop held from 2 to 5 November 1992 in Zhangzhou, Fujian Province PRC. ACIAR Proceedings No. 48, 140–148.

Williams, E.R. and Matheson A.C. 1994. Experimental Design and Analysis for Use in Tree Improvement. CSIRO, Melbourne and ACIAR, Canberra, 174 p.

Yang, M., Zeng, Y., Zhang, X. and Zhang, X. 1994. Effect of low temperatures on *Acacia*. In: Brown, A.G. ed. Australian Tree Species Research in China. Proceedings of an international workshop held from 2 to 5 November 1992 in Zhangzhou, Fujian Province, PRC. ACIAR Proceedings No. 48, 176–179.

Harris-Daishowa's *Acacia* Species Trials at Eden, NSW

Peter Mitchell[1]

Abstract

Results from a planting of *Acacia mearnsii, A. dealbata* and *A. silvestris* in southern NSW, Australia indicate that *A. mearnsii* is displaying superior early growth to *E. nitens*, the main commercial species planted by Harris-Daishowa (Aust) Pty Ltd, but this early growth advantage may not be maintained. Growth of individual trees within plots was very variable due to dry conditions and insect attack.

A. mearnsii has very favourable pulpwood properties when compared to *E. nitens* plantation material and natural eucalypt regrowth currently harvested by Harris-Daishowa. Future trials will include mixed plantings of eucalypts and acacias.

HARRIS-DAISHOWA (Aust) Pty Ltd (HDA) is an exporter of hardwood woodchips situated on the South Coast of NSW, which currently exports between 700 000 and 850 000 tonnes per annum for the Daishowa Paper Manufacturing Company of Japan.

The Company began operation in 1967 with the bulk of the eucalypt chips exported providing feedstock to produce high-grade printing and writing papers, computer paper, photocopying and facsimile paper.

HDA began eucalypt species elimination trials in 1989, as a result of political pressure to augment our log supplies from native forest with that derived from plantation. These trials have shown *E. nitens* is the best performing species on high altitude, high rainfall sites (greater than 600 m altitude and in excess of 850 mm per annum of rainfall), but on lower coastal sites the choice of species is less clear.

Based on trials in Southern Australia it was felt that *E. globulus* would be most suitable for coastal sites, but initial good early growth has been followed by severe defoliation of juvenile leaves in year two by *Mycosphaerella* sp. fungus.

On advice from Suzette Searle of CSIRO Forestry and Forest Products, HDA installed an *Acacia* species trial at the Jews Head site, Eden. This trial consisted of 15 bipinnate acacia species represented by 35 seedlots. Heavy early browsing by rabbits and wallabies prevented meaningful analysis of growth data but the vigour displayed by individuals prompted the installation of a further trial in 1996. The early results of this trial are the subject of this report.

[1] Harris-Daishowa (Aust.) Pty Ltd, P.O. Box 189, Eden NSW 2551 Australia

Materials and Methods

Seed

Based on Searle's advice and observations from the 1994 trial, 10 seedlots of *A. dealbata*, nine seedlots of *A. mearnsii* and five seedlots of *A. silvestris*, along with a control seedlot of *E. nitens* were selected. Seed was supplied by the Australian Tree Seed Centre, Canberra, Australia and grown at a commercial nursery at Tathra, 45 km north of Eden.

A list of seedlots used in the Trial is given in Table 1.

Nursery

Pre-germination treatment: immersed in boiling water and allowed to cool for 15 minutes.

Sowing date: 20/12/95 — two–three seeds per cell
Pots: Hiko V93, 93cc capacity
40 trees per tray.
Potting Mix: 2 parts composted pine fines; 1 part pearlite; 1 part coconut fibre peat; nutrients (per m^3) — 1 kg dolomite, 525 g nutricote 27 day, 1.2 kg mini-osmocote

Table 1. Seedlots in Harris Daishowa Acacia species trial 1996.

Plot no.	Seedlot no.	Species	Provenance	State	Latitude		Longitude		Altitude (m)
					Deg.	Min.	Deg.	Min.	
1	16267	*Acacia dealbata*	32 Mile Road	VIC	37	25	148	37	350
2	16271	*Acacia dealbata*	Errinundra Plateau	VIC	37	11	148	52	960
3	16376	*Acacia dealbata*	22–18 km WNW Bemboka	NSW	36	37	149	26	1035
4	16383	*Acacia dealbata*	43–48 km NW Swansea	TAS	41	55	147	56	615
5	16384	*Acacia dealbata*	18.6 km S Orford	TAS	42	41	147	52	120
6	16385	*Acacia dealbata*	6–15 km SSE Snug	TAS	43	6	147	14	143
7	16743	*Acacia dealbata*	Jamieson–Licola Rd	VIC	37	28	146	24	1200
8	18024	*Acacia dealbata*	Captains Flat	NSW	35	37	149	26	700
9	18624	*Acacia dealbata*	Ben Lomond	NSW	30	3	151	43	1400
10	18973	*Acacia dealbata*	Kandos	NSW	32	56	149	54	600
11	14770	*Acacia mearnsii*	Pollocks Flat Rd	NSW	36	39	149	35	260
12	16246	*Acacia mearnsii*	10 km S of Nowra	NSW	34	59	150	36	10
13	16380	*Acacia mearnsii*	10.5 km E of Nowa Nowa	VIC	37	45	148	12	31
14	16621	*Acacia mearnsii*	Tuross R, SW Bodalla	NSW	36	11	149	58	15
15	17927	*Acacia mearnsii*	Tantanoola	SA	37	41	140	28	30
16	17933	*Acacia mearnsii*	Wattle Circ, Omeo Hwy	VIC	37	27	147	50	200
17	17934	*Acacia mearnsii*	Womboyn Lake	NSW	37	17	149	54	30
18	18975	*Acacia mearnsii*	N Bungendore	NSW	35	11	149	32	760
19	18979	*Acacia mearnsii*	Blackhill Reserve	VIC	37	12	144	29	520
20	15852	*Acacia silvestris*	Deua River, Deua NP	NSW	35	58	149	45	350
21	15854	*Acacia silvestris*	Wadbilliga Nat. Park	NSW	36	16	149	38	260
22	16254	*Acacia silvestris*	11 km WNW of Narooma	NSW	36	11	150	1	130
23	16260	*Acacia silvestris*	30 km W of Narooma	NSW	36	14	149	48	570
24	17939	*Acacia silvestris*	Bruthen	VIC	37	35	147	54	200
25		*Eucalyptus nitens*	Boral Seed Orchard, Camden	TAS					

Trial site

Location
Country: Australia
State: New South Wales (NSW)
Nearest town: Rocky Hall, 40 km west of Eden
Latitude: 37°20′S
Longitude: 149°30′E
Altitude: 250 m a.s.l.

Topography
General relief: Rolling
Slope: Gentle (3–15%)
Soil: Granite sediments derived from Wallagaraugh adamellite

Site history
Previous land use: Grazing cattle on slightly improved pasture
Vegetation prior to trial:
Themeda australis (kangaroo grass)
Pennisetum cladestinum (kikuyu)
Hypochoeris radicata (flatweed)
Pteridium esculentum (bracken)
Rubus fruticosus (blackberry)
Rumex acetosella (sorrell)
Acacia mearnsii (black wattle)

Rainfall
Median rainfall for site, 1890–1976: 696 mm
Mean rainfall for site, 1890–1976: 789 mm
Actual rainfall for site for year prior to planting: 670 mm
Actual rainfall for site for year following planting: 748 mm

Establishment history
Feb. 96: disc ploughed in strips (one pass)
April 96: winged ripped (to 1 m depth) and mounded with 4 × 70 cm disc mounting plough mounted on Komatsu D85A bulldozer.
June 96: mounds sprayed with Glyphosate (1.1 litres/ha active ingredient) and Simazine (5 litres/ha a.i.) using tractor boom spray.
July 96: planted at 3.5 m between rows and 2.0 m between trees (1429 trees/ha) using spade. Tree guards erected at planting. Plastic mesh (40 cm tall × 25 cm dia) with 3 bamboo stakes.
Oct. 96: fertilised at 140 g per tree using granular NPKS fertiliser (14.7 : 11.8 : 0 : 11.8)
Nov. 97: replanted (approximately 15% mortality due to drought/insect attack).

Trial design
Experiment design: randomised complete block 5 × 5
No. of replicates: 4
No. of plots/rep.: 25
No. of trees/plot: 10
Buffer row: adjoining row was *A. mearnsii* (single row)

Results

The trial was measured at 11 months (18/6/97) following the outline 'Proposed Measurement Guidelines for Acacia Species/Provenance Trials' compiled by Searle (February 1996). This involved measuring diameter 10 cm above the soil and total stem length. Height, diameter, volume and survival of the trees at 11 months are given in Table 2.

Volume was estimated using:
Volume = $\frac{1}{3}$ × basal area × height; where basal area = π × diam. × diam./4

This is graphically represented for each seedlot in Figure 1.

Table 2. SP7 — Wattle species trial — Rocky Hill — Summary of 11 month measurement.

Plot no.	Seedlot no.	Species	Provenance	State	Ave hght (m)	Ave diam (mm)	Ave vol (cm^3)	STDEV of vol	Survival (%)
1	16267	*Acacia dealbata*	32 Mile Road	VIC	1.09	11.1	103	175	90%
2	16271	*Acacia dealbata*	Errinundra Plateau	VIC	1.18	12.5	133	99	78%
3	16376	*Acacia dealbata*	22–18 km WNW Bemboka	NSW	0.76	7.0	34	55	83%
4	16838	*Acacia dealbata*	43–48 km NW Swansea	TAS	0.93	10.9	100	179	73%
5	16384	*Acacia dealbata*	18.6 km S Orford	TAS	0.86	9.2	58	94	60%
6	16385	*Acacia dealbata*	6–15 km SSE Snug	TAS	0.82	8.9	105	184	70%
7	16743	*Acacia dealbata*	Jamieson–Licola Rd	VIC	1.15	11.7	100	163	90%
8	18024	*Acacia dealbata*	Captains Flat	NSW	1.03	9.6	57	76	48%
9	18624	*Acacia dealbata*	Ben Lomond	NSW	0.52	5.8	23	33	53%
10	18973	*Acacia dealbata*	Kandos	NSW	1.08	11.0	117	167	65%
11	14770	*Acacia mearnsii*	Pollocks Flat Rd	NSW	0.75	8.8	44	63	88%
12	16246	*Acacia mearnsii*	10 km S of Nowra	NSW	1.05	11.9	102	163	90%
13	16380	*Acacia mearnsii*	10.5 km E of Nowa Nowa	VIC	1.22	15.0	155	173	83%
14	16621	*Acacia mearnsii*	Tuross R, SW Bodalla	NSW	1.37	15.6	218	292	98%
15	17927	*Acacia mearnsii*	Tantanoola	SA	1.52	19.9	361	436	93%
16	17933	*Acacia mearnsii*	Wattle Circ, Omeo Hwy	VIC	1.22	12.2	154	129	83%
17	17934	*Acacia mearnsii*	Womboyn Lake	NSW	0.99	11.2	102	152	95%
18	18975	*Acacia mearnsii*	N Bungendore	NSW	1.73	22.2	372	328	100%
19	18979	*Acacia mearnsii*	Blackhill Reserve	VIC	1.19	14.0	123	150	93%
20	15852	*Acacia silvestris*	Deua River, Deua NP	NSW	1.06	9.3	62	89	83%
21	15854	*Acacia silvestris*	Wadbilliga Nat. Park	NSW	0.81	6.4	23	36	80%
22	16254	*Acacia silvestris*	11 km WNW of Narooma	NSW	1.09	8.9	62	57	95%
23	16260	*Acacia silvestris*	30 km W of Narooma	NSW	0.79	7.2	24	31	83%
24	17939	*Acacia silvestris*	Bruthen	VIC	0.85	7.6	32	35	85%
25		*Eucalyptus nitens*	Boral Seed Orchard, Camden	TAS	1.06	18.9	145	116	83%

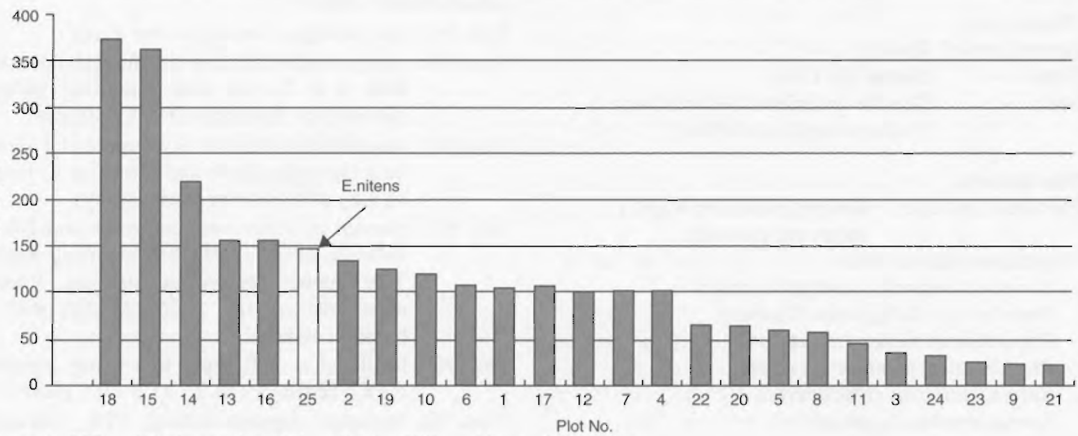

Figure 1. SP7 — Wattle species trial — Rocky Hill — 11 month measure.

Discussion

Obviously it is dangerous to draw any major conclusions from a 11 month measurement of a tree species elimination trial. Encouraging early growth is often not maintained, especially on poorer sites.

In overall terms, trees within the trial have suffered as a result of 4 years of below average rainfall leading up to trial installation. Annual rainfall for the period 12 months before and after planting appear normal but distribution has been poor, with 17 of these 24 months receiving less than average. The granite type soil has very poor moisture-holding capacity and dries rapidly. Table 2 shows that the *E. nitens* control had a mean height of 1.06 m and 80% survival at 11 months, whereas the same seedlot planted at the same site in 1992 (a wet year), measured 1.7 m with 97% survival.

At 11 months *A. mearnsii* showed best performance in terms of volume, height and diameter with the North Bungendore, NSW and Tantanoola, S.A. provenances being outstanding.

When all seedlots within a species were grouped *A. mearnsii* displayed best overall survival at 91% with *A. dealbata* and *A. silvestris* being 71 and 85% respectively.

Table 2 highlights the variability of tree size within a seedlot when standard deviation of volume is examined. Much of this can be attributed to a combination of dry conditions and perhaps insect attack by chrysomelid beetle grub.

The fact that *A. mearnsii* has displayed the best early growth is not surprising based on local observations of the vigour of this species as a pioneer of freshly disturbed and/or burnt sites. This species has been regarded as a 'weed' in newly established eucalypt and *P. radiata* plantations in coastal Southeast Australia, where it often outperforms the main crop if left untreated for a period of 4 or 5 years, after which the main crop usually dominates. Similarly, *A. dealbata* has often dominated higher altitude plantations. In both scenarios the wattles invade at high stockings (up to 10 000 stems per ha) and seem capable of maintaining good growth at close spacings.

The early results of this ACIAR trial, a 1994 entomology trial with *A. mearnsii* and the 1994 Acacia Species Trial has ensured continuing interest by HDA in the temperate acacias as a possible plantation species for poorer coastal sites in Southeast Australia. Fang Guigan et al. (1991) reported a basic density for *A. mearnsii* of 608 kg/m^3, pulp yield of 53% on oven dry weight basis and pulp productivity of 320 kg per m^3 of wood. This compares more than favourably with a recent *E. nitens* sample from HDA plantations which had corresponding figures of 430 kg/m^3, 54% and 260 kg per m^3. HDA considers regrowth eucalypt as its best pulpwood, with recent samples producing figures of 598 kg/m^3 basic density, 55% pulp yield and 368 kg per m^3 pulpwood productivity.

Plantation grown *A. mearnsii* is currently being used commercially in South Africa as a component of a wood furnish for Kraft pulp production. Similarly A. *dealbata* is recognised by North Forest Products in Tasmania as a very good quality pulpwood (Logan, 1989). HDA has also exported *A. dealbata* which has been harvested concurrently with eucalypt regrowth.

The poor form displayed by some temperate acacias grown in plantation is a potential problem that may be reduced by tree breeding or alternatively by utilising multi-stem harvesting techniques such as portable chipper plants that incorporate in-field delimbing, debarking and chipping. These units 'flail' the branches and bark from trees, using rotating chains, and are therefore suitable for processing multiple leaders and crooked trees, whereas the grapple harvesters commonly used to date in Australia for plantation trees are limited to single, reasonably straight stems.

HDA will continue to maintain the ACIAR trial outlined in this report and also intends installing two trials in 1998 that will examine the potential of eucalypt/acacia combinations. This approach has the potential of capturing the early fast growth of acacias in a first thinning which harvests all acacias and some of the eucalypts at say, eight years old, and allows the eucalypts to grow to an age at which pulp properties are optimised (15–20 years). Work by CSIRO Forestry and Forest Products (Khanna 1995) has shown that despite competition for light and water, the growth of individual eucalypt trees was greater when in mixture with acacia, suggesting that the advantage of additional nitrogen made available from nitrogen fixation by acacia outweighed losses to competition.

References

Fang Guigan, Balodis, V., Wang Jingxia and Clark, N.B. 1991. Kraft pulping properties of *Acacia mearnsii* and *A. silvestris*. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 145–150.

Khanna, P.K. 1995. Comparison of growth and nutrition of young monocultures and mixed stands of *Eucalyptus globulus* and *Acacia mearnsii*. Proceedings of the International Congress on Tropical Forests Ecosystems, 3rd Conference on Forest Soils (ISSS-AISS-IBG). Vol. 4: Soils and Plantation Forestry, Mullawarman Univ. Press. Samarinda. Indonesia, 38–53.

Logan, A.F. 1986. Australian Acacias for Pulpwood. Proceedings of an international workshop held in Gympie, Queensland, Australia, 4–7 August 1986.

Prospects for Commercial Plantations of *Acacia melanoxylon* and *A. dealbata* in Tasmania

W.A. Neilsen, P.D. Kube and H.J. Elliott[1]

Abstract

Provenance and stand silviculture research trials and operational plantations established in Tasmania testify the potential of the temperate acacias *Acacia melanoxylon* (blackwood) and *A. dealbata* (silver wattle) as commercial plantation species. Height and diameter of *A. melanoxylon* at age 9 years were 9 m and 11 cm respectively. In young trials of *A. dealbata*, the height of the best performing provenance was 1.7 m at age 16 months. A silvicultural regime for growing blackwood in combination with a nurse crop of *Pinus radiata* is being implemented in commercial plantations. This regime involves establishing 500 blackwood and 800 *P. radiata* per hectare, form-pruning the blackwood to remove any branches greater than 30 mm in diameter and then lift-pruning both blackwood and *P. radiata* to produce sawlogs, thus improving the economics of the blackwood plantation.

EIGHTEEN *Acacia* species occur naturally in Tasmania. Most of these are small to medium sized shrubs, but *Acacia melanoxylon* (blackwood) and *A. dealbata* (silver wattle) can grow to a large size and are harvested from native forests for timber, pulpwood and other uses (Gray 1990).

A. melanoxylon occurs over most of southeastern Australia and north to Queensland. In Tasmania, it is found from sea level to 1000 m elevation, but is most common in cool humid areas of low frost intensity and moderate to high annual rainfall (approximately 1500 mm). It reaches its best development in terms of tree height and diameter in the swamps and riverine forests in the far northwest of Tasmania, and this is where the *A. melanoxylon* timber industry is centred. *A. melanoxylon* can reach heights of 30–40 m and diameters of 100–120 cm. It is a fine ornamental furniture and veneer timber, much in demand in Australia and overseas. In Australia, substantial quantities are also used for wall lining and craft items. The desirability of the timber and the potential to grow veneer and sawlog sized trees in a reasonable time gives it the potential to be a good plantation species. It has been planted extensively though sporadically in various parts of the world (Allen 1992).

A. dealbata occurs in southeastern Australia and is widely distributed in Tasmania. It occurs as a dominant shrub in dry eucalypt forest and woodland, as a large tree in wet eucalypt forest, and on the margins and in disturbed areas of rainforest. On good sites it can reach a height of 25–30 m with diameter 30–75 cm. The potential of *A. dealbata* for commercial plantations in Tasmania is indicated by its rapid growth and good form in native forests. Interest in the species has increased because of its promising pulping characters (e.g: Phillips et al. 1991; Sibly et al. 1976) and occasional use as a furniture or feature timber. Although there has been interest in *A. dealbata* in many parts of the world (Kube and Brooks 1996), there are no large-scale commercial plantations either in Australia or elsewhere.

Since the late 1980s forest scientists in Tasmania have undertaken research to establish the commercial potential of *A. melanoxylon* and *A. dealbata* plantations for high-quality furniture timber production. They have sought to define plantation establishment techniques, develop silvicultural regimes, determine growth rates, and evaluate the importance of genetic variation. Most of this research is ongoing. Their research and operational experience to date is described in detail in Neilsen and Brown (1996) and Kube and Brooks (1996). This paper summarises that research.

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Methods

Provenance variation

Seed of *A. melanoxylon* was collected from 127 Tasmanian trees, either from single trees of superior phenotype or groups of trees, so that within- and between-provenance comparisons could be made. Attention was paid to high and low altitude seedlots. Six mainland provenances were included. Provenance trials were established at three sites in northern Tasmania as replicated single row plots or blocks and trial establishment details are provided in Neilsen and Brown (1996).

Provenance trials of *A. dealbata* were established on two sites in Tasmania in 1992 and 1993. Twenty-eight provenances were included — 23 from Tasmania, three from Victoria and two from New South Wales. For all provenances except three, individual tree identities were maintained. In total there were 244 family lots. Trial locations and establishment details are provided in Kube and Brooks (1996).

Growth rates of *A. melanoxylon*

The performance of *A. melanoxylon*, with and without cover crops, was evaluated in relation to other potential plantation species in a trial in northeastern Tasmania. The site was located in a mild climate (altitude 120 m, rainfall 980 mm) which has been described by Wilkinson and Neilsen (1990). Species (and provenance) and combinations planted were: *E. nitens* (Toorongo Vic.), *E. globulus* (Moogara Tas.), *P. radiata* (first generation S.O.), *A. melanoxylon* (Smithton Tas.), *P. radiata*/*A. melanoxylon*, *E. nitens*/*A. melanoxylon*, *E. regnans* (Moogara Tas.), *E. delegatensis*, and *E. obliqua*.

Each treatment was planted as a 40-tree plot, consisting of four rows × 10 trees. Plots with *A. melanoxylon* under a cover-crop of *P. radiata* or *E. nitens* were planted row for row, with two rows of each species in a four-row plot. Treatments were replicated in three blocks.

A further trial, on a frosty site covering 20 ha, was established to determine the potential of blackwood as a plantation species when grown alone and in combination with commercial cover crops of *P. radiata*, *E. nitens* or *E. globulus*. Various combinations of spacing, thinning and pruning were trialed. The area was fenced to restrict animal browsing. The trial consisted of block plantings of 25 treatments and there were four replicates. Plots were all 0.2 ha with dimensions of 12 rows (39.6 m) × 50 m. The 25 treatments included: six *A. melanoxylon* only; seven *A. melanoxylon* under *P. radiata*; six *A. melanoxylon* under *E. nitens*; five *A. melanoxylon* under *E. globulus*; and one *P. radiata* only.

Growth and establishment of *A. dealbata*

Information on plantation growth rates of *A. dealbata* in Tasmania was obtained from three sets of trials. These were: 1) a series of plantation establishment trials established in 1992 on four sites; 2) a series of species trials established on poor quality sites in 1980, and 3) small block plantings and trials established on good quality sites in the early 1980s. For the trials established in the 1980s growth rates are probably underestimated due to poor establishment techniques. The 1992 trials had good establishment techniques and represent a sound comparison with the growth rates of *Eucalyptus* spp., however data are only available to 18 months after planting. Complete establishment details and site descriptions are given in Kube and Brooks (1996).

Commercial plantations of *A. melanoxylon*

Between 1991 and 1995 commercial plantations of *A. melanoxylon* were established at four sites using both *P. radiata* and eucalypt cover crops. *P. radiata* was used as a cover crop over the majority of the area but only the *A. melanoxylon*/*P. radiata* combination will be discussed in detail in this paper. The site was located at Beulah (altitude 200 m, rainfall 1250 mm) in northern Tasmania.

Prior to planting, areas were rolled and broadcast-burnt before windrowing and heaping, using bulldozers and excavators. The windrows and heaps were burnt, re-heaped and re-burnt to eliminate cover for browsing animals, and the area was fenced and 1080 poison laid to control these pests. Mound ploughs and winged rippers were used to cultivate areas <15% slope. Where slopes exceeded 15%, the planting site was ripped along the contours at 3 m spacing followed by discing. The *P. radiata* cover crop was planted at 800 stems/ha in rows 5 m apart, with seedlings planted 2.5 m apart within the rows. *A. melanoxylon* was planted at 500 stems per hectare in single rows in the middle of every second bay of pines. Row spacing was 10 m, with seedlings spaced every 2 m in the rows. Plants were fertilised with high analysis fertiliser (125 g of 20:10:0 diammonium phosphate and sulfate of ammonia per tree) 3 months after planting.

Results and Discussion

Provenance variation in *A. melanoxylon*

There were significant differences between provenances of *A. melanoxylon* for height growth and survival (Figure 1). The northern mainland provenances showed below-average height growth and survival and this was pronounced in those from Queensland, which ranked lowest for height and survival at 2 years and at 6 years only a few specimens remained. Low survival was due mainly to frosting damage. There was no substantial difference between Tasmanian, Victorian and southern NSW provenances. There were no consistent trends for Tasmanian provenances, except that frosting effects were consistently worse for high-altitude northeast provenances and far northwest provenances.

Provenance variation in *A. dealbata*

Early height measurements of *A. dealbata* provenance trials suggest there may be important differences in growth at the regional, provenance (or locality) and family level (Table 1). Heights of the best two provenances were about 20% greater than the poorest two provenances. Survival of all provenances was good with the range from the best to the worst provenances being only 89–98%. The majority of genetic variation for growth rates occurred at the family level. Variation between families within the same provenance was often as great, or more than, the variation between the best and worst provenance. An extreme example is the provenance from Elephant Pass; this provenance had the best single family (height 1.83 m) as well as the worst (1.11 m). Survival for all families was good, and ranged between 75 and 100%.

The heritability for height growth at 1 year was 0.21, with a standard error of 0.03. This indicates moderate genetic control over growth. Other studies have found heritabilities to increase with age, and the same result would be expected here. It therefore seems likely that tree breeding will make economic gains for growth. In addition, if selections can be made to avoid problems of defoliation by the fireblight beetle (*Acacicola orphana*: Coleoptera, Chrysomelidae) and poor tree form, then the plantation potential of this species in Tasmania will be greatly enhanced.

Growth of *A. melanoxylon*

The tendency of *A. melanoxylon* to have poor form has led to experimentation with nurse crops (Barr 1981; Nicholas 1981, 1988; Hickey 1988). The principle of a nurse crop is to co-establish a fast-growing species with *A. melanoxylon*, ideally to create a 'light-well' effect that draws the blackwood up toward the light and encourages a tall straight tree with a minimum of branch development. The main problem with a nurse crop is management of the two species so that the *A. melanoxylon* does not become over-topped (and thus suppressed) by the nurse crop. This is prevented by careful selection of nurse crop species and by thinning.

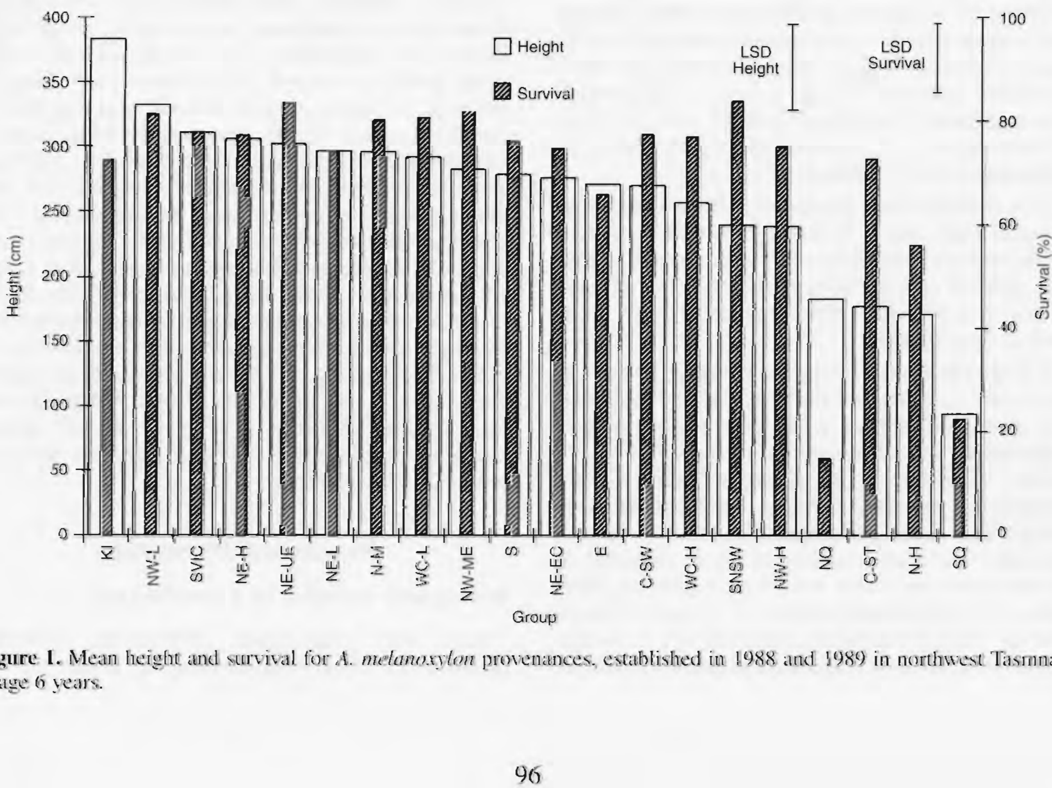

Figure 1. Mean height and survival for *A. melanoxylon* provenances, established in 1988 and 1989 in northwest Tasmania, at age 6 years.

Table 1. Mean heights and range of family means for *Acacia dealbata* provenances 16 months after planting at the Florentine Valley in southwestern Tasmania, and 12 months after planting at Meunna in northwestern Tasmania.

Provenance	Region	Florentine Valley			Meunna		
		Prov. mean (m)	Best family (m)	Poorest family (m)	No. fam.	Prov. mean (cm)	Rank
Barnback	Southeast Tasmania	1.70	1.68	1.29	7	16	(24)
Branches Creek	Northwest Tasmania	1.64	1.81	1.33	10	41	(5)
Camden	Northeast highlands, Tas.	1.58	1.58	1.27	9	26	(15)
Errinundra	Eastern Vic.	1.57				21	(18)
Geeveston	Southeast Tasmania	1.56	1.63	1.22	10	43	(4)
Liffey	Central Highlands, Tas	1.56	1.64	1.31	8	29	(14)
Dolcoath Hill	Northwest Tasmania	1.52	1.69	1.32	10	33	(11)
Hastings	Southeast Tasmania	1.51	1.67	1.20	10	35	(9)
Maggs Mountain	Central Highlands, Tas	1.51	1.63	1.30	10	16	(25)
Haleys New Country	Northeast highlands, Tas.	1.50	1.58	1.36	10	32	(12)
Castra	Northwest Tasmania	1.49	1.63	1.24	11	37	(8)
Goulds Country	Northeast lowlands, Tas.	1.48	1.65	1.28	10	48	(2)
Roses Tier	Northeast highlands, Tas.	1.48	1.67	1.26	10		
Elephant Pass	East coast, Tasmania	1.47	1.83	1.11	10	51	(1)
Triabunna	East coast, Tasmania	1.47	1.62	1.29	10	14	(27)
Arthur River	Western Tasmania	1.44	1.75	1.28	10	21	(20)
Inglis	Northwest Tasmania	1.43	1.60	1.28	9	29	(13)
Connors Plain	Macalister, Vic.	1.42				37	(7)
Sidling	Northeast lowlands, Tas.	1.41	1.59	1.19	10	22	(17)
Captains Flat	Southern NSW	1.40	1.72	1.33	7	23	(16)
King River	Western Tasmania	1.40	1.66	1.29	11	15	(26)
Tarrana (TSP)	East coast, Tasmania	1.40	1.79	1.30	10	34	(10)
Snug	Southeast Tasmania	1.40	1.65	1.20	8	46	(3)
Forester	Northeast lowlands, Tas.	1.39	1.71	1.35	10	39	(6)
Bembooka	Southern NSW	1.37	1.73	1.21	10	21	(19)
Swanport	East coast, Tasmania	1.36	1.67	1.13	10	19	(23)
Bagdad	Midlands, Tasmania	1.33	1.66	1.30	10	20	(21)
Goongerah	Eastern Vic.	1.25				20	(22)
Standard error		0.04	0.10	0.10			

Good early growth was obtained on the mild trial site in northeast Tasmania. At 9 years height averaged about 9 m and mean diameter 11 cm (Figures 2 and 3). Both the volume and the diameter of *A. melanoxylon* under the *E. nitens* cover-crop were falling behind that of the other *A. melanoxylon* treatments, which suggests greater competition on that treatment (Figure 3). Mean tree volume at 9 years varied from 39 dm^3 for *A. melanoxylon* under *E. nitens* to 399 dm^3 for the *E. nitens* on the same plots. All species except *E. delegatensis* and *E. obliqua* had significantly greater volume than *A. melanoxylon* (Figure 2). *P. radiata* trees had about four times the volume of *A. melanoxylon* while for *E. nitens* and *E. globulus* volume was about seven times greater.

On the frosty site, severe frosts throughout the trial area at 1 year affected both *A. melanoxylon* and the *E. globulus* nurse crop. Almost all *A. melanoxylon* survived, the majority sprouting from the base, and by 2 years had reached the original heights recorded at 1 year. Heavy winter frosts at age 2 years caused further damage but not on the scale of the first winter. Growth of the three nurse crop species was good, despite some frost damage to the *E. globulus*. Frosting continued to affect *A. melanoxylon* to 6 years. Height growth to age 6 years was poor but improved significantly as shelter increased, with *E. globulus*, *P. radiata* and *E. nitens* providing increasing shelter in that order (Figure 4). There were no significant differences in survival (average 85%) between *A. melanoxylon* trials under the three cover crops, but survival without a cover crop was significantly less (70%).

The use of dense nurse crops, which would produce the best form and suppress branching, is unlikely to be economic, with a high cost of plants, reduced growth of crop trees and high cost of thinning. There is little hope of early commercial thinnings from such nurse crops. *A. melanoxylon*

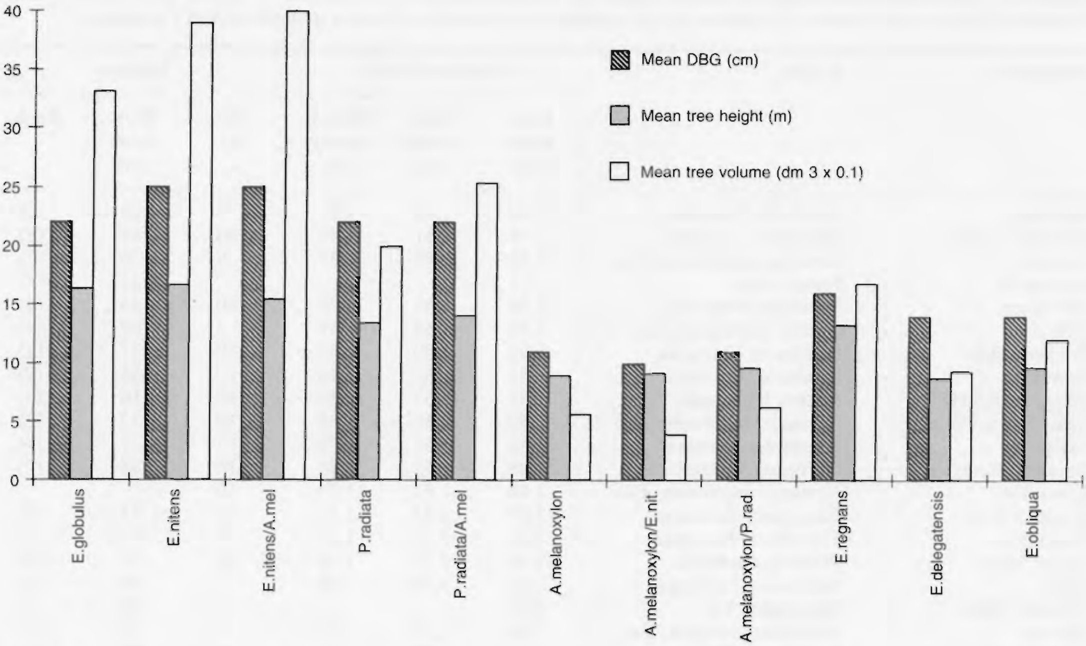

Figure 2. Mean DBH, height and tree volume at age 9 years for species established in northeast Tasmania.

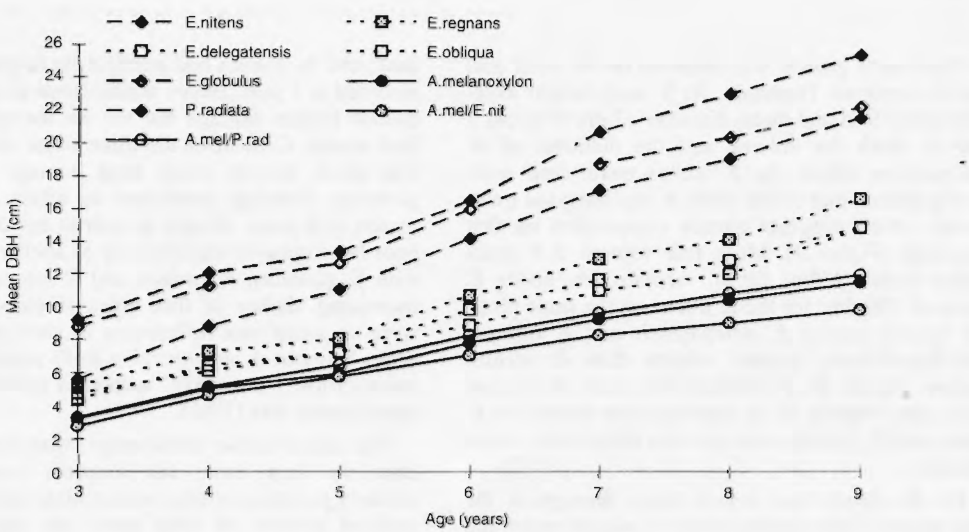

Figure 3. Mean DBH for ages 3–9 years for species established in northeast Tasmania.

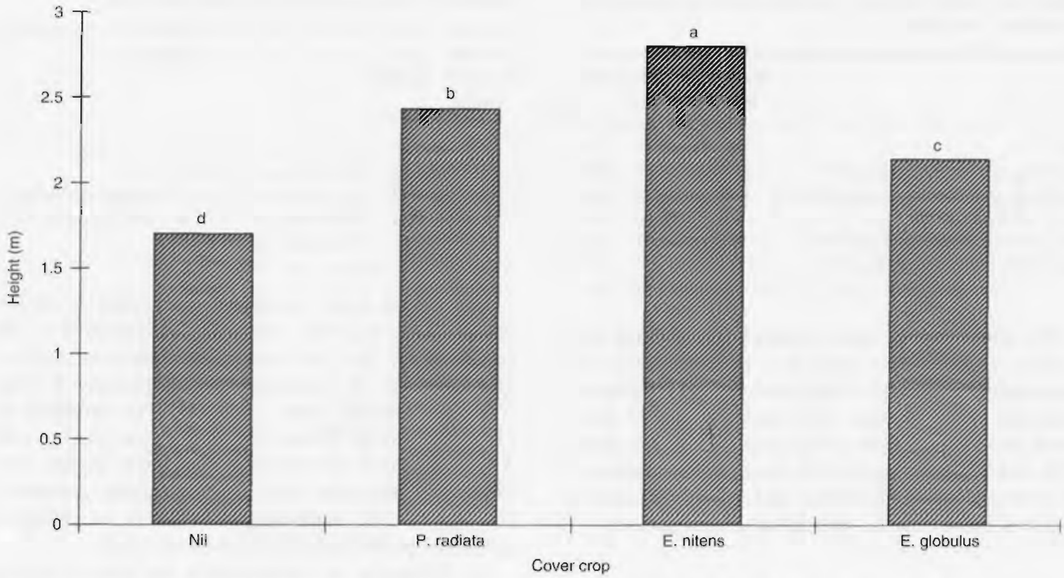

Figure 4. Height of *A. melanoxylon*, at 6 years, for silvicultural treatments under various cover crops.

plantations have grown successfully without a cover crop, but pure plantings in Tasmania have shown poor form with multiple branching and poor apical dominance. Overseas, *A. melanoxylon* grown in pure stands has needed frequent pruning to restrict branching and improve form (Nicholas 1988).

The best growth rates recorded in Tasmania (average height and diameter growth at 9 years of 1 m $year^{-1}$ and 1 cm $year^{-1}$ respectively) were less than some reported overseas. Diameter growth rates of 1.45 cm $year^{-1}$ have been obtained in New Zealand (New Zealand Forest Research Institute 1982) while up to 3.5 cm $year^{-1}$ has been recorded in South Africa (de Zwaan 1984). In Tasmania frost appears a major problem and present plantations are limited to milder sites, generally below 300 m altitude. Rotation objectives of around 45 years will be achieved in Tasmania, provided the site has a mild environment and browsing animals and weeds are controlled.

Growth and establishment of *A. dealbata*

Acacia dealbata grows satisfactorily in Tasmania using the standard plantation establishment techniques, although potential problems are poor survival, extreme growth variability, and poor form. Many of these problems appear to arise from the foliage loss that occurs at transplanting, which is presumed to occur due to desiccation. Seedlings that retained all their foliage had high survival, grew quickly and developed a single stem; those that lost more than two-thirds of their foliage had poor survival, depressed growth rates, and generally developed multiple stems.

Establishment of *A. dealbata* was more difficult than for the commonly used eucalypt species (*E. nitens* and *E. globulus*); *A. dealbata* seedlings had substantial foliage loss while the eucalypt species had very little. These problems can be partly alleviated by using large bare-root seedlings, higher initial stockings and form-pruning when the trees are 2–3 m tall (1–2 years after planting). Browsing pressure is much less on *A. dealbata* than on *A. melanoxylon*, and possibly less than on *E. nitens*. Therefore secure fences need not be as high a priority as they are for *A. melanoxylon*.

Measured growth rates of *A. dealbata* were variable and sometimes very poor (Table 2). The best growth rates recorded were 23 m^3 ha^{-1} yr^{-1}, but on some sites with excellent growth potential, growth rates were less than 1 m^3 ha^{-1} yr^{-1}. Poor growth rates are probably due to poor plantation establishment practices, severe transplant shock (resulting in loss of all foliage at planting) or browsing by the fireblight beetle, *Acacicola orphana*. Early results from the 1992 establishment trials and 1993 provenance trials indicate that good early growth can be obtained through good establishment practices. Heights of 1.5–2 m are readily achievable 12 months after planting (Table 1).

Table 2. Growth rates of *A. dealbata* on high quality sites in northern Tasmania.

	Welcome Swamp	Chester Creek	Calder
Age	10	11	8
Stocking, all trees (stems ha^{-1})	2360	4740	1600
Stocking, trees >10 cm (stems ha^{-1})	1265	1610	nm
MAI, all trees (m^3 $ha^{-1}yr^{-1}$)	17.3	27.9	0.5
MAI, trees >10 cm (m^3 $ha^{-1}yr^{-1}$)	15.1	22.7	nm
Mean dbh increment (cm yr^{-1})	1.5	1.3	0.5

The most useful and comprehensive long-term growth information will be provided by the provenance trials in northwestern and southern Tasmania. Assessments of growth rates, tree form, insect resistance and wood properties between about 1998 and 2000 will provide a thorough evaluation of the potential of *A. dealbata*, and the importance of genetic variation in the utilisation of this species.

Commercial plantations of *A. melanoxylon*

Over 800 ha of commercial *A. melanoxylon* plantation have now been established in Tasmania and *P. radiata* has been used as a cover crop for most (540 ha) of the area. Plantation-grown *A. melanoxylon* and the *P. radiata* cover crop require pruning and thinning to correct form and produce quality clearwood sawlogs. A combination of cover crop and pruning is used for *A. melanoxylon* plantations in Tasmania, because some improvement in form from the cover crop will allow pruning on an economic schedule and the cover crop can be utilised to improve the economic return of the regime. *P. radiata* offers the potential to provide a cover crop and grow a profitable pruned sawlog as an interim crop.

A regime of one form-pruning and a three lift-pruning to 6.4 m is being implemented routinely in these plantations in Tasmania (Table 3). Currently the older compartments in the plantation have been form-pruned and the *P. radiata* has been first-pruned and waste-thinned. High pruning of the *A. melanoxylon* should be complete by age 11 years, at which time the blackwood will be thinned to final stocking. In a plantation of *A. melanoxylon* with a *P. radiata* cover-crop being managed for clear-wood production, first form-pruning and first and second lift-pruning of the *A. melanoxylon* should correspond with first, second and third pruning of the *P. radiata* respectively. Clearwood pine sawlogs will be removed at around 20–25 years, with the final *A. melanoxylon* harvest estimated to occur at 40–45 years.

Table 3. Pruning regime for *A. melanoxylon.*

Mean dominant height (m)	Age (years)	Pruning
5	5	Form-prune to 2.7 m
7	7	1st prune to 2.7 m & form-prune to 4.6 m
9	9	2nd prune to 4.6 m & form-prune to 6.4 m
11	11	3rd prune to 6.4 m

One of the main problems in growing *A. melanoxylon* with a cover crop will be removal of the cover crop, as a commercial harvest, without damaging the *A. melanoxylon*. In growing a clearwood *P. radiata* crop, protection is afforded by planting rows of *P. radiata* at 5 m row spacing with *A. melanoxylon* planted between each second row. With two adjacent rows of *P. radiata* present at felling, the *A. melanoxylon* should be afforded sufficient protection to minimise damage.

In Tasmania, *A. melanoxylon* has been routinely planted at 500 stems/ha with the *P. radiata* cover crop planted at 800 stems/ha. Although some authors (Barr 1981; Nicholas 1988; Bishop et al. 1985) have advocated greater numbers of *A. melanoxylon* (around 1500 stems/ha), sufficient final crop trees can be obtained from a much lower number with suitable pruning.

References

Allen, D. 1992. Blackwood plantations in Tasmania. Tasmanian NRCP Report No. 8, Forestry Commission, Tasmania, and Department of the Arts, Sport, the Environment, Tourism and Territories, Canberra. Tasmanian Government Printer, 88 p.

Barr, N. 1981. Growing Tasmanian blackwood for furniture timber. New Zealand Farmer, 102, 62–63.

Bishop, D., Buckman, I. and Eastman, D. 1985. Trees for timber and shelter on the West Coast. New Zealand Forest Service. 32 p.

de Zwann, J.G. 1984. Blackwood (*Acacia melanoxylon*) group system in the indigenous forests of the Tsitsikamma. IUFRO excursion on the site and productivity of fast-growing plantations, South Africa, May 1984.

Gray, A. 1990. A field key to native and naturalised acacia species in Tasmania. Tasforests, 2 (1), 79-83.

Kube, P. D. and S. J. Brooks 1996. Evaluation of *Acacia dealbata* as a plantation species in Tasmania. Forestry Tasmania, and Forest Industry Council.

Hickey, J. 1988. Management and silviculture of blackwood in forests in Tasmania. Forestry Commission, Tasmania. Paper presented AFDI Conference, Albury 1988.

Neilsen, W.A. and Brown. D.R. 1996. *Acacia melanoxylon* plantations in Tasmania: research and development. Forestry Tasmania, 193 p.

New Zealand Forest Research Institute 1982. Australian blackwood (*Acacia melanoxylon*). What's New in Forest Research, No 121.

Nicholas, I.D. 1981. *Acacia melanoxylon* (Australian blackwood) establishment. In: New Zealand Forest Research Institute Symposium No 22: Forest nursery and establishment practice in New Zealand, 216–221.

— 1988. The silviculture of blackwood in New Zealand. The International Forestry Conference for the Australian Bicentenary. Australian Forest Development Institute.

Phillips, F.H, Logan, A.F, Balodis, V. and Ward, J.V. 1991. Studies on pulpwood resources in southern Tasmania. Part 1: Kraft pulps. Appita 44 (2), 85–90.

Sibly, P., Tyler, T. and Pearson, A. 1976. Utilisation of unbarked forest thinnings of acacia and eucalypt species in the cold soda process. Appita 44 (2), 59–61.

Wilkinson, G.R., and Neilsen, W.A. 1990. Effect of herbicides on woody weed control and growth of plantation eucalypt seedlings. Australian Forestry, 53, 69–78.

Acacia mangium: Potential Species for Commercial Plantations in Lao PDR

Xeme Samountry[1]

Abstract

Acacia mangium has been grown in Lao PDR since 1985. From practical experience and the results gained from species and provenance trials at Namsouang Silviculture Research Centre the species has proved promising for sustainable plantation development.

LAO PDR is a land-locked country in Southeast Asia. It is mountainous, with only about 20% of the total land area classified as flat or undulating. Its geographical location, coupled with topographical features, provide the country with a vast range of climatic conditions.

The country has two main climatic zones: the first is the alluvial plains along the Mekong River and its tributaries, characterised by a lowland tropical monsoon climate with average annual rainfall 1250 mm in the central part and 2500 mm in the southern part, with an average temperature of 25°C. The second zone is in the uplands, where altitudes are 1000 m or more with an average temperature of 20°C or lower in some parts (Samountry and Applegate 1995). More details are shown in Figure 1.

Acacia mangium: a Potential Species for Plantation Development in Lao PDR

Based on the environmental/ecological requirements of species and the practical experience gained in the country, *A. mangium* has proved a promising species for sustainable plantation forestry development in Lao PDR. In particular, with respect to small sized log production, it has the potential to reduce the impact on the natural forest to supply raw material for panel wood industries and perhaps aid restoration of biodiversity.

[1] Lao–ADB Plantation Forestry Project, Department of Forestry, PO Box 4683, Vientiane, Lao PDR

Introduction of *A. mangium*

The UNDP/FAO project LAO/82/006: Forest Development and Watershed Management in the North first introduced the species into the country in 1985, as a nitrogen-fixing tree for better farming practice. Seed was ordered from CSIRO, Australia (source: Sleumsy, DoF). Seedlings were produced in Ban Xiang Mouak Nursery and planted in Luang Prabang district, a project area 400–500 m above sea level, with average rainfall 1500 mm per year and average temperature between 24 and 26°C.

The second introduction was in 1988, along with other fast-growing exotic species, for the purpose of species and provenance trials at Namsouang Silviculture Research Centre and for Community Forestry (source: B. Mounda, DoF). With the technical and financial assistance from CSIRO and ACIAR, the Department of Forestry has undertaken species and provenance trials at Namsouang Silviculture Research Centre, at altitude 180–200 m above sea level, average annual rainfall 1500 mm and annual average temperature 25°C. The results from the trials are shown in Table 1.

A. mangium currently used for commercial plantation forestry development

The Lao–ADB Plantation Forestry Project is a pilot loan project introduced by the Government in 1994. Its main activities are to establish demonstration plots and model farmer plots and invest in commercial plantations through promoting the private sector by means of credit facilities for farmers and enterprises

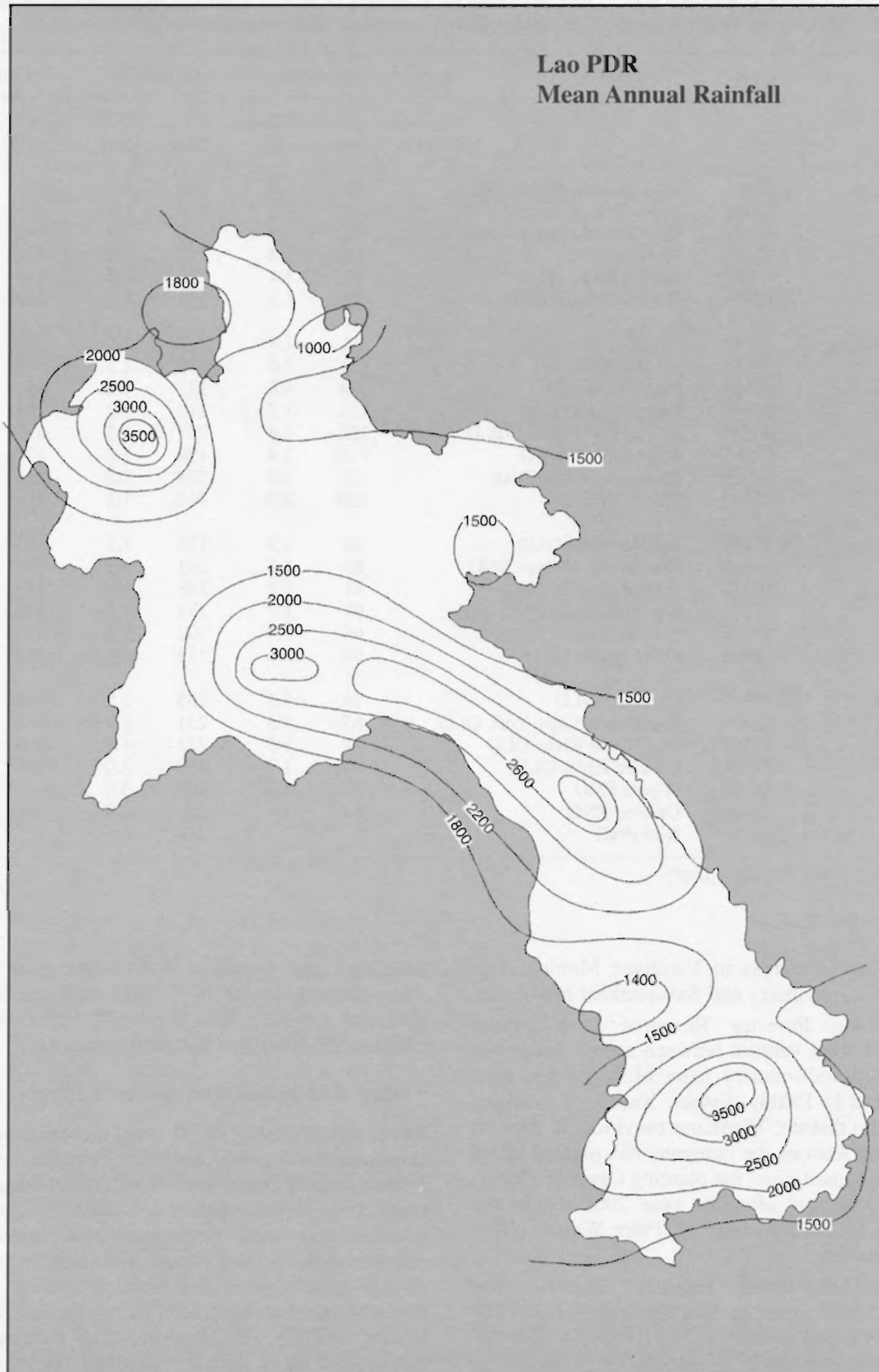

Figure 1. Mean annual rainfall (mm) in Lao PDR (Source: Lao-ADB Plantation Forestry Project).

Table 1. Mean height and diameter at 6, 12 and 24 months after planting of *Acacia* species in the species/provenance trials at Namsouang Silviculture Research Centre. The results show *A. mangium* outperformed other *Acacia* species.

Species	Seedlot	Provenance	6 months		12 months		24 months	
			Ht (cm)	DGL (cm)	Ht (cm)	DBH (cm)	Ht (cm)	DBH (cm)
A. aulacocarpa	16948	Isago Arimia River PNG	80	1.2	206	1.1	566	4.9
	16981	Kapal NW of Wipim PNG	102	1.5	233	1.5	553	5.7
	17551	Bensback-Balamuk PNG	100	1.5	210	1.4	499	5.2
	17560	Dimisisi PNG	86	1.3	202	1.4	523	5.0
	17628	Keru Village PNG	93	1.4	230	1.5	549	5.9
	17873	Wipim-Oriomo PNG	77	1.2	197	1.1	495	5.1
A. auriculiformis	16145	Wenlock River QLD	94	1.5	252	1.4	523	5.4
	16148	Manton River NT	121	2.0	218	1.3	542	5.1
	16155	Mann River NT	124	1.8	223	1.2	554	5.2
	16485	Kings Plains QLD	111	1.7	219	1.2	549	5.5
	16729	15 km WNW Coen QLD	122	1.8	221	1.3	615	5.8
	17966	Boggy Creek QLD	116	1.8	198	1.1	498	4.7
	18090	Morehead River PNG	121	1.8	204	2.2	511	5.3
	18102	Mibini PNG	126	2.0	235	1.5	523	5.9
A. crassicarpa	16128	Jardine River QLD	48	1.5	173	1.3	512	5.5
	16598	Bimadebun Village PNG	86	1.5	201	1.2	605	6.2
	16977	Wipim District PNG	81	1.5	232	1.5	573	5.7
	17871	Wipim-Oriomo PNG	95	1.7	241	1.7	596	6.1
	17944	Claudie River QLD	65	1.5	202	1.2	592	5.5
	17948	Chilli Beach QLD	98	1.6	216	1.5	580	6.4
A. mangium	15357	Cardwell QLD	76	1.5	235	1.9	642	6.8
	15681	Heathlands Cape York QLD	63	1.3	231	1.9	658	8.8
	16592	Mai Kussa River QLD	77	1.5	251	1.9	605	6.1
	17946	Claudie River QLD	67	1.3	259	2.0	625	7.0
	18056	Wipim PNG	85	1.6	294	3.0	663	8.2
	18088	Oriomo PNG	82	1.5	254	1.9	698	7.5
	16938	Kini PNG			208	2.0	737	7.1

(Source: Silviculture Division, DoF)

in four subproject areas in Vientiane Municipality, Vientiane, Bolikhamsay and Savannakhet provinces.

Lane Xang Forestry Resource Development Company, a joint venture between a state enterprise and HIPA Wood-industry from Malaysia has concession areas in Paklay district, Xayabury province and Hinheup district, Vientiane province. In the last two planting seasons the company has planted about 1000 ha of *A. mangium*; the planting target in 1998 is about 1500 ha and after the year 2000 the yearly target will be 2000 ha (source: Peter Wallis, HIPA Forest Industries).

BGA-LAO-Plantation Forestry Limited has signed an MOU with the Government of Lao PDR and now a feasibility study is in process. In 1996–97 the company planted 172 hectares of *A. mangium* and the planting targets for 1998 and 1999 are 2000 and 5000 ha respectively. From the year 2000, the planting target would be 7000 ha per year until the total planting target of 50 000 hectares has been achieved (source: John Rodwell, Chief Executive Officer, GF-Brierley Company Limited).

Future seed production and seed supply

Since the introduction of the Government's new economic mechanism, the role of the Department of Forestry has changed from direct undertakings in any economic development activities to providing policies and legal framework and provision of services to the private sector, including the provision of high-quality seeds of promising species. In 1997, in collaboration with CSIRO's Australian Tree Seed Centre (ATSC), the Department of Forestry established 10.4 ha of pure *A. mangium* and *A. auriculiformis* stands as seed production areas in Bolikhamsay and Savannakhet provinces.

Cooperation and collaboration with international and regional institutes

As a result of the group discussion from a national seminar on forestry research planning jointly organised by the Department of Forestry and FORSPA (FAO) in December 1996, four research priorities relating to plantation forestry were identified (FORSPA 1997). These are:

- Species and provenance trials and tree improvement.
- Nutrient management, including the use of mycorrhizas for site amelioration.
- Socioeconomic analysis of plantation forestry.
- Pest and disease management.

However, there are existing resources constraints, and in order for the Department of Forestry to undertake and manage research activities in relation to the above priorities, development of close cooperation and collaboration with international and regional research institutes is needed.

Conclusion

A. mangium has been introduced into the country since 1985 and used for various purposes. Even though more data/information on species–site interaction from scientific experiments within the country are needed, based on practical experience and the current species trials at Namsouang, the species has proved to have potential for sustainable plantation development in Lao PDR. Due to existing resources constraints close cooperation and collaboration with international and regional research institutes must be developed, in order for the Department of Forestry to undertake and manage research work relating to sustainable plantation forestry development.

Acknowledgments

I would like to express my gratitude to the Australian Centre for International Agricultural Research for its invitation and to the Lao government for permission to participate in this workshop. Many thanks also to Mr. Stephen Midgley and Mr. Khongsak Pinyopusarerk for their comments and to Mrs. Khamvay Nanthavong for typing this paper.

References

FORSPA 1997. Report on the National Seminar on Research Planning 9-11 December 1996, Publication No. 17/1997.

Samountry, Xeme and Applegate, G. 1995. Tree growth prediction to support forest plantation development in Lao PDR. In: Booth, T., ed., Matching Trees and Sites. ACIAR Proceedings No 63. Australian Centre for International Agricultural Research, Canberra,

An Ex-Ante Evaluation of Temperate Acacia Forestry Research: Some Estimates of the Potential Impacts of an ACIAR-supported Project

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Abstract

The paper reports on an economic evaluation of the ACIAR project that undertook research to identify suitable Australian acacias for sustainable development in China, Vietnam and Australia (FST/92/27). Two categories of benefit are recognised — one derived from marketable commodities, the other is an environmental benefit from acacia planting–nitrogen fixation and carbon sequestration.

The evaluation derived estimates over a 30-year time horizon; project PN9227 is estimated to generate research benefits ranging from $A1.07 million under pessimistic assumptions about adoption to $A3.00 million under optimistic assumptions about adoption and the realised cost savings. The rate of return to funds invested in PN9227 could range from 7 to 14%, depending on assumptions about the research impact and the level of adoption of the identified species of acacia. The most likely benefits, as estimated in the base case scenario, are about A1.39 million over a 30-year time horizon, with a rate of return of about 9%.

IN analysing any piece of research it is useful to establish the magnitude of benefits likely to accrue from that research before it begins or, if it has started, prior to its completion. This type of analysis is called an ex-ante analysis, speculative in part, but to a large extent informed by technological, social and economic constraints pertaining to the problem addressed by research.

[1] The authors are grateful to Mrs Heather Crompton (ACIAR) and Dr Ken Menz and Peter Grist (Centre for Resource and Environmental Studies, Australian National University, Canberra) for their comments on an earlier draft. The original paper has been revised to take into account comments made by delegates at the Third International Acacia Workshop, Hanoi, Vietnam. However, the authors are responsible for the content of the paper.

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This paper discusses an ex-ante evaluation of the ACIAR-supported project 'Australian acacias for sustainable development in China, Vietnam and Australia' (FST/92/27), which has sought to provide a wider choice of successful, frost-tolerant, tree-form legumes for land rehabilitation and economic return (Searle 1995). It is a first step towards estimating the potential impact of ACIAR-supported temperate acacia forestry research. It arose from a recommendation at the project mid-term review that 'Economic analyses showing the benefits of acacia forestry and of research into the utilisation of acacia products (tannin, timber, pulp, and treated poles) should be conducted' (ACIAR 1997).

The Nature and Utility of Ex-Ante Evaluations

There are many critics of cost:benefit analyses, and many sceptics about ex-ante analyses. Thus, it is worth probing into the nature and value of the ex-ante evaluations. By definition, ex-ante estimates are evaluations that lead to estimates of future benefits to be realised if, and only if, a number of assumptions are met. They are conditional estimates. Most of these assumptions are about future events. Invariably some of the events do not occur or may take on forms different from those envisaged in the ex-ante analyses. In some cases ex-ante analyses are pessimistic and the realised benefits exceed the estimated ex-ante benefits; in other cases they are over optimistic and the realised benefits are either zero or much less than what was envisaged.

In the literature these evaluations are often inappropriately referred to as ex-ante *economic* evaluations, this misrepresents the nature of these analyses, which are often a result of a joint effort between the technical scientists and social scientists who assess what the proposed technology means in economic terms. Table 1 summarises the key contributions to ex-ante analyses by technical and social scientists.

The principle of conservatism

An ex-ante analysis is intended to do as much justice to a research project as possible, without over-estimating expected benefits beyond a project's capacity to deliver. The long-term goal of ex-ante evaluation teams is to provide an unbiased estimate of potential benefits from research which, if the assumptions made are realised, are confirmed by ex-post evaluations of projects.

Table 1. The joint contribution of technical scientists and social scientists to ex-ante analyses of research projects.

Variable	Source	Comment
Description of the technology before research	Project scientist	This is used to describe the situation before research, including management and production practices.
The description of the proposed technology	Project scientist	In many cases the scientist does not know the proposed technology fully. However, in order to complete the ex-ante analysis the scientist has to describe what technology he or she expects out of the research.
The description of the likely impact of the technology, say on yields or costs of production	Project scientist and social scientist	These impacts are often not known wholly by the scientist. While they are not yet observable in the real world, they can sometimes be estimated from preliminary analyses.
Probability of success	Project scientist or other expert familiar with the area of science in question	In the extreme case, where the project fails when one assumed a non-zero probability of success, then benefits will be grossly overestimated.
Estimation of likely future adoption of the technology	Project scientist, with input from extension specialists where they are available	This is one of the most critical parameters. If realised adoption is zero, the realised benefits are zero irrespective of the estimates in the ex-ante analysis or the quality of research.
Estimation of the economic and other impacts of the technology at the farm level	Social scientist	The absolute size of this impact is important and dependent on the variable targeted by research (yield, cost of input, impact on environmental degradation).
Description of the before-research socioeconomic situation	Social scientist	This description includes quantity produced and consumed of the agricultural commodity targeted by research. It includes prices, elasticities, and cost of production.
Estimation of the after-research socioeconomic situation	Social scientist using a research evaluation or some other model	A model is used to estimate quantity produced and consumed, prices, cost of production of the agricultural commodity targeted by research, after research.

The utility of ex-ante evaluations

There are three main uses of ex-ante analyses.

(a) Even if no quantitative estimates of potential benefits are made, the process of undertaking an ex-ante analysis is useful both to the researchers and to the funding organisations. They encourage those involved to think beyond the laboratory and experimental designs, and to ask questions relating to applicability of research, adoption and potential users of research results. This process is enlightening in itself and may lead to better project design and implementation.

(b) In the long run, results of ex-ante evaluations can lead the research organisations and funding bodies to an improved mix of projects, targeting areas with higher potential benefits. The practice thus leads to better decisions as to what projects to fund and what areas research organisations should focus on.

(c) An explicit process to assess the potential benefits from a research organisation's portfolio leads over time to a closer match between the research organisation's effort and the priorities of those who fund the research.

Some Features of ACIAR Project FST/92/27

Identification of suitable acacia species

ACIAR project FST/92/27 has three subprojects. Subproject A was designed to identify the most productive Australian acacia tree species with planting potential for cool, frost prone, low fertility, mountainous, subtropical regions of Vietnam, China and Australia. The aim was to widen the choice of successful tree-form legume species for economic return and land rehabilitation in cool subtropical regions. In the three countries (Vietnam, China and Australia) the species identified to date as having some potential are:

Vietnam: *A. cincinnata, A. mearnsii*, A. melanoxylon*;*

China: *A. binervia, A. cincinnata, A. dealbata, A. elata, A. falciformis, A. filicifolia, A. glaucocarpa, A. implexa, A. leucoclada, A. mearnsii*, A. melanoxylon*, and A. silvestris;*

Australia: *A. dealbata, A. decurrens, A. mearnsii*, and A. melanoxylon*.*

* denotes the species included in the estimation of the illustrative potential benefits of FST/92/27, reported in this paper.

Collection of rhizobia strains for temperate acacia

Sub-project B aimed to identify strains of rhizobia that persist in the soil and are suitable for inoculation of *Acacia* species and provenances selected in sub-project A, and also for introduction into the cool subtropics of Vietnam, China and Australia.

Strategies for management of insect and other pests

Sub-project C aimed to generate information on acacia pests that would lead to selection of a more appropriate range of species and provenances for planting in insect-prone areas. Table 2 summarises some of the pests and production constraints identified in the first two years of ACIAR FST/92/27.

The Nature of Benefits from Temperate Acacia Research

The benefits listed in this paper are estimates from only two species of acacia — *Acacia mearnsii* and

Table 2. Pests and problems of acacia for temperate region identified to date.

Vietnam	China	Australia
Termites (Brown 1996, S4)	Termites (Brown 1996, S4)	Frost damage (Searle 1996b, p.2)
Drought (Searle 1996b, p.29)	Frost damage (Searle 1996b, p.30)	Drought
Excessive rain (Searle, 1996b, p.29)	Drought (Searle 1996b, p.29)	Excessive rain, root rot (Searle 1996b, p.2)
Weeds (Searle 1996b, p.29)	Excessive rain (Searle 1996b, p.29)	Boron toxicity (Searle 1996b, p.2)
		Case-moth (Brown 1996, S4)
		Fireblight (Brown 1996, S4)
		Yellow-tailed black cockatoos (Searle 1996b, p.7)
		Parrots (Searle 1996b, p.2)
		Rabbits (Searle 1996b, p.2)
		Water logging (Searle 1996b, p.7)
		Wind (Searle 1996b, p.7)

Source: Brown 1996; Searle 1996b

A. melanoxylon. These two species were selected because they are the most promising of the species in the three countries, and while they are in the same family of acacias, the two species have very different attributes. *A. mearnsii* has a rotation of 6-8 years compared to the 40–50 year rotation of *A. melanoxylon.* However, *A. melanoxylon* grows best on sheltered, fertile, well drained but moist soils (Searle 1996b). While *A. mearnsii* is grown for fuelwood, tannins, and pulpwood, *A. melanoxylon* is grown for high-quality timber. Both species are nitrogen-fixing with a capacity for stabilising soil and reducing erosion.

Where can *A. mearnsii* or *A. melanoxylon* grow?

Booth and Yan Hong (1991) reported on research to identify climatic areas in China suitable for *A. mearnsii.* Dr Trevor Booth (CSIRO Division of Forestry and Forest Products, Canberra) also used a similar approach to map the areas where *A. mearnsii* or *A. melanoxylon* can grow in the three collaborating countries. Table 3 shows the descriptions of requirements for growth of the two species.

Figure 1 shows the areas where *A. mearnsii* can grow in Vietnam, revealing that only a small part of Vietnam is suitable for the production of *A. mearnsii.* On the other hand Figure 2 shows that a much larger area of Vietnam is suitable for the production of *A. melanoxylon*.

Figure 3 shows the areas where *A. mearnsii* can grow in China. Figure 4 shows that a slightly larger area of China is suitable for the production of *A. melanoxylon*.

Figures 5 and 6 show the areas where *A. mearnsii* and *A. melanoxylon* can grow in Australia. These figures suggest that the two species can be grown in almost identical areas in Australia.

Figures 1–6 provide a useful indication of the basis for estimates of maximum possible benefits from temperate acacia research in Vietnam, China and Australia. They also indicate agroclimatic suitability for the production of the two species.

However, there is an economic question that needs to be addressed — that is, how many hectares of land will be diverted to temperate acacias? The answer depends partly on the markets for the commodities from acacia and the demand for the non-market environmental services (such as nitrogen fixation and carbon sequestration) associated with temperate acacias. The answer also depends on the economic returns from other crops and economic activities competing for farmer resources in the areas where it is feasible to grow temperate acacias. If land suitable for temperate acacias is currently unsuitable for other enterprises, then the opportunity cost of using the land to grow temperate acacias is zero. In these cases, the farmer's decision whether or not to divert land to growing temperate acacias will be straightforward. It would be economically profitable to divert all the land suitable to the production of temperate acacias.

However, if there are other less risky, more profitable crops, or other economic activities with a higher return than planting temperate acacias, then farmers in those areas are likely to resist investment in temperate acacias. To answer this economic question requires geographical information system (GIS) data on economic returns from what is currently grown to be overlaid on Figures 1–6 to generate modified maps reflecting economic feasibility of temperate acacia in the three countries. Maps showing economic feasibility of acacia will highlight only a subset of the areas in green in Figures 1–6. The areas of economic feasibility will be those areas where the economic returns, per unit, are equal to or greater than the economic returns per unit from the current use of the land.

Table 3. Descriptions of requirements for *A. mearnsii* or *A. melanoxylon* based on the natural distribution of the species and on trial and plantation data.

Attribute	*A. mearnsii*	*A. melanoxylon*
Mean annual precipitation (mm)	700–2300	800–2940
Dry season (number of months)	0–6	0–6
Minimum and maximum temperature in the hottest month	21–35°C	19–33°C
Minimum and maximum temperature in the coldest month	–3[a]–17°C	–3–16°C
Mean annual temperature	10[b]–20°C	9–25°C
Absolute minimum (max and min) temperature[c]	not applied	–6–10°C

a: 0°C for China
b: 14°C for China
c: Only used in the case of China
Source: Booth (pers. comm. July 1997)

Figure 1. Climatically suitable areas for *A. mearnsii* in Vietnam (source: Booth (unpubl.) July 1997).

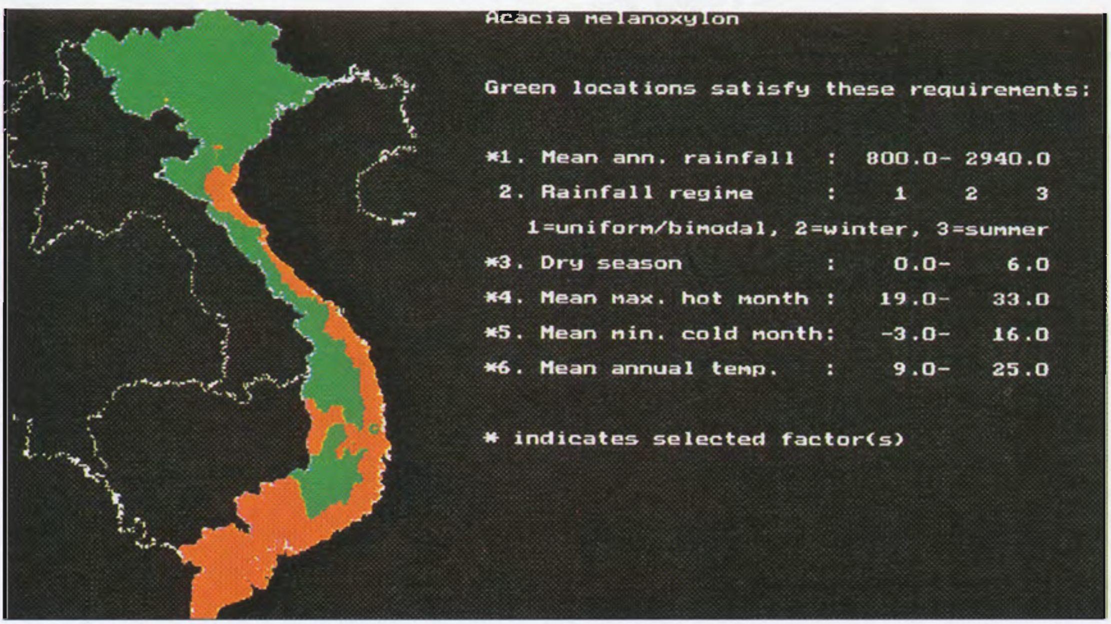


Figure 2. Climatically suitable areas for *A. melanoxylon* in Vietnam (source: Booth (unpubl.) July 1997.

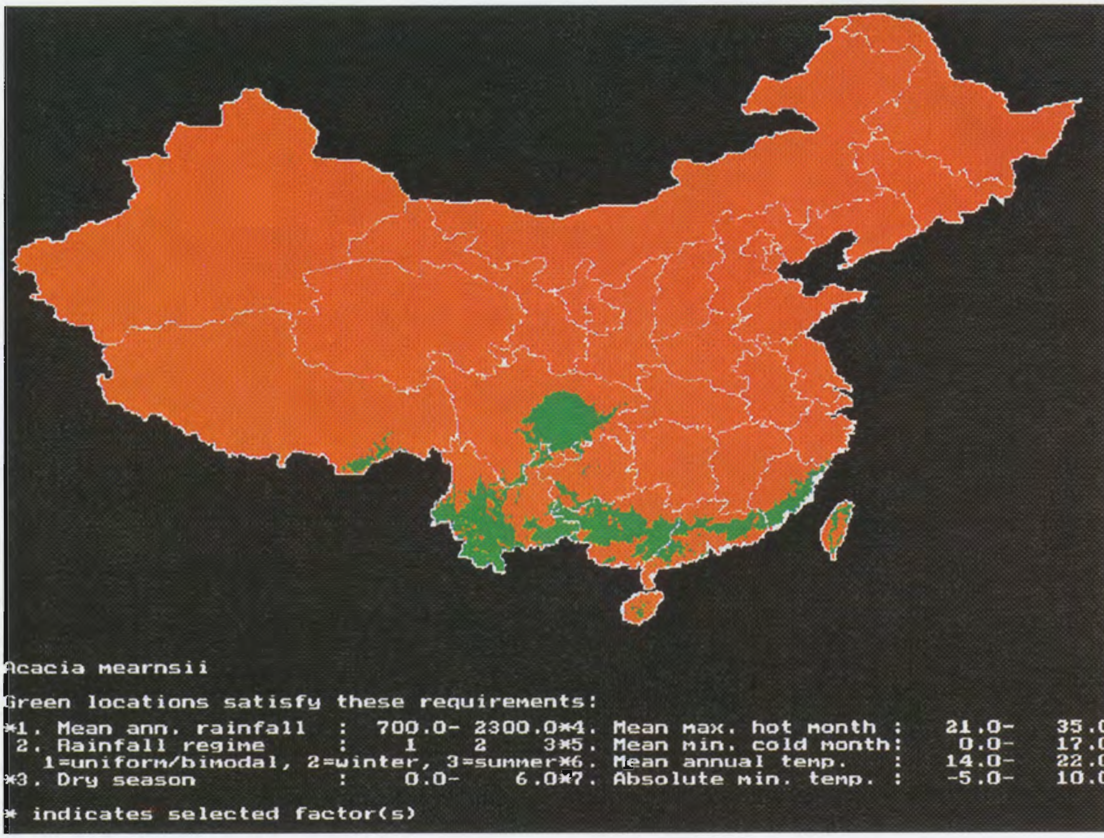


Figure 3. Climatically suitable areas for *A. mearnsii* in China (source: Booth (unpubl.) July 1997.

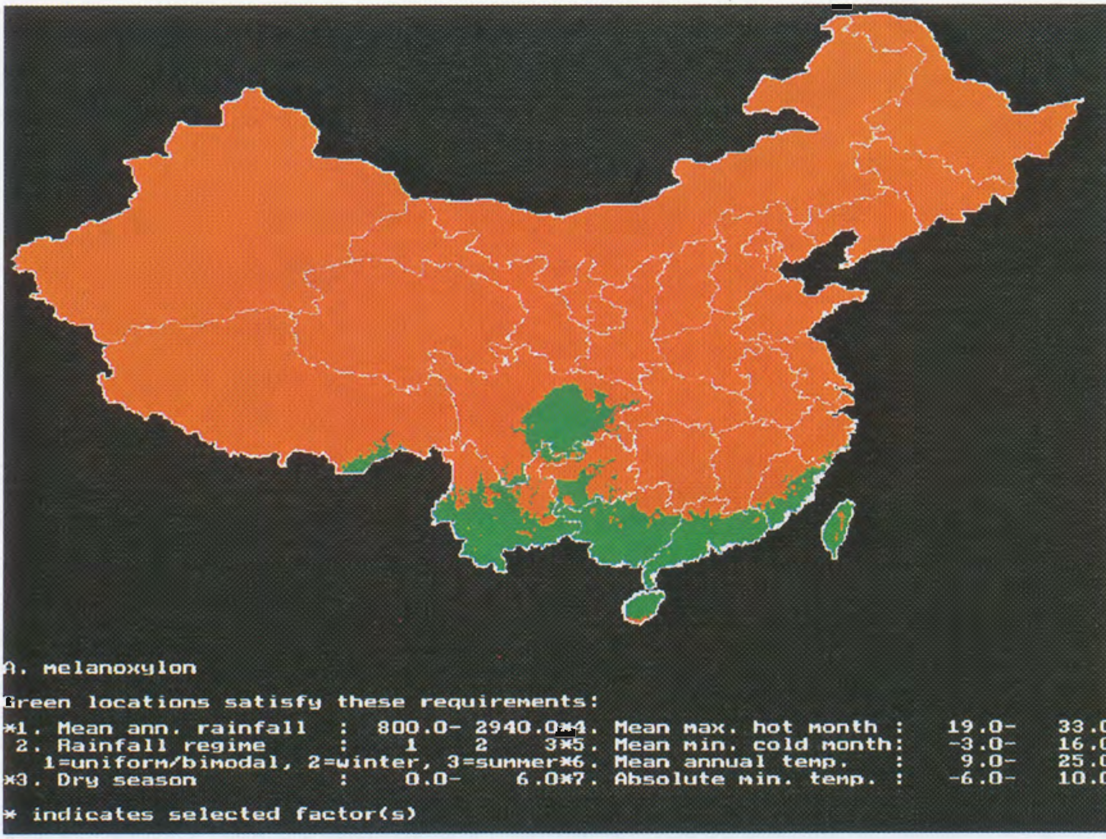


Figure 4. Climatically suitable areas for *A. melanoxylon* in China (source: Booth unpubl.).

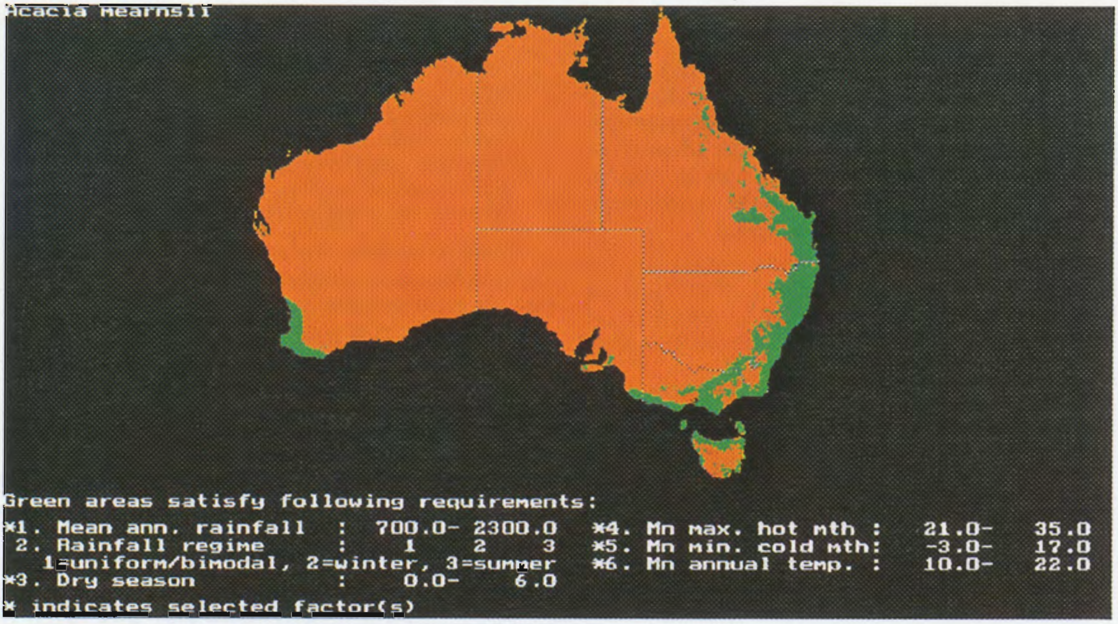


Figure 5. Climatically suitable areas for *A. mearnsii* in Australia (source: Booth (unpubl.).

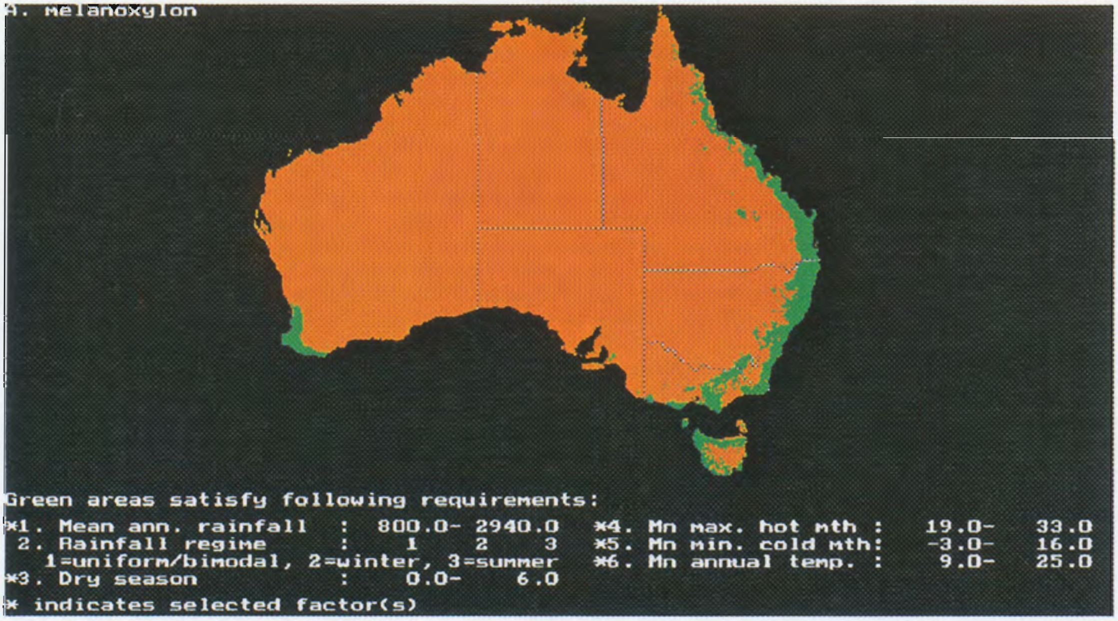


Figure 6. Climatically suitable areas for *A. melanoxylon* in Australia (source: Booth (unpubl.).

Without maps showing economic suitable subsets of Figures 1–6 for the production of temperate acacias, matters of economic feasibility were resolved through a literature search. The key question in the search was what insurmountable economic constraints may prevent the adoption of technologies for growing temperate acacias, even in those areas where Figures 1–6 indicate agroclimatic feasibility for a temperate acacia industry.

Figures 1–6 and the following comments by the independent technical reviewers of FST/92/27 on this issue provided the starting point in the search for information on economic feasibility of temperate acacias:

> 'Current plantings in Vietnam and China are relatively small and there is obviously a long way to go in convincing farmers to plant acacias in preference to fruit trees and other crops. Similarly in Australia acacias are not currently a high priority for planting by government or private landowners, although more interest is now being shown in planting industrial-sized estates of high-value forest species such as blackwood *A. melanoxylon* in Tasmania and woodlots (and perhaps larger plantations) of *A. mearnsii* on private land in Western Australia' (ACIAR 1997).

Table 4 indicates the areas where the production of temperate acacias may be economically feasible in the three collaborating countries. This table is central to the estimation of potential benefits from temperate acacia research. The key hypothesis in the analysis is that the benefits from temperate acacia research will accrue only to those areas where these acacia species are planted, that is where farmers reason that land planted to temperate acacias can yield an economic return that equals or betters that of existing uses.

Table 4. Areas where the production of temperate acacias (*A. mearnsii* and *A. melanoxylon*) may be economically feasible.

	Vietnam	China	Australia
Area planted to species in 1991 (ha)	Small to 280[a]	10 000[e]	0 to 482[j]
Estimated annual increase (ha)	600[b]	2 000[f]	24[k]
Maximum possible area (ha) by 2024			
Pessimistic (ha)	300 000[c]	260 000[g]	1202[k]
Optimistic (ha)	500 000[c]	700 000[h]	1500[l]
Proportion of economically feasible area planted to *A. mearnsii*	0.1[d]	0.4[i]	0.0[m]
Proportion of economically feasible area planted to *A. melanoxylon*	0.9[d]	0.6[i]	1[m]

a ACIAR (1997) indicates that current plantings are small but they do not provide a quantitative estimate of hectares planted to the species. Nguyen Hoang Nghia and Le Dinh Kha (1993) indicate that *A. mearnsii* and *A. melanoxylon* were introduced to Vietnam in about 1980 and 1967 respectively. The estimate in the table is based on the strike rates in Awang and Taylor (1993, p.2) and Nguyen Hoang Nghia and Le Dinh Kha (1993). Midgley et al. (1995) estimate that Vietnam had about 80 000 ha planted to all acacias in 1995.

b This estimate is based on Nguyen Hoang Nghia and Le Dinh Kha (1993) who claim that total area planted to acacia species is growing annually by 10 000–15 000 hectares. Account is taken of the fact that probably most of the new planting to other acacias species (e.g. *A. mangium and A auriculiformis*).

c This estimate is from ACIAR (1997). This more recent estimate is higher than that in Nguyen Hoang Nghia and Le Dinh Kha (1993) where an estimate of 130 000–150 000 ha for all acacia planting by the year 2000 was made.

d This estimate is based on the relative sizes of the agroclimatically suitable areas shown in Figures 1 and 2.

e The estimate in the table for 1991 in southern China is from Wang and Fang (1991). A slightly higher estimate of 10 400 ha planted to *A. mearnsii* is given in Gao Chuan Bi, and Li Ji Yuan (1991). The estimate is quoted also in Gao Chuan Bi et al. (1991). According to Dr Wang Haojie (pers comm, October 1997) this is the area currently planted to acacias in China.

f The estimate of annual planting rate is from Moncur et al. (1991). This estimate is for *A. mearnsi.* To date there has not been significant plantings of *A. melanoxylon.*

g Based on ACIAR (1997). The ratio of pessimistic to the optimistic estimate is assumed to be the same in China and Vietnam.

h This estimate is from ACIAR (1997).

i This estimate is based on the relative sizes of the agroclimatically suitable areas shown in Figures 3 and 4.

j David Allen (Forestry Tasmania, pers. comm., August 1997). See Table 7 for annual planting of *A. melanoxylon.*

k Estimated from Table 7, supplied by David Allen (Forestry Tasmania, pers comm, August 1997).

l Based on Table 7 supplied by David Allen (Forestry Tasmania, pers comm, August 1997).

m The economic viability of *A. mearnsii* and *A. melanoxylon* in Australia is being explored. For the reasons given in the text, in the base case we assume that an Australian producer will show more interest in *A. melanoxylon.* However, since this paper is exploring potential for the two acacia species, one of the scenarios assumes that about 10% of the farmer effort is devoted to *A. mearnsii.*

Table 5. Selected parameters relevant to the estimation of benefits from temperate acacia forestry research.

	Yield/ ha	*A. mearnsii*			*A. melanoxylon*		
		Vietnam	China	Australia	Vietnam	China	Australia
1	Tannin (t/ha)	21[a]	21[a]	21[a]	na	na	na
2	Pulpwood (t/ha)	15–25[b]	15–25[b]	15–25[b]	na	na	na
3	Fuelwood (t/ha)	15–25[c]	15–25[c]	15–25[c]	na	na	na
4	High value timber (t/ha)	na	na	na	15–25[d]	15–25[d]	15-25[d]
	Environmental goods						
5	Amount of nitrogen fixed (kg/ha/year)	8.4[e]	8.4[e]	8.4[e]	5.7[e]	5.7[e]	5.7[e]
6a	Quantity of carbon sequestered (kg/ha)	152[f]	152[f]	152[f]	251[f]	251[f]	251[f]

a Turnbull (1986a, p. 166) gives typical yields of bark (dry) for a well-managed South African commercial plantation 10–11 years old in Natal. To get an estimate the quantity of tannin assume a tannin content of 40% dry weight of bark (Thomas 1993).

b Turnbull (1986a, p. 166). In Vietnam, China, and Australia respectively, current estimates suggest that 0, 50, and 25% of *A. mearnsii* and *A. melanoxylon* are for pulpwood.

c Turnbull (1986a, p. 166). In Vietnam, China, and Australia, current estimates suggest that 50, 0 and 25% respectively of *A. mearnsii* and *A. melanoxylon* are for fuelwood.

d Turnbull (1986a, p. 166). In Vietnam, China, and Australia, current estimates suggest that in all three countries 50% of *A. mearnsii* and *A. melanoxylon* are grown for high-value timber.

e Khanna (1997, p. 111) estimated nitrogen fixation in mixed stands (50% eucalypts and 50% acacias) 2 years after planting around 2.5 kg/ha/month — where about 2.5 kg/ha is already in the soil before the planting of acacia. It is known that acacias fix most of the nitrogen in the first 3–5 years of growth; after that they fix about 5 kg of N per year (Khanna, pers. comm.). These two pieces of information enable an estimate of N left in the soil, after harvest, using the following equation:
$[2.5 \times 48 + 5*(\text{the rotation length} - 4)]/\text{rotation length}$.

f These estimates of carbon sequestered over a rotation length of 6 to 8 years for *A. mearnsii* and a rotation length of 40 years for *A. melanoxylon*.

What is the nature of the benefits from temperate acacia research?

The different benefits from temperate acacia research is listed in Table 5.

(i) Tannin

For Vietnam and China, tannins from acacia bark are of some economic importance (see Awang and Taylor 1993, p. 1–14).

Australia imports powdered tannin extract each year (see Table 6) mainly from Brazil, South Africa and USA. Tannin extracts are used for weather-resistant adhesives in manufacturing reconstituted board products.

Table 6. Australian imports of tannins.

Year	Imports of tannins (tonnes)
1993–94	6 541
1994–95	8 415
1995–96	7 136
1996–97	64 339

Source: Australian Bureau of Statistics (1997)

While there may be potential from import substitution, this is likely to be limited for the following reasons. Earlier attempts to establish plantations for tannin bark were commercial failures because of the prevalence of fires, lack of markets for the wood, high freights and stripping costs and the lack of tannin extract factories (Searle 1995a). These constraints still exist (Searle 1996a). Thomas (1993) summarises those economic constraints, quoting a 1962 Victorian forester's assessment:

> 'The imported *A. mearnsii* tannin extract (a) is cheaper; good quality tannin extract, readily available from South Africa at a competitive price, (b) is consistent in strength, (c) is convenient — a phone call could organise supply, (d) is easier to handle, (e) requires little storage space, (f) does not deteriorate on storage and is not attacked by moulds and (g) is not seasonal.'

However, this does not mean that Australia gains nothing from *Acacia* research that impacts on the quantity produced and the price of tannins. Australia will benefit from lower prices of the tannins as a result of research. Thus even if Australian farmers do not produce tannins locally, Australia benefits from research which improves the production of tannins in other countries. More benefits would be realised if Australian producers increased the planting of *A. mearnsii.*

(ii) Pulpwood

Temperate acacias have potential as species for pulp. Clark et al. (1994) suggest that *A. mearnsii* and *A. melanoxylon* are particularly suitable for pulp production from the viewpoint pulpwood productivity (kg of pulp/m^3 wood), pulp yield (oven dry wood to oven dry wood) and other indicators.

Indicator	*A. mearnsii*	*A. melanoxylon*
Pulpwood productivity (kg of pulp/m^3 wood)	608	502
Pulp yield (oven dry wood to oven dry wood)	52.8	55.0

It is estimated that in China and Australia 50 and 25% respectively of temperate acacias are planted for use as pulpwood.

(iii) Fuelwood

A. mearnsii is one of the *Acacia* species that Turnbull (1986a) described as excellent firewood. On the south coast of New South Wales, *A. mearnsii* is used in wood-burning kilns because it is readily available, easily regenerated and has very hot burning characteristics (Dr Owen Rye, pers. comm. 1996). If the research under FST/92/27 succeeds and farmers take up the results, it will help reduce the fuelwood shortage in Vietnam. Current estimates suggest that about 50% of *A. mearnsii* plantings in Vietnam and about 25% of those in Australia are for firewood.

(iv) High-value timber

A. melanoxylon is the best known of Australia's temperate acacia timber species. The most significant commercial production occurs in Tasmania from natural stands, with up to half being felled in the State's northwest (Searle 1996a). However, there could be uptake in Vietnam and China. Table 7 shows the area planted to *A. melanoxylon* in Australia. Current estimates suggest that about 50% of acacia planting in China and about 25% of those in Australia are for timber.

Table 7. Planting of *A. melanoxylon* in Australia (ha), 1976–1995*.

Species	Pure blackwood	With hardwood nurse crop	With softwood nurse crop	Total
1976	0.61	0	0	0.61
1978	1.27	0	0	1.27
1988	2.86	0	78.92	81.78
1989	0	0	37.54	37.54
1990	0	0	28.7	28.7
1991	0	73.52	3.88	77.4
1992	0	0	79.57	79.57
1993	0	0	171.96	171.96
1994	0	115.85	141.97	257.82
1995	0	0	226.66	226.66
Total	4.74	189.37	769.2	963.31

* Apart for column 2 which gives planting's of pure *Acacia melanoxylon*, the rest of the table gives data on planting of *Acacia melanoxylon* in mixed stands with 50% of the planted area occupied by some other tree species.

Source: David Allen (Forestry Tasmania, August 1997).

(v) Environmental goods: nitrogen fixation by acacia

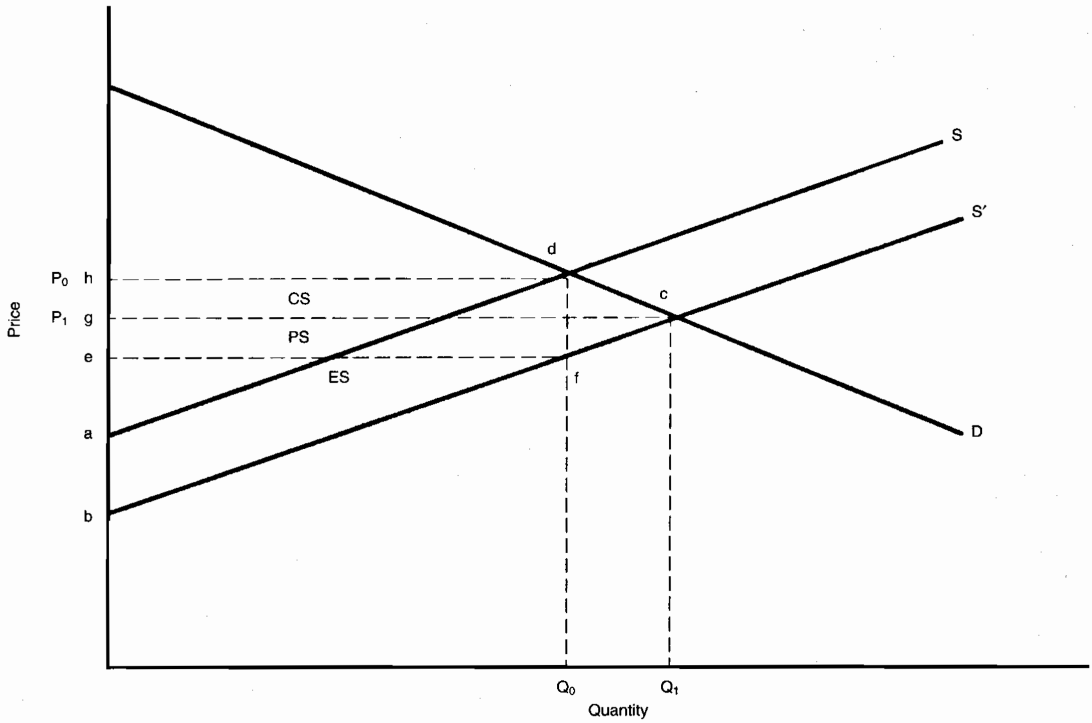
Khanna (forthcoming) indicates that the usefulness of data on N_2 fixation available in the literature is often limited by methodological shortcomings. The main weaknesses are lack of suitable field based methodologies, lack of field-based experiments to measure N in the biomass and lack of information on the biological and soil factors determining N_2 fixed by trees. However, there are results that indicate the significant contribution of acacias to soil fertility through biological fixation (Khanna 1997). Awang and Taylor (1993, p.4) highlight the environmental value of acacia planting to rural communities in Vietnam and China.

(vi) Environmental goods: carbon sequestration

This paper explicitly includes estimates of possible environmental benefits associated with improved carbon sequestration as a result of increased planting of acacias. They are included in this paper for illustrative purposes to indicate the orders of magnitude of global public-good benefits from acacia research if and when farmers and the forest products industry adopt the research results.

(vii) Other uses

Acacias can be used to produce other goods, including oils for perfumes, pollen, cut flowers, fodder for livestock, seeds for human food, and gum arabic. However, these other commodities are not considered in this analysis.



The following notation is used.

Po is the price of the forest product before research
P1 is the price of the forest product after research
Qo is the quantity produced and consumed of the forest product before research
Q1 is the quantity produced and consumed of the forest product after research
S is the supply function for the forest product before research
S' is the supply function for the forest product after research
D is the demand function for the forest product
a is the intercept of the supply function before research
b is the intercept of the supply function after research
c is the point of intersection between the demand and supply curve after research which gives the price after research as P1
d is the point of intersection between the demand and supply curve after research which gives the price before research as P0
df is the cost saving per unit of output due to research. In the case of the three ACIAR supported projects, the cost saving is attributed to (i) the introduction of higher yielding tree species (ii) faster growing tree species (iii) nitrogen-fixing aspects of some introduced tree species, and (iv) the reduction in a number of externality costs like costs of reduced soil fertility, soil erosion costs, costs of off-site impacts and carbon sequestration costs.
ES is the total change in economic surplus which is given by the area 'abcd'
PS is the change in producer surplus and is given by the area 'efcg'
CS is the change in consumer surplus and is given by the area 'gcdh'
ES is equal to the sum of PS and CS.

Figure 7. A simple illustration of the estimation of welfare gains from research.

Estimation of Potential Benefits from Temperate Acacia Forestry Research

Methodology for estimation of commodity-based benefits

In this paper a well-known research evaluation model is used to estimate commodity-based benefits from research. Figure 7 is a graphical representation of the model. Using this model, the impact on producers and consumers of tannin, pulpwood, fuelwood and high value timber are estimated. The impact on producers and consumers is measured by the change in producer and consumer surplus, respectively. The method used in this study to estimate commodity-based benefits from research is to that shown in Figure 7.

As Figure 7 shows, it is possible to calculate separate estimates of changes in consumer surplus (area 'gdeh') and producer surplus (area 'efcg'). This paper reports estimates of total potential benefits given by the area 'abcd' in Figure 7.

Project FST/92/27 is expected to change the unit cost ($A/tonne) of producing the selected acacia commodities in Table 5. One way to estimate these unit costs is to take a representative farmer and estimate his/her costs of production per hectare before research, taking into account the rotation length of the tree crop and both the variable and fixed costs incurred by the farmer. If the yield before research is known then it is possible to estimate the unit cost before research. Undertaking a similar analysis but with the farmer using the technology from research gives an estimate of the after-research unit costs. The cost savings to the farmer then equal the difference between the before- and after-research unit costs per tonne. This cost saving is usually denoted by the symbol 'k'. In the case of FST/92/27, a cost saving is likely to be achieved through changes the project is likely to make to the 'before-research' situation. Before FST/92/27 few planted suitable nitrogen-fixing, insect-resistant tree legumes for the reforestation of cold frost-prone mountainous regions. The project has identified productive *Acacia* tree species with planting potential for cool subtropical regions of the world. The species identified in FST/92/27 are superior to those available before research as the comparison in Table 8 indicates.

Table 8. Species comparison before and after FST/92/27.

	Before FST/92/27	After FST/92/27 (if successful)
Species used for the production of pulpwood Harris-Daishowa Australia	*Eucalyptus nitens*	*A. mearnsii*
Basic wood density (kg/m^3)	430	608
Pulp yield on oven dry weight basis (%)	54	53
Pulp productivity(kg/m^3)	260	320

Source: Mitchell, these Proceedings

Ha Huy Thinh et al. (these Proceedings) also conclude from preliminary results that some Australian temperate acacia species are quite adaptable and promising for planting on high land sites of Vietnam. Similar results are available for China (Brown 1996).

Estimates of cost savings

In this paper cost savings are estimated as a function of the prices of the respective commodities. Table 9 shows the prices used in the analysis and the estimated cost savings. In the base case, it is assumed that the project will lead to a reduction in the cost of production of commodities derived from the two acacia species equal to 0.5% of the corresponding prices. The cost savings under this scenario are lower than those estimated by Davis et al. (1994) mainly

Table 9. Prices of acacia products and estimated cost savings.

Commodity	Price in Australia (a) ($A/tonne)	Price in China RMB/tonne (b)	Cost saving ($/t)	Cost saving ($/t)	Cost saving ($/t)
			= 0.001*price	= 0.005*price	= 0.01*price
Tannins	1000	10 000	$1.00	$5.00	$10.00
Fuelwood	53	200	$0.05	$0.27	$0.53
Pulpwood	50	300	$0.05	$0.25	$0.50
High-value timber	2107	Not stated	$2.11	$10.54	$21.07

a Searle (1996a) and from ACIAR's database (for pulpwood)
b Estimates by Dr Wang Haojie, Deputy Director, Research Institute of Subtropical Forestry, China (pers comm, October, 1997).

because FST/92/27 targeted much harsher agro-climatic production environments than those targeted in the earlier projects. Two other scenarios are constructed, assuming that FST/92/27 leads to reductions in the cost of production of commodities derived from the two acacia species equal to 0.1% and 1% of the corresponding prices.

While the prices in Table 9 were estimated for Australia and China price information in Midgely et al. (1995) suggests that these prices can be used to approximate prices in Vietnam.

The total annual benefit to research is equal to the change in economic surplus (ΔES) which is estimated by the following equation (Lubulwa and McMeniman 1996):

$$\Delta ES = kQ_0 + 0.5\ k\ (Q_1 - Q_0) \qquad (1)$$

The total benefit from a research-induced supply curve is equal to the cost savings on the initial output Q_0 plus the economic surplus due to the increment to production and consumption of the commodity. Solving for Q_1 in terms of the parameters of the demand and supply functions and substituting this in equation (1) leads to the following algebraically alternative but numerically equivalent expression for the total benefit:

$$\Delta ES = kQ_0 + 0.5(Q_0/P_0)[\varepsilon_s\varepsilon_d k^2/(\varepsilon_2 + \varepsilon_d)] \qquad (2)$$

where k is the absolute value of the cost reduction, ε_s is the elasticity of supply, and ε_d is the elasticity of demand (both obtained from ACIAR's database).

The methodology for the estimation of non-market, environmental benefits

This paper differs from the earlier studies by McKenney et al. (1993, 1994) and Davis et al. (1994), and is closer to Lubulwa et al. (1998) in that the research impact includes an estimate of the non-commodity benefits of forest research, namely soil fertility and carbon sequestration. This extension of the methodology is partly inspired by Thomas and Bright (1990), who argued that economic evaluations of agroforestry projects should take into account the negative and positive interactions between trees and agricultural activities.

Nitrogen fixation

Crops that can fix nitrogen make available to the crop and to the soil (after harvesting the nitrogen-fixing crop) a quantity of nitrogen fertiliser that a farmer would normally have to purchase. The value of nitrogen fixed by acacia is estimated using the following equation:

$$E_{1t} = P_{1t} *(1 + r)*Ho*A_t*N_t$$

where

- E_{1t} is monetary value of the after harvest, residual nitrogen fixation benefits from planting acacia in year t;
- P_{1t} is the price of per tonne of nitrogen fertiliser (FAO 1991, p. 124). This estimate is \$A845/t;
- r is the rate of growth (about 3% per annum) in the area planted to *A. mearnsii* and *A. melanoxylon*;
- H_o is the number of hectares that can be planted to *A. mearnsii* and *A. melanoxylon* in the base year;
- A_t is the proportion of the hectares potentially planted to *A. mearnsii* and *A. melanoxylon* in year t (regarded as a measure of adoption of technology from FST/92/27);
- N_t is the residual nitrogen fixed by an acacia plant in kg/ha/year from Table 5.

Carbon sequestration benefits

Increased planting of acacia leads to a temporary withdrawal from the atmosphere, of emissions of carbon dioxide, one of the important greenhouse gases. Harvesting of acacia products eventually re-releases carbon into the atmosphere, with the rate of re-release depending on how acacia products are used. When acacia products are used for firewood, for example, the re-release is almost immediate. However, when acacia is used to produce high value timber, the carbon sequestration impacts last for a long time after harvest. An estimate of the value of residual carbon sequestration benefits (E_{2t}) is given as the difference between the value of carbon sequestered in an acacia plant pre-harvest (C_{bt}) at time t and the value of carbon released after harvest (C_{at}) at time t. Thus

$$E_{2t} = C_{bt} - C_{at}$$

where

- E_{2t} is monetary value of the carbon sequestration benefit from planting acacia in time t;
- $E_{2t} = P_{2t} *(1 + r)*Ho*A_t/(1 + d)\hat{}(t - 1)$
- P_{2t} equals (the imputed value of carbon sequestered in acacia plants per ha pre-harvest) minus (the imputed value of carbon released when 1 ha of acacia crops is harvested, assuming a half-life of carbon of 2.5 years). It is the value of carbon sequestration per ha of acacia planting after adjusting for the carbon released into the atmosphere after harvest. In this paper P_{2t} = \$A193/ha and is obtained from Tomich et al. (1996) as follows: $P_{2t} = [(272 - 218)/0.7]* (20/8)$ where the constant 0.7 is used to convert estimates from US to Australian dollars, (\$A7/t) and the ratio (20/8) is to adjust for a longer rotation for *A. mearnsii* compared to *A. mangium*.

r is the rate of growth in the area planted to *A. mearnsii* and *A. melanoxylon*

d is a rate of discount assumed to be 8%.

t stands for a given year

H_o is the number of hectares suitable for planting to *A. mearnsii* and *A. melanoxylon* in the base year.

A_t is the proportion of the potential hectares planted to *A. mearnsii* and *A. melanoxylon* in year t. This a measure of adoption of technology from FST/92/27.

C_{at} is the value of carbon released again into the atmosphere after the harvest of acacia crops, assuming a half-life of carbon of 2.5 years. In this analysis all the carbon re-release is from the harvest of *A. mearnsii*. The analysis uses a 30-year time horizon, too short to capture the release of carbon from the harvest of *A. melanoxylon,* which has a rotation length of 40–50 years.

Adoption pattern for the technology from FST/92/27

An important parameter in the estimation of potential benefits from ACIAR-supported project FST/92/27, is the adoption pattern for the technologies the project develops. In the analysis use is made of two possible adoption paths. The key parameters in these adoption paths are summarised in Table 10. Adoption path 1 is pessimistic in that it assumes that it is likely to take about 10 years in China and Vietnam and Australia before the technology from FST/92/27 is adopted. Adoption is interpreted as the start of planting of the new species by farmers. Since the rotation length for *A. mearnsi* is 6 to 8 years, benefits do not start flowing to producers and consumers until trees are harvested about 7 years from the start of planting. Adoption path 2 is optimistic and assumes that adoption of technology from FST/92/27 will be almost immediate.

Estimated Benefits

Table 11 summarises results for the base-case scenario assuming a pessimistic adoption path and that the technology developed under FST/92/27 will lead to a cost reduction to producers of tannins, pulpwood, fuelwood and high-value timber equal to 0.5% of the corresponding commodity price.

Table 11 indicates that in the base-case the project is likely to generate benefits valued at about $A1.39 million over a 30-year time horizon. Taking into account the research costs of $A1.16, the project is estimated to generate a net present value of benefits equal to about $A0.23 million and an internal rate of return of about 8.5%. If one ignores the environmental benefits then the project is likely to generate a net present value of benefits equal to about –$A0.73 million, with a slightly reduced internal rate of return of about 2.1%.

The estimates in Table 11 depend crucially on the assumptions and information in Table 4, Table 5 and Table 10. For example the low value of benefits estimated to accrue to Vietnam is largely due to the small area planted in Vietnam to the two acacia species under consideration in this paper. China's large share in the estimated benefits is due to the large area planted in China to the two acacia species under consideration. Similarly the zero benefits in the first 16 years reflect the assumption made in Table 10 that it is likely to take about 10 years before tree species introduced under FST/92/27 are planted by farmers in Vietnam, China and Australia, and another 6 to 8 years before farmers harvest these trees.

Table 10. Two possible adoption paths.

Variable used in estimating adoption curve	Vietnam	China	Australia
Start date of the project	1994	1994	1994
Completion date of the project	1997	1997	1997
Adoption path 1 — Pessimistic			
No. of years from start of project to start of tree planting by farmers	10	10	10
No. of years from start of project to start of flow of benefits	17	17	17
No. of years from start of project to maximum adoption	20	20	20
First year of adoption	2004		2004
Adoption path 2 — Optimistic			
No. of years from start of project to start of tree planting by farmers	5	5	5
No. of years from start of project to start of flow of benefits	12	12	12
No. of years from start of project to maximum adoption	15	15	15
First year of adoption	1999	1999	1997
Maximum adoption (proportion)	70%	70%	70%

Table 11. The base-case scenario showing the flow of benefits from temperate acacia research which reduces the cost of producing tannins, pulpwood, fuelwood and high-value timber by 0.5% of the current price of the respective commodities, assuming a pessimistic adoption path ($A '000, 1994).

Year	Year	Vietnam	China	Australia	Total research benefits	Total research costs	Net research benefits	Net research benefits (excluding environmental benefits)
0	1994	$0	$0	$0	$0	208.523	($209)	($209)
1	1995	$0	$0	$0	$0	510.995	($511)	($511)
2	1996	$0	$0	$0	$0	420.64	($421)	($421)
3	1997	$0	$0	$0	$0	405.31	($405)	($405)
4	1998	$0	$0	$0	$0	0	$0	$0
5	1999	$0	$0	$0	$0	0	$0	$0
6	2000	$0	$0	$0	$0	0	$0	$0
7	2001	$0	$0	$0	$0	0	$0	$0
8	2002	$0	$0	$0	$0	0	$0	$0
9	2003	$0	$0	$0	$0	0	$0	$0
10	2004	$0	$0	$0	$0	0	$0	$0
11	2005	$0	$0	$0	$0	0	$0	$0
12	2006	$0	$0	$0	$0	0	$0	$0
13	2007	$0	$0	$0	$0	0	$0	$0
14	2008	$0	$0	$0	$0	0	$0	$0
15	2009	$0	$0	$0	$0	0	$0	$0
16	2010	$0	$0	$0	$0	0	$0	$0
17	2011	$16	$561	$63	$640	0	$640	$182
18	2012	$16	$565	$63	$644	0	$644	$183
19	2013	$16	$569	$64	$649	0	$649	$185
20	2014	$16	$574	$64	$654	0	$654	$186
21	2015	$16	$574	$64	$654	0	$654	$186
22	2016	$16	$574	$64	$654	0	$654	$186
23	2017	$16	$574	$64	$654	0	$654	$186
24	2018	$16	$574	$64	$654	0	$654	$186
25	2019	$16	$574	$64	$654	0	$654	$186
26	2020	$16	$574	$64	$654	0	$654	$186
27	2021	$16	$574	$64	$654	0	$654	$186
28	2022	$16	$574	$64	$654	0	$654	$186
29	2023	$16	$574	$64	$654	0	$654	$186
NPV ($A m) (a)		$0.03	$1.22	$0.14	$1.39	$1.16	$0.23	($0.73)
						IRR (b)	8.5%	2.1%

(a) NPV stands for net present value. The entries in this row give the discounted values of the flow of benefits. The discount factor is 8 percent per annum. While the entries in the top of the table are in thousands of dollars, the entries in this row are expressed in millions of dollars ($A).

(b) IRR stands for the internal rate of return as estimated using Microsoft Excel, where IRR is defined as the interest rate received for an investment consisting of payments (defined here to be the research costs and represented as negative values in the table) and income (defined here to be the research benefits and taking on positive values) that occur at regular periods.

Sensitivity analyses

Ex-ante evaluations are often encumbered by lack of information. Consequently it is often necessary to undertake more sensitivity analyses than in other studies. This paper reports results for the following analyses:

Scenario 1 is the base-case which assumes a pessimistic adoption path but with cost saving equal to 0.5% of commodity price;

Scenario 2 assumes pessimistic adoption with cost saving equal to 0.1% of commodity price;

Scenario 3 assumes pessimistic adoption with cost saving equal to 1% of commodity price;

Scenario 4 assumes optimistic adoption levels with cost saving equal to 0.1% of commodity price;

Scenario 5 assumes optimistic adoption levels with cost saving equal to 0.5% of commodity price;

Scenario 6 assumes optimistic adoption levels with cost saving equal to 1% of commodity price;

Table 12 summarises the results from the six sensitivity analyses. Common to the six sensitivity analyses is the total research cost of FST/92/27. The discounted total research cost of $A1.16 million in the sensitivity analyses includes funds invested by CSIRO Division of Forestry and Forest Products, ACIAR's partner countries (Vietnam and China) and ACIAR. The results for the six scenarios are discussed below.

The base case

The base-case scenario is designed to capture the current assessments in the literature and to represent, at this stage, the most likely outcome for a project. The base case for FST/92/27 assumes that the project, if successful, will lead to a cost reduction (equal to 0.5% of price of commodity), in the three collaborating countries. This has been discussed above with respect to Table 11. The salient features of the base-case are reproduced in Table 12 because it is used as a reference scenario in discussing the other scenarios.

Table 12 reports the benefits from FST/92/27 decomposed by the commodities affected by research. The low benefits associated with fuelwood and pulpwood reflect the low prices assumed for these two commodities in the analysis, and partly reflect the assumption in the analysis that most of *A. mearnsii* planted in China is not for fuelwood.

Table 12. Sensitivity analyses benefits by country and by affected commodity, assumed to arise from FST/92/27.

Scenario description	B1	B2	B3	B4	B5	B6	C	D	E	F	G
	Tannin	Pulpwood	Fuelwood	Timber	Nitrogen	Carbon	Research cost	Total research benefits	Net present value of benefits	Internal rate of return	Internal rate of return
									B1 to B6	B1 to B6	B1 to B4
1 Base case: Pessimistic adoption path 1 in Table 10 + cost saving = 0.005*price	$0.164	$0.007	$0.001	$0.224	$0.030	$0.964	$1.16	$1.39	$0.23	9%	2%
2 Pessimistic adoption path 1 in Table 10 + Cost saving = 0.001*price	$0.033	$0.001	$0.000	$0.045	$0.030	$0.964	$1.16	$1.07	($0.08)	7%	Negative
3 Pessimistic adoption path 1 in Table 10 + Cost saving = 0.1*price	$0.328	$0.014	$0.002	$0.447	$0.030	$0.964	$1.16	$1.79	$0.63	10%	6%
4 Optimistic adoption path 2 in Table 10 + Cost saving = 0.005*price	$0.276	$0.012	$0.001	$0.375	$0.050	$1.621	$1.16	$2.34	$1.18	12%	4%
5 Optimistic adoption path 2 in Table 10 + Cost saving = 0.001*price	$0.055	$0.002	$0.000	$0.075	$0.050	$1.621	$1.16	$1.80	$0.65	10%	Negative
6 Optimistic adoption path 2 in Table 10 + Cost saving = 0.1*price	$0.551	$0.024	$0.003	$0.750	$0.050	$1.621	$1.16	$3.00	$1.84	14%	8%

Changing the size of the cost saving

Table 12 indicates that if FST/92/27 leads to high cost savings to farmers in Vietnam, China and Australia, then the net present values of benefits and the rate of return associated with the project will be higher than in the base case. However, the cost savings in Scenario 3 may not be achievable. For example, Scenario 3 assumes that FST/92/27 could lead to a $A10/t cost reduction in the production of tannins. Given the low cost of producing tannins in countries that compete with Australia in this industry, this may be too large a cost reduction to be achieved.

Adoption

Similarly, comparing scenarios 1–3 with scenarios 4–6 suggests that adoption of technology is crucial. Scenarios 1–3 are based on the same set of assumptions as scenarios 4–6, except that the adoption path is changed to allow faster adoption of the results from FST/92/27 in scenarios 4–6. If better temperate *Acacia* species from FST/92/27 are adopted and planted earlier by farmers, then the net benefits from the project and the rate of return on research funds invested almost double.

Concluding Comments

This paper has discussed an ex-ante evaluation of an ACIAR-supported research project on temperate acacia forestry. Because the project was not completed at the time of the study, the analysis is speculative in part. An attempt has been made to modify the estimates of potential impact to take into account the economic constraints likely to hinder adoption by farmers.

Project FST/92/27 is estimated to generate total research benefits ranging from $A1.07 million, on the low side under pessimistic assumptions about adoption, to $A3.00 million under optimistic assumptions about adoption and the magnitude of the research impact at farm level. It is estimated that the rate of return to funds invested in FST/92/27 could range from 7 (Scenario 2) to 14% (Scenario 6), depending on assumptions about the research impact and the level of adoption of the identified species of acacia. The most likely estimate of total benefits, as estimated in the base-case scenario (see Table 11), are about $A 1.39 million over a 30-year time horizon, with a rate of return of about 9%. This rate of return and estimate of net present value are lower than the estimates by Davis et al. (1994) for projects on *Eucalyptus, Acacia,* and *Casuarina* in warmer agroclimatic zones in China and Australia. An important explanation for the lower estimates in this paper is that only a subset of the best two out of 13 promising *Acacia* species for the temperate climates are included in the analysis. Furthermore, compared to the project evaluated in Davis et al. (1994), FST/92/27 targets much harsher agroclimatic environments.

The estimates in this paper are considered as conservative. For example, they do not take into account research spillovers, that is the potential benefits from introducing the tree species studied under FST/92/27 to identical agro-climatic zones in other countries. These research spillovers are likely to exceed the ecological costs, not estimated in the study, associated with species introduction. Part of the research under FST/92/27 was designed to establish the nature, if any, of these ecological costs.

Finally, this analysis has shown that, in line with other forest research, temperate acacia forestry research is worth funding for public good reasons. Examples of these public good benefits include the carbon sequestration and the improvement in the quality of currently degraded land through biological nitrogen fixation.

References

ACIAR 1997. ACIAR project review of FST/92/97: Australian Acacias for Sustainable Development in China, Vietnam and Australia. Australian Centre for International Agricultural Research, Canberra.

Australian Bureau of Statistics. 1997. Imports of Wattle Extracts. Information Services Division, Australian Bureau of Statistics (ABS), Canberra.

Awang K and Taylor, D.A., ed. 1993. Acacias for rural, industrial and environmental development in Vietnam. Proceedings of the second meeting of the Consultative Group for Research and Development of Acacias (COGREDA). Winrock International Institute for Agricultural Research and the Food and Agriculture Organisation of the United Nations, Bangkok, Thailand.

Booth, T.H. and Yan Hong 1991. Identifying climatic areas in China suitable for *Acacia mearnsii* and *A. mangium*. In: Turnbull, J. W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 52–56.

Brown. A.G., ed. 1996. Australian acacias for sustainable development in China, Vietnam and Australia. Prepared as a presentation by the project scientists to the review of ACIAR Project 9227. CSIRO Forestry and Forest Products, Canberra, Australia.

Clark, N.B., Balodis, V., Fang Guigan and Wang Jingxia 1994. Pulpwood potential of acacias. In: Brown, A.G., ed., Australian Tree Species Research in China. ACIAR Proceedings No. 48. Australian Centre for International Agricultural Research, Canberra, 196–202.

Davis, J.S., McKenney, D.W. Turnbull, J.W. and Searle, S.D. 1994. Impact of Australian tree species research in China: an update. In: Brown, A. G., ed., Australian Tree Species Research in China. ACIAR Proceedings No. 48. Australian Centre for International Agricultural Research, Canberra, 9–18.

FAO 1991. Fertiliser. FAO Yearbook 1991. Food and Agriculture Organisation of the United Nations, Rome Italy.

Gao Chuan Bi and Li Ji Yuan 1991. *Acacia mearnsii* provenance trials in southern China. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research: ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 209–214.

Gao Chuan Bi, Li Ji Yuan, and Williams, E.R. 1991. Performance of *Acacia mearnsii* provenance/progeny in southern China. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research: ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 215–218.

Khanna, P.K. 1997. Comparison of growth and nutrition of young monocultures and mixed stands of *Eucalyptus globulus* and *Acacia mearnsii*. Forest ecology and Management, 94, 105–113.

Khanna, P.K. (forthcoming). Nutrient cycling under mixed-species tree systems in southeast Asia. Agroforestry Systems.

Lubulwa G., Gwaze D., Clarke, J., Milimo P. and Mulatya, J. 1998. Estimates of socioeconomic benefits of ACIAR forestry projects in Africa and Thailand. The Commonwealth Forestry Review, 77(1), 19–28.

Lubulwa, G. and McMeniman, S. 1996. The Economic Evaluation Unit model for project-level economic evaluations. A users manual. ACIAR, Canberra.

McKenney, D.W., Davis, J.S. and Campbell, K.L. 1994. Towards an information system to support forestry research priority setting: some preliminary results for Canada. Information Report O-X-433, Natural Resources Canada. Canada Forest Service-Ontario, Great Lakes Forestry Centre.

McKenney, D.W., Davis, J.S., Turnbull, J.W. and Searle, S.D. 1993. Impact of Australian tree species selection research in China: an economic perspective. Forest Ecology and Management, 60, 59–76.

Midgley, S.J., Byron, R.N., Chandler, F.C., Ha Huy Thinh, Tran Vo Hung Son, and Hoang Hong Hanh. 1995. Do trees need passports? A socio-economic study of the role of exotic tree and other plant species in Huang Tri Province, Vietnam. Draft report. CSIRO Division of Forestry, Centre for International Forestry Research (CIFOR), Forest Science Institute of Vietnam, Australian Agency for International Development (AusAID).

Moncur, M.W., Moran, G.F. and Grant, J.E. 1991. Factors limiting seed production in *Acacia mearnsii*. In: Turnbull, J. W., ed., Advances in Tropical Acacia Research.. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 20–25.

Nguyen Hoang Nghia and Le Dinh Kha 1993. Acacias for rural, industrial and environmental development in Vietnam. In K. Awang and D.A. Taylor 1993, ed., Acacias for Rural, Industrial and Environmental Development in Vietnam, proceeding of the second meeting of the Consultative group for research and development of acacias (COGREDA) held in Udorn Thani, Thailand, February 15-18, 1993. Winrock International Institute for Agricultural Research and the Food and Agriculture Organisation of the United Nations, Bangkok, Thailand.

Searle, S. 1995a. Australian acacias, no longer the forgotten genus. Institute of Foresters of Australia Newsletter, Volume 36 No. 2, 9–15.

— 1995b. Acacias for the cool subtropics. ACIAR Forestry Newsletter No. 20.

— 1996a. Wood and non-wood uses of temperate Australian acacias. In: Proceedings of 1996 Australian Forest Growers Conference: Farm Forestry and Plantations: Investing in Future Wood Supply. Mount Gambier, South Australia, 9-12 September 1996, 256–266.

— 1996b. Sub-Project A: Collection, cultivation, and characterisation of acacias for the cool tropics. In: Brown, A.G., ed., Australian Acacias for Sustainable Development in China, Vietnam and Australia. Prepared as an input by the project scientists in the review of ACIAR Project 9227. CSIRO Forestry and Forest Products, Canberra Australia.

Thomas, S. 1993. Black wattle (*Acacia mearnsii*) a revitalised industry for Australia. In: Australian Forest Grower. Special lift-out Section No. 24 Autumn 1993, 16, No. 1.

Thomas, T.H. And Bright, G.A. 1990 A spreadsheet approach to the economic modelling of agroforestry systems. In: Prinsley, Roslyn T. ed., Agroforestry for Sustainable Production: Economic Implications. Commonwealth Science Council. London.

Tomich, T.P., Kuusipalo, J., Menz, K. and Byron, N. 1996–97. Imperata economics and policy. Agroforestry Systems, 36, 233–261.

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

— 1986b. Australian vegetation. In: Turnbull, J.W., ed., Multipurpose Australian Trees and Shrubs: Lesser-known Species for Fuelwood and Agroforestry. ACIAR Monograph No. 1. Australian Centre for International Agricultural Research, Canberra, 29–44.

Wang Huoran and Fang Yulin 1991. The history of acacia introductions to China. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 64–66.

Potential of Selected *Acacia* Species in Cebu Province, Philippines

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Abstract

There is a lack of species suitable for planting in different reforestation sites in Cebu Province, Philippines, and hence this trial was established at two sites, Tabuelan and Talisay, to test Australian hardwood species not previously grown in Cebu. The soil at Tabuelan was derived from coralline limestone, and was very shallow, while the Talisay site soils were derived from basaltic parent rock material and were deeper. Both soils are representative of large tracts in Cebu Province.

Eleven *Acacia* species (13 seedlots) were screened for suitability for the region. The experiment was laid-out in a randomised complete block design with three replicates each with seven plants per seedlot, and a spacing of 4 m between rows and 2 m within the row. Growth was assessed in terms of height and diameter. Diameter was measured 1 cm above the ground using a vernier calliper. Survival counts were taken a year after planting.

Based on the 2- and 4-year growth and 1-year survival data, *A. neurocarpa* (SL 18170), *A. crassicarpa* (SL 17604, SL 17948), *A. leptocarpa* (SL 18003) and *A. oraria* (SL 16140) were found to have potential for areas of Cebu Province where soils are of coralline origin, very susceptible to erosion and marginally suitable for tree planting.

REGION 7, known as Central Visayas, is situated at the geographic centre of the Philippine archipelago at 9°37′ to 11°5′ north latitude and 122°35′ east longitude. It comprises four provinces, Bohol, Cebu, Negros Oriental and Siquijor, on separate islands covering a total land area of 15 000 km^2, constituting about 5% of the total land area of the Philippines. The region is characterised by highlands dominating the interior of the provinces with narrow coastal strips of arable land, the relief characterised by limestone-capped hills and smooth crested mountains.

At present, forest covers only 5% of the Central Visayas land area. This is mainly due to the continuous depletion of natural and man-made forest through timber poaching, shifting cultivation or kaingin-making, forest fires, and pest/disease infestation. Coupled with this is the low survival of outplanted seedlings in reforestation schemes. Available reforestation species are limited—*Swietenia macrophylla, Gmelina arborea, Acacia auriculiformis* and *Eucalyptus camaldulensis*. The lack of suitable species for planting and low survival pose problems for reforesting the vast denuded lands of the region.

One objective of ACIAR PN9208 'Tree establishment technologies in the Philippines' was to evaluate species and provenances of trees and shrubs for forestry, fuelwood and agroforestry uses in the Philippines, comparing species of Australian origin with those available locally. This paper reports on trials undertaken as part of the project. A more extensive report is contained in Baggayan and Baggayan (1995).

Materials and Methods

Seedling production

Seeds acquired from the Australian Tree Seed Centre were raised in the nursery following their recommended pregermination treatments. There were 11 species with 13 seedlots in the trial. The species/seedlots used are given in Table 1.

A ratio of 1:1 local topsoil and river sand was used as potting medium in 7.5 × 15 cm plastic bags. Peat-based *Rhizobium* inoculants provided by the

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Table 1. Species planted in the trial and their origin.

Acacia species	Seedlot number	Locality	Latitude		Longitude		Altitude (m)
			Deg.	Min	Deg.	Min.	
ampliceps	15762	Mile Beach WA	19	46	120	41	5
aulacocarpa	17873	Wipim Oriomo PNG	8	49	142	54	45
aulacocarpa	18228	Kununurra WA	15	38	128	40	37
crassicarpa	17604	Tokwa W Morehead WP PNG	8	42	141	32	30
crassicarpa	17948	Chilli Beach Qld	12	38	143	23	3
colei	14660	Turkey Creek WA	17	4	128	12	400
glaucocarpa	18065	Cadarga Qld	26	7	150	55	350
leptocarpa	18003	Cooper Ck Nabarlek NT	12	19	133	19	60
neurocarpa	18170	33 km S Atlook Ck NT	19	3	134	9	350
oraria	16140	Coen River Qld	13	57	143	11	170
salicina	18543	Rollingstone Qld	24	30	148	36	180
simsii	15654	Mata PNG	8	40	141	45	50
stenophylla	18523	Georgina River Qld	21	37	38	18	0

University of Queensland and specific for the species under test were used. Inoculants were mixed with water, the seedlings dipped in the slurry and the slurry then watered onto the seedlings after pricking out.

Design and layout

The experiment was laid out in a randomised complete block design with three replicates each with seven plants per seedlot, and a spacing of 4 m between rows and 2 m within the row.

Study sites

The experiment was established on two sites on Cebu Island. One is situated at Tabuelan (latitude 10°22′N), a municipality in the northwestern part of Cebu with tree cover almost completely removed. The very thin soils overlay coralline rock (a crowbar was used to break the rock to make the planting holes). The other site is in the upland of Talisay municipality, located at the south central part of the province (latitude 10°9′N) with soils derived from basalt.

Both sites are marginally suitable for reforestation, hilly with slopes of 35–60% at Tabuelan and 30–40% at Talisay; average annual rainfall 1600 mm with about 162 rainy days; mean min. temperature 23.5°C, mean max. 31.6°C, and mean daily 27.5°C.

The Tabuelan site is situated within the timberland which lies northwest of Cebu Province at an altitude ranging from 118 to 170 m above sea level, typical of the shoreline municipalities of Cebu which are mainly hilly to mountainous with limited flatlands along the shores. It belongs to climatic type IV of the corona classification with no pronounced dry season. Although the area is classified as timberland due to the predominant slope category (35–60%), the place is devoid of perennial tree species except for some patches planted to coconut. The area is classified 70–80% grassland and is dominated by *Chromolaena odorata* and *Lantana camara*. The main soil type is Lugo clay which developed from shale parent rock. The soils are undifferentiated, shallow, and are subject to seasonal moisture stress. Exposed sideslopes are quite rocky. Considering the entire area, 15–30% is stony or rocky.

The Talisay site is situated within the timberland of Talisay, Cebu. It is in the south central part of Cebu Province and has moderate to steep gradients with altitudes ranging from 550 to 570 m above sea level. The area belongs to climatic type III of the corona classification (no very pronounced maximum rain period, with a short dry season lasting from 1 to 3 months). The area is mainly cogonal i.e. covered by *Imperata cylindrica*. Some of the species in the area are *Mallotus multiglandulosus, Macaranga tanarius, Pipturus arborescens, Ficus septica, Ficus nota, Pinus kesiya, Tectona grandis* and *Gmelina arborea*. The site is on the top of a hill and exposed to high winds.

Erosion hazard in both sites is severe. Table 2 presents some features of the soils at the two project sites.

Table 2. Soil properties of the Tabuelan and Talisay sites.

Land quality	Tabuelan	Talisay
Altitude (m above sea level)	118–170	550–570
Effective soil depth (cm)	20–40	25–55
Texture	gravelly clay	gravelly clay
Compaction	none	slight
pH	7–8	6–6.85
Organic matter (%) (Walkley/Black)	1.5–7	0.50–3.50
Olsen extractable P (μg/g)	1.5–6	0.40–1.80
Cation exchange capacity (m.e./100 g soil)	30–50	15–28

Site preparation and planting

The area was prepared through clear brushing of grasses and other vegetation. Planting holes 30 × 30 × 30 cm were dug at 2 × 4 m spacings. Fertiliser (60 g di-ammonium phosphate (DAP) per plant) was applied 7 months after planting, then another 100 g per plant 3 months after the first application. The fertiliser was applied 30 cm from the stem in three equidistant holes and covered with 3 cm of soil.

Data collection and analysis

Bi-monthly measures of height and diameter were made over 2 years. Height was taken from the ground to the highest leader shoot of the plant by means of a height stick, while basal diameter was taken just above the ground using a vernier calliper.

Survival was assessed 3 weeks and 1 year after planting. After 4 years height, basal diameter, and diameter at breast height were measured again.

Results

Growth and survival

Growth was assessed in terms of height and diameter. The 2- and 4-year-old mean growth and 1-year survival data of the two project sites are presented in Tables 3, 4 and 5.

Table 3. Growth of *Acacia* species at Tabuelan.

Acacia species	Seedlot number	Two years after planting		Four years after planting		DBH (cm)
		HT mean (m)	BD mean (cm)	HT (m)	BD (cm)	
ampliceps	15762	1.7 ±	2.6 ±	2.1 ±	3.8 ±	1.7 ±
aulacocarpa	17873	—	—	—	—	—
aulacocarpa	18228	—	—	—	—	—
colei	14660	2.5 ± 0.61	3.2 ± 1.72	3.6 ± 1.19	4.3 ± 1.67	2.5 ± 1.48
crassicarpa	17604	1.3 ±	1.5 ±	2.3 ±	2.3 ±	0.8
crassicarpa	17948	1.7 ±	2.5 ±	1.5 ±	3.1 ±	0.7
glaucocarpa	18065	1.6 ±	1.4 ±	3.6 ±	3.0 ±	3.0
leptocarpa	18003	3.3 ± 0.71	3.9 ± 1.2	4.1 ± 1.44	7.1 ± 2.11	3.6 ± 1.61
neurocarpa	18170	3.1 ± 0.53	3.5 ± 1.15	3.8 ± 0.73	4.8 ± 1.56	2.8 ± 0.95
oraria	16140	2.2 ± 0.61	5.0 ± 1.77	4.2 ± 0.9	8.5 ± 3.28	4.1 ± 1.23
salicina	18543	3.0 ± 1.22	2.8 ± 1.22	2.3 ± 0.44	2.5 ± 0.65	1.2 ± 0.58
simsii	15654	1.8 ±	2.2 ±	—	—	—
stenophylla	18523	1.0 ±	1.3 ±	1.2 ±	1.9 ±	0.5

Note:
HT = height ± SE
BD = basal diameter (just above the ground) ± SE
DBH = diameter at breast height (1.3 m above the ground) ± SE

Table 4. Growth of *Acacia* species at Talisay, Cebu.

Acacia species	Seedlot number	Two years after planting		Four years after planting		DBH (cm)
		HT mean (m)	BD mean (cm)	HT (m)	BD mean (cm)	
ampliceps	15762	1.7 ±	2.6 ±	—	—	—
aulacocarpa	17873	—	—	—	—	—
aulacocarpa	18228	0.8 ±	1.4 ±	6.5	16.4	6.7
colei	14660	2.7 ± 1.24	2.9 ± 1.31	3.9	5.8	3.7
crassicarpa	17604	3.7 ± 0.48	6.7 ± 2.05	5.3	12.7	8.1
crassicarpa	17948	3.4 ± 1.27	6.7 ±	5.2	11.4	7.9
neurocarpa	18170	4.2 ± 0.93	6.0	4.4	7.0	4.7
oraris	16140	2.4 ± 0.56	5.3	4.3	9.3	6.3
salicina	18543	1.7 ± 0.65	1.8	3.1	3.6	2.1
stenophylla	18523	1.0 ±	6.5	—	—	—

Note:
HT = height
BD = basal diameter (just above the ground)
DBH = diameter at breast height (1.3 m above the ground)

Table 5. Percentage survival of 1-year-old *Acacia* species in Tabuelan and Talisay project sites.

Acacia species	Seedlot number	Survival (%)	
		Tabuelan	Talisay
ampliceps	15762	42.9	42.9
aulacocarpa	17873	4.8	9.5
aulacocarpa	18228	28.6	38.1
crassicarpa	17604	57.1	100.0
crassicarpa	17948	38.1	100.0
colei	14660	66.7	100.0
glaucocarpa	18065	26.8	—
leptocarpa	18003	81.0	—
neurocarpa	18170	76.2	100.0
oraria	16140	95.2	100.0
salicina	18543	65.2	81.0
simsii	15654	28.6	—
stenophylla	18523	19.1	23.8

Discussion

Survival

Of the 11 species studied, *A. crassicarpa* (17604 and 17948), *A. colei* (14660), *A. neurocarpa* (18170) and *A. oraria* (16140) all had 100% survival at Talisay site. Among those that did not survive well are *A. aulacocarpa* (17873 and 18228) and *A. stenophylla* (18523), and *A. ampliceps* (15762).

Thompson (1994) reported that *A. aulacocarpa* seems adapted to acid (pH 4–6) soils. Since the Talisay site is alkaline, this may have caused the low field survival there.

At Tabuelan best survival was obtained for *A. oraria* (95%), *A. leptocarpa* (81%) and *A. neurocarpa* (76%). Both seedlots of *A. aulacocarpa* failed completely at this site.

In general, *A. aulacocarpa*, *A. glaucocarpa*, *A. simsii* and *A. stenophylla* were not well suited to the conditions in Cebu Province, showing poor field survival.

In a study conducted in Dumarao Capiz by Lustica (1997), *A. crassicarpa* attained a survival of 92% out of six species of *Acacia* tested.

Height and diameter

At Talisay *A. neurocarpa* (18170) grew tallest, 4.2 m mean height 2 years after planting. The two seedlots of *A. crassicarpa* (17604 and 17948) also performed well with 3.7 m and 3.4 m, respectively. Four years after planting, *A. crassicarpa* and *A. neurocarpa* still outperformed the other species in terms of height, basal diameter and diameter at breast height. Although the tallest trees at this site were of *A. aulacocarpa* at 6.5 m, the survival was poor at 38%. *A. salicina* (3.1 m) and *A. colei* (3.9 m) were the two smallest acacias 4 years after planting.

At Tabuelan, the best performing trees were *A. leptocarpa* (3.3 m), *A. neurocarpa* (3.1 m) and *A. salicina* (3.0 m) 2 years after planting. After the fourth year *A. oraria*, *A. leptocarpa*, and *A. neurocarpa* were tallest (3.8–4.2m average height). Diameter at breast height was greatest for *A. leptocarpa*.

A. ampliceps and *A. stenophylla* grew poorly. *A. aulacocarpa* died before the second year.

A. crassicarpa and *A. neurocarpa* had the largest stem diameter at Talisay 2 years after planting. After the fourth year, *A. crassicarpa* had the most promising growth rates both in terms of diameter and height. *A. colei* and *A. salicina* were the smallest trees.

At Tabuelan the largest diameters were developed by *A. oraria*, *A. leptocarpa* and *A. neurocarpa*, while *A. crassicarpa* and *A. stenophylla* grew poorly.

Based on growth and survival data, *A. neurocarpa*, *A. crassicarpa*, *A. leptocarpa* and *A. oraria* were found to have potential for the province. With these potential species, pilot provenance plantations should be established throughout the region to further test their adaptability on a regional basis. This would also help determine the usefulness of these species for social and community forestry and reforestation projects in the region. The acceptance of these species by the upland farmers can be likewise obtained. The plantations could also serve as future seed sources for agroforestry, forestation, and research in the region.

Nursery and plantation technologies for these potential species/seedlots should be developed, using local materials where possible, so that their planting is economically viable and environmentally feasible.

The study shows that there is a strong site × species interaction, but that very rapid growth of acacias, mainly for fuelwood, can be obtained on Cebu Island.

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References

Baggayan, J.L. and Baggayan, R.L. Jr 1995. Tree establishment technologies in the Philippines (Cebu Province, Philippines). An ACIAR PN 9208 Terminal Report, Department of Environment and Natural Resources, Region 7 (Central Visayas), Banilad, Mandaue City, Philippines, 64 p.

Lustica, A.L. 1997. Trial planting of introduced reforestation species in Dumarao, Capiz. In: Development in Agroforestry Research, PCARRD Book Series No. 160, 270 p.

Thompson, L.A.J. 1994. *Acacia aulacocarpa*, *A. cincinnata*, *A. crassicarpa* and *A. waterensis*: an Annotated Bibliography. CSIRO Division of Forestry, Australian Tree Seed Centre, Canberra, Australia.

Selection of *Acacia* Species and Provenances for Planting in Vietnam

Nguyen Hoang Nghia and Le Dinh Kha[1]

In Vietnam, *Acacia* species occupy an especially important place in forest planting strategy to supply raw materials for domestic paper industry, wood for export and environment protection. According to statistical data, in the period from 1986 to 1992 in Vietnam, of about 1 million hectares of plantations established with 20 tree species, the percentage area of *Acacia* plantations reached 7–8% (Science and Technology Department, Ministry of Forestry, 1994).

In the early 1960s, almost 20 *Acacia* species were introduced into Vietnam for trials and planting. However only *A. auriculiformis* showed high adaptability and fast growth, so it becomes an important plantation species, especially in South Vietnam. In the early 1980s *A. mangium* was planted in many trials in some areas and it is now being planted in many places, especially on fertile and moist soil. At present, the most important *Acacia* species are *A. auriculiformis* and *A. mangium*, other promising species are *A. crassicarpa, A. aulacocarpa, A. holosericea* etc. (Nguyen Hoang Nghia and Le Dinh Kha 1993).

Materials and Methods

Plant materials

Five *Acacia* species, a total of 73 provenances/seedlots, have been put in 18 trials established in the period from 1982 to 1995 at eight locations in six provinces over the whole country. They are:

- *A. mangium* 34 provenances.
- *A. auriculiformis* 19 provenances.
- *A. crassicarpa* 11 provenances.
- *A. aulacocarpa* 6 provenances.
- *A. cincinnata* 3 provenances.

Trial sites

The trials were established by the Research Centre for Forest Tree Improvement (RCFTI) and other regional research centres of the Forest Science Institute of Vietnam (FSIV) such as the Forest Science and Production Centre for Northeast Vietnam (Vinh Phuc province), Hoa Thuong Station (Thai Nguyen), Forest Science and Production Centre for Northern Central Vietnam (Quang Tri), Forest Science and Production Centre for Southeast Vietnam (Dong Nai) etc. or in collaboration with projects, local research and production organisations such as La Nga Research Centre.

On the other hand, data were also collected from trials, planting models and plantations in some provinces. Most of the trials have been established on lowlands having typical climate and soil conditions for main planting areas of our country such as the midlands of North, Central and Southeast Vietnam.

Da Chong: Latitude: 21°08′N, longitude: 105°28′E, altitude: 50 m. Mean ann. temperature: 23.1°C, mean ann. rainfall: 2140 mm. Ferallitic soil, poor in nutrients.

Dai Lai: Latitude: 21°22′N, longitude: 105°45′E, altitude: 30–60 m. Mean ann. temperature: 23.1°C, mean ann. rainfall: 1922 mm. Ferallitic soil, very poor in nutrients, strongly eroded and degraded.

Dong Ha: Latitude: 16°44′N, longitude: 107°00′E, altitude: 20–60 m. Mean ann. temperature: 24.7°C, mean ann. rainfall: 2089 mm. Ferallitic soil, very poor in nutrients, strongly eroded and degraded.

Song May: Latitude: 11°15′N, longitude: 107°06′E, altitude: 40–60 m. Mean ann. temperature: 27°C, mean ann. rainfall: 1641 mm. Ferallitic soil, poor in nutrients but deep soil.

La Nga: Latitude: 12°36′N, longitude: 107°10′E, altitude: 50 m. Mean ann. temperature: 25°C, mean ann. rainfall: 2400 mm. Ferallitic soil, poor in nutrients.

Bau Bang: Latitude: 11°15′N, longitude: 106°38′E, altitude: 50 m. Mean ann. temperature: 26.5°C, mean ann. rainfall: 2175 mm. Sandy soil with a clay layer at depth.

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Experiment design, layout and data analysis

Except for four trials, namely Da Chong (1982), Hoa Thuong (1984), Dai Lai (1986) and Dong Ha (1991) that had only one replication, all remaining trials have randomised complete block design with three–four replications and generally 49 trees/plot. Some trials include some provenances of some species, while other trials contain provenances of one species.

At early stage, main growth data collected were:

- Height
- Ground-level diameter and/or breast-height diameter (D1.3 m)
- Survival rate

Later, other data such as number of stems, percentage of trees having more than one stem, flowering, pest and disease situation were also collected. Data have been analysed using Datachain and Genstat programs (Williams and Matheson 1994).

Results

Among the main *Acacia* species introduced into Vietnam for trial and planting, the most promising are *A. auriculiformis, A. mangium* and *A. crassicarpa. A. auriculiformis* of unknown origin has been planted on a large scale. A limited number of provenances of the other two species have been tried in many areas in order to select promising provenances for large-scale planting on suitable sites.

Provenance trial of *A. mangium*, Dai Lai, 1988

A set of nine *A. mangium* provenances, plus one provenance each of *A. auriculiformis*, *A. crassicarpa* and *A. aulacocarpa* have been grown in this trial. The trial site is representative of the barren midland hills of North Vietnam. The Forest Tree Breeding Division and the Forest Science and Production Centre for Northeast Vietnam (Dai Lai, Vinh Phuc) have collaborated to implement the trial. Results are listed in Table 1.

Among five outstanding provenances, three were *A. mangium,* namely Hawkins Creek, Kuranda and Kennedy; the remaining were Shoteel L.A. of *A. crassicarpa* and Oenpelli of *A. auriculiformis*. Most *A. mangium* provenances had 1.4–1.6 stems, only Ingham provenance showed similar poor growth and many-stemmed form to *A. aulacocarpa*. Due to the strongly degraded, poor site without fertiliser, the average growth increment was very low. Data recorded from seedlot 0407 in a demonstration plantation established with fertiliser on the same site at the same time (fertiliser was given to tea plants planted under trees) highlight the especially important role of fertiliser as well as other intensive cultivation measures needed for *A. mangium* plantations on poor sites.

Provenance trial of *A. mangium*, Bau Bang, 1988

A set of the seedlots of 14 provenances of three *Acacia* species has been included in the trial at Bau Bang in 1988. *A. mangium* has 11 provenances, *A. auriculiformis* has two and *A. aulacocarpa* has one provenance. This set is similar to the set of provenances on trial at Dai Lai. The trial site is characterised by sandy soil and a clay layer at a depth that may cause waterlogging in rainy season. The ranking of the provenances at 7 years of age in the field can be seen in Table 2.

Table 1. Height and diameter growth of 3-year-old provenances at Dai Lai.

Acacia species	Seedlot	Provenance	H (m)	D (cm)	Stems/tree	Multistem-trees (%)
crassicarpa	13863	Shoteel L.A.	4.0	3.7	1.6	50.0
mangium	31I	Hawkins Creek	3.8	4.3	1.4	31.3
	27II	Kuranda	3.3	3.9	1.4	34.7
	34I	Kennedy	3.3	3.7	1.5	40.2
auriculiformis	13854	Oenpelli	3.2	3.3	2.0	69.7
mangium	0407	Dendros seed	3.2	3.4	1.5	39.7
	0515	Mossman	2.8	3.2	1.5	37.5
	27I	Kuranda	2.8	2.8	1.5	35.2
	33I	Bronte	2.6	3.2	1.6	47.7
	26	Cardwell	2.4	2.7	1.5	46.7
	30II	Ingham	1.6	2.5	2.5	85.5
	13865	Buckley L.A.	1.3	2.5	2.5	67.3
	0407	Dendros seed	5.0	5.7	1.6	51.1

Table 2. Height and diameter growth of 7-year-old provenances at Bau Bang.

Acacia Species	Seedlot	Provenance	V (m^3)	D (cm)	H (m)	Survival in 1991 (%)
mangium	34I	Kennedy	0.06	11.9	10.2	70
	26	Cardwell	0.05	11.3	10.4	69
	27I	Kuranda	0.04	10.6	9.6	73
	33I	Bronte	0.04	10.4	9.6	71
	31I	Hawkins Creek	0.04	10.4	9.5	62
	0515	Mossman Region	0.03	9.7	9.5	63
	30II	Ingham	0.03	9.7	9.2	49
	13846	Mossman	0.03	9.3	10.0	67
	27II	Kuranda	0.03	9.5	9.5	78
	0407	Dendros seed	0.03	9.8	8.5	63
auriculiformis	13854	Oenpelli	0.03	8.5	10.0	93
mangium	NLG	unknown	0.02	8.7	8.5	60
auriculiformis	local	Dong Nai	0.02	8.2	8.3	52
	13865	Buckley L.A.	0.01	5.3	5.7	10

All of the best ranking provenances in this trial were *A. mangium.* At Dai Lai some provenances such as Kennedy, Kuranda and Hawkins Creek were also outstanding performers, while the others, namely Cardwell and Bronte, showed average performance. It is interesting that the seedlot 27II of the provenance Kuranda, which was outstanding at Dai Lai, grew less than the seedlot 27I in this trial. *A. aulacocarpa* showed both poor growth and low survival, so that it can be considered unsuitable for planting in this area.

Provenance trial of *A. mangium*, La Nga, 1989

A set of eight provenances, including seven similar provenances from the former trials, was tested at La Nga in 1989. The trial was exploited very early so that the data shown in Table 3 were taken from 20-month-old provenances.

The best ranking provenances were seedlot 02 (unknown origin), Hawkins Creek, Bronte, Kennedy and Cardwell. This is similar to the results obtained from the trials at Bau Bang and Dai Lai.

Table 3. Height and diameter growth of 20-month-old *A. mangium* provenances at La Nga.

Seedlot	Provenance	D (cm)	H (m)
2	unknown	7.5	6.4
31I	Hawkins Creek	6.5	5.9
33I	Bronte	6.5	5.6
34I	Kennedy	6.4	5.7
26	Cardwell	6.4	6.1
0515	Mossman region	5.8	5.7
13846	Mossman	5.8	5.1
0407	Dendros seed	5.5	5.1

Provenance trial of *A. mangium*, Song May and Bau Bang, 1989

Six provenances of *A. mangium* were selected by the South-Eastern Forest Research Centre (belonging to FSIV) for testing at Song May and Bau Bang in 1989 under the framework of the Australia-Vietnam Forestry Development Project. Growth data of 4-year-old provenances are presented in Table 4.

It can be clearly seen from the table that the response of the provenances at the two sites is quite different, as demonstrated by their ranking. Cardwell and Tully Region are very promising provenances in both sites, while some provenances show high ranking at one but low ranking at the other site. It can be seen that per increment Song May site produces twice the volume of Bau Bang site, but survival at Song May was low at about 50%. The promising provenances in these two trials are Cardwell, Tully Region and Derideri.

Table 4. Growth of 4-year-old *A. mangium* provenances at Song May and Bau Bang, 1989.

Seedlot	Provenance	V (m^3)	D (cm)	H (m)	Survival (%)
Song May					
0554	Tully Region	0.10	13.2	14.2	53
15700	Cardwell	0.09	13.2	13.9	51
0523	Gap Creek Area	0.09	13.2	13.4	55
16679	Bloomfield	0.08	12.5	13.5	52
0517	Herbert R. Valley	0.08	12.5	13.6	53
0515	Mossman Region	0.08	12.4	13.5	46
Bau Bang					
15700	Cardwell	0.04	10.5	10.1	90
16591	Derideri	0.04	10.5	9.8	59
0554	Tully Region	0.03	9.3	9.4	88
0517	Herbert R. Valley	0.03	9.3	9.3	82
16679	Bloomfield	0.02	8.8	8.3	72
0523	Gap Creek Area	0.02	7.8	7.1	62

Provenance trial of *A. mangium*, Song May and Bau Bang, 1990

Six provenances of *A. mangium* were tested again in 1990 and growth data are listed in Table 5. In contrast to the trials established in 1989, growth of 3-year-old provenances at Bau Bang is markedly higher than growth at Song May. In general, the mean increment reaches a high level and shows the considerable potential of this species for planting at both sites in the southeastern region of Vietnam.

It should be noted that the ranking of the provenances tested at the two sites is quite different, sometimes showing contrary tendencies. At Song May, the Innis Region provenance occupies the first position, while at Bau Bang the same provenance is last. A similar situation has occurred with the provenances Pascoe (Queensland) and Pongaki (PNG). The Cardwell and Derideri provenances in particular are quite stable and they occupy high ranking positions at both sites.

Thus, three provenances selected for both sites are Derideri, Cardwell and Pascoe River, while Innis Region could also be selected at Song May and Pongaki at Bau Bang. It should be noted that Pongaki also proved promising in some other trials.

Table 5. Growth of 3-year-old *A. mangium* provenances at Song May and Bau Bang, 1989.

Seedlot	Provenance	V (m^3)	D (cm)	H (m)	Survival (%)
Song May					
0579	Innis Region	0.04	10.0	9.2	n.a
15700	Cardwell	0.03	9.8	9.0	n.a
16591	Derideri	0.03	9.6	8.9	n.a
16679	Bloomfield	0.03	9.6	8.4	n.a
0535	Pascoe River	0.02	8.6	8.3	n.a
16589	Pongaki E.M.	0.02	8.3	7.5	n.a
Bau Bang					
16591	Derideri	0.05	10.9	11.1	64
0535	Pascoe River	0.05	10.5	11.5	63
16589	Pongaki E.M.	0.04	10.1	11.5	69
15700	Cardwell	0.04	9.9	10.9	78
16679	Bloomfield	0.04	10.3	9.8	59
0579	Innis Region	0.03	8.9	9.1	73

Provenance trial of *A. auriculiformis*, Bau Bang, 1990

The South-Eastern Forest Research Centre of FSIV carried out a trial including six provenances of *A. auriculiformis* at Bau Bang in 1990 and the ranking of the provenances is shown in Table 6. At 3 years of age, four provenances to be selected are Morehead River (from both Australia and Papua New Guinea), Mai Kussa (PNG) and Noogoo Swamp (Northern Territory, Australia).

Table 6. Growth of 3-year-old *A. auriculiformis* provenances at Song May and Bau Bang, 1989.

Seedlot	Provenance	V (m^3)	D (cm)	H (m)	Survival (%)
16484	Morehead	0.03	8.5	10.1	73
16683	Morehead (PNG)	0.03	8.8	9.0	56
16610	Mai Kussa (PNG)	0.02	8.0	8.4	62
16147	Noogoo Swamp	0.02	7.5	9.2	70
16152	E. Alligator	0.02	7.1	8.3	86
15951	Sai Thong (Thai)	0.01	6.6	8.6	55

Provenance trial of *A. auriculiformis*, Dai Lai, 1991

The trial including 12 provenances of *A. auriculiformis* has been established at Dai Lai by the North-Eastern Forest Science and Production Centre of the FSIV. Data collected from 4.5-year-old provenances can be seen in Table 7. In the very harsh conditions of midland northern Vietnam such as Dai Lai, growth rate of *A. auriculiformis* is not high. This is also similar to the results of the other trials undertaken previously in this area. The best provenances are Coen River, Kings Plains, Mibini, Morehead River (16484, Australia) and Goomadeer River.

Table 7. Growth of 4.5-year-old *A. auriculiformis* provenances at Dai Lai 1991.

Seedlot	Provenance	D (cm)	H (m)
16142	Coen River	7.4	6.8
16485	Kings Plains	7.0	6.8
16106	Mibini	6.9	6.6
16484	Morehead River	6.9	7.0
16154	Goomadeer	6.8	6.9
16684	Bensbach	6.4	5.7
16148	Manton River	6.3	6.6
16152	E. Alligator	6.1	6.0
16151	Mary River	5.9	6.0
16163	Elizabeth River	5.5	5.7
16107	Old Tonda	5.2	5.0
16158	Gerowie Creek	5.0	5.0

Integrated provenance trial, Da Chong, 1990

A set of provenances including 39 provenances of five main *Acacia* species has been tested at Da Chong (Table 8). After 54 months in the field trial, the ranking by average growth of the species tested can be summarised as follows:

- *A. crassicarpa*: D = 10.7 cm H = 8.0 m
- *A. auriculiformis*: D = 10.2 cm H = 8.6 m
- *A. mangium*: D = 10 cm H = 8.1 m
- *A. cincinnata*: D = 7.3 cm H = 6.1 m
- *A. aulacocarpa*: D = 7.2cm H = 6.0 m

It can be concluded that among five species tested, three species, namely *A. auriculiformis*, *A. crassicarpa* and *A. mangium,* are very promising at Da Chong site.

Regarding selection for superior growth, promising provenances of *A. auriculiformis* are Coen River, Manton River, Mibini, Elizabeth and Kings Plains; of *A. mangium*, Pongaki, Gubam, Iron Range and Ingham; of *A. crassicarpa,* Dimisisi, Gubam, Bimadebun, Mata and Derideri; and of *A. aulacocarpa,* Keru to Mata provenance.

Integrated provenance trial, Dong Ha, 1991

The trial containing 34 provenances of five main *Acacia* species has been established by the Forest Science and Production Research Centre of FSIV at Dong Ha (Table 9). Due to lack of seedlings, the trial had only one replication. After 52 months in the field trial, the ranking by average height and diameter growth of the species tested can be summarised as follows:

- *A. mangium*: D = 8.3 cm H = 6.7 m
- *A. crassicarpa*: D = 8.0 cm H = 7.8 m
- *A. cincinnata*: D = 5.9 cm H = 6.7 m
- *A. auriculiformis*: D = 5.5 cm H = 5.9 m
- *A. aulacocarpa*: D = 5.5 cm H = 5.4 m

The ranking of the provenances within species tested is quite similar to the ranking at Da Chong. Promising provenances of *A. auriculiformis* are Coen River, Elizabeth River, Old Tonda, Mibini and Manton River; of *A. mangium* Pongaki, Iron Range and Gubam; and of *A. crassicarpa* Derideri, Oriomo, Gubam and Mata.

Integrated provenance trial, La Nga, 1991

A set of provenances, including 37 provenances of four main *Acacia* species, was tested at La Nga in 1991 (Table 10). After 16 months in the field trial, the ranking of the species tested can be shown as follows:

- *A. auriculiformis*: D = 5.1 cm H = 4.2 m
- *A. crassicarpa*: D = 5.0 cm H = 4.4 m
- *A. mangium*: D = 4.2 cm H = 3.6 m
- *A. aulacocarpa*: D = 3.0 cm H = 2.8 m

Generally, the ranking of the provenances within species in this trial is similar to that obtained in the two above-mentioned trials. The outstanding provenances of *A. auriculiformis* are Coen River, Morehead River, Goomadeer River and Old Tonda Village; of *A. mangium* Gubam, Iron Range and Pongaki; of *A. crassicarpa* Dimisisi, Oriomo and Derideri; and of *A. aulacocarpa,* Keru to Mata.

Conclusions

Among the five main *Acacia* species tested in the whole country, three species—*A. auriculiformis, A. mangium* and *A. crassicarpa*—have performed best. For *A. auriculformis*, the most promising provenances are Coen River, Manton River, Old Tonda Village, Morehead River (Qld and PNG), Mibini and Elizabeth River. The provenance Kings Plains is outstanding at Da Chong, however it has grown poorly in other trials.

The best provenances of *A. mangium* are Cardwell, Kuranda and Kennedy in the early trials and Pongaki, Gubam, Iron Range in later trials. Derideri and Pascoe are also promising, however they need more trials in the future.

The best provenances of *A. crassicarpa* are Dimisisi, Gubam, Oriomo, Derideri and Mata. For *A. aulacocarpa*, the best provenance is Keru to Mata.

Table 8. Growth of 54-month-old provenances tested at Da Chong, 1990.

Acacia species	Seedlot	Provenance	D (cm)	H (m)
auriculiformis	16148	Manton River	11.7	9.6
	16142	Coen River	11.3	9.9
	16106	Mibini	11.1	8.9
	16163	Elizabeth River	10.7	8.6
	16485	Kings Plains	10.5	9.2
	16484	Morehead R.(Qld)	10.3	8.1
	16107	Old Tonda Village	10.1	8.8
	16152	E.Alligator River	10.0	8.6
	16158	Gerowie Creek	9.7	8.4
	16154	Goomadeer River	9.6	8.5
	16684	Bensbach	9.3	7.7
	16683	Morehead R.(PNG)	9.3	7.6
	16151	Mary River	8.5	8.1
mangium	16589	Pongaki E.M.	11.8	9.1
	16681	Ingham	11.1	8.4
	16586	Gubam	10.5	8.3
	15677	Iron Range	10.2	8.7
	15367	Mossman	10.1	8.0
	15678	Helenvale	10.1	8.4
	15694	Townsville	9.6	7.2
	16679	Bloomfield-Ayton	9.3	7.9
	13621	Piru, Ceram	6.8	6.5
crassicarpa	16602	Dimisisi	12.0	8.6
	16597	Gubam	12.0	9.3
	16598	Bimadebun	11.4	8.4
	13681	Mata	11.1	7.4
	16605	Derideri	10.7	8.5
	13682	Oriomo	10.4	8.0
	13680	Wemenever	10.3	7.5
	16599	Pongaki	10.0	7.6
	16128	Jardine River	8.6	6.3
aulacocarpa	16113	Keru to Mata	10.1	8.6
	16112	Morehead	39.2	7.5
	13865	Buckley L.A.	5.8	5.0
	13866	Garioch	5.5	4.5
	16180	Maningrida	5.3	4.4
cincinnata	15961	Julatten	8.0	6.6
	13864	Shoteel L.A.	8.0	6.8
	15365	Mossman	6.0	5.0

Table 9. Growth of 52-month-old provenances tested at Dong Ha, 1991.

Acacia species	Seedlot	Provenance	D (cm)	H (m)
auriculiformis	16107	Old Tonda Village	6.6	5.6
	16142	Coen River	6.4	6.3
	16163	Elizabeth River	6.4	7.0
	16106	Mibini	6.3	6.0
	16148	Manton River	6.0	6.8
	16154	Goomadeer River	5.9	5.8
	16484	Morehead R.(Qld)	5.9	5.5
	16152	E.Alligator	5.7	5.8
	16683	Morehead R.(PNG)	5.6	5.4
	16158	Gerowie Creek	5.2	6.1
	local	Dong Nai	5.0	5.4
	16485	Kings Plains	4.5	4.8
	16151	Mary River	2.3	5.8
mangium	16589	Pongaki	10.2	8.3
	15677	Iron Range	10.0	7.2
	16586	Gubam	9.5	7.5
	15367	Mossman	8.4	6.1
	16681	Ingham	7.0	6.1
	15694	Townsville	6.8	5.6
	16679	Bloomfield-Ayton	6.3	5.4
crassicarpa	16605	Derideri	9.6	9.6
	13682	Oriomo	9.1	8.6
	16597	Gubam	8.9	8.6
	13681	Mata	8.4	8.0
	13680	Wemenever	7.5	7.9
	16602	Dimisisi	7.2	7.1
	16598	Pongaki	7.1	6.8
	16128	Bimadebun	5.9	5.8
aulacocarpa	16112	Morehead	7.5	7.2
	13866	Garioch	5.8	5.8
	13865	Buckley L.A.	4.7	4.8
	16180	Maningrida	4.1	4.3
cincinnata	15961	Julatten	6.1	6.4
	15365	Mossman	5.7	7.0

Table 10. Growth of 16-month-old provenances tested at La Nga, 1991.

Acacia species	Seedlot	Provenance	D (cm)	H (m)
auriculiformis	16683	Morehead R.(PNG)	5.6	4.2
	16484	Morehead R.(Qld)	5.4	4.5
	16107	Old Tonda Village	5.4	4.4
	16148	Manton River	5.4	4.1
	16684	Bensbach	5.4	4.0
	16154	Goomadeer River	5.3	4.4
	16106	Mibini	5.3	4.2
	16142	Coen River	5.3	4.5
	16163	Elizabeth River	5.0	4.3
	16152	E.Alligator	5.0	4.0
	16158	Gerowie Creek	5.0	4.0
	16485	Kings Plains	4.8	4.1
	local	Dong Nai	4.4	4.1
	16151	Mary River	4.2	3.4
mangium	hybrid	Hybrid seed	5.0	4.0
	16586	Gubam	4.8	4.1
	15694	Townsville	4.7	3.7
	15677	Iron Range	4.7	4.1
	16589	Pongaki	4.4	4.0
	15678	Helenvale	4.2	3.5
	15367	Mossman	4.1	3.5
	16681	Ingham	3.8	3.3
	local	Hoa Thuong	3.8	3.4
	16679	Bloomfield-Ayton	3.6	3.2
	13621	Piru, Ceram	3.2	3.0
crassicarpa	16602	Dimisisi	5.6	5.0
	13682	Oriomo	5.3	4.7
	16128	Jardine River	5.0	4.3
	16605	Derideri	5.0	4.5
	16597	Gubam	5.0	4.6
	13681	Mata	4.8	4.3
	16599	Pongaki	4.5	3.6
aulacocarpa	16113	Keru to Mata	4.3	4.2
	16180	Maningrida	3.3	3.0
	13865	Buckley L.A.	3.0	2.4
	16112	Morehead	2.5	2.5
	13866	Garioch	2.0	2.1

References

Nguyen Hoang Nghia and Le Dinh Kha, 1993. Species and Provenance Trial of *Acacia* Species. Scientific Report, Forest Science Institute of Vietnam, Hanoi.

Nguyen Hoang Nghia and Le Dinh Kha, 1996. Acacia species and provenance selection for large-scale planting in Vietnam. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of a QFRI-IUFRO conference, Caloundra, Queensland, Australia, 443–448.

Science and Technology Department, Ministry of Forestry, 1994. Planting Techniques of some Tree Species. Agriculture Publishing House, Hanoi.

Williams, E.R. and Matheson, A.C. 1994. Experimental Design and Analysis for Use in Tree Improvement. CSIRO and ACIAR, Melbourne, 174 p.

Domestication of Exotic *Acacia* Species in Bukidnon Province, Philippines.

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Abstract

In the Philippines large areas of degraded uplands, now dominated by cogon grass (*Imperata cylindrica*), are in need of reforestation. On the island of Mindanao, Bukidnon Forests Incorporated (BFI) has become a model project in the domestication of exotic tropical acacias in the effort to restore productivity to these degraded uplands. BFI has been planting *Acacia mangium* as one of its main species and has been conducting trials to evaluate the performance of this and other acacia species since its founding in 1988. Results from one of BFI's species evaluation trials and a species-provenance trial of promising exotic acacias are summarised. Results of a small *A. mangium* provenance trial in Bukidnon are also presented. *A. mangium* has generally shown superior growth compared to *A. auriculiformis*, *A. aulacocarpa* and *A. crassicarpa*. Within *A. mangium*, PNG provenances generally showed faster growth while seedlots collected from two local seed stands were consistently inferior for growth in the trials. However, *A. aulacocarpa* is being considered for large scale deployment due to superior stem form relative to *A. mangium* and other acacias.

THE Philippine archipelago has more than 7000 islands lying between 5°N and 21°N with a total land area of 300 000 km^2 (30 million ha). The northern to central region of the archipelago, including the country's largest island of Luzon (105 000 km^2), can experience 15 or more typhoons per year (Munro 1988).

Rapid population growth and economic development in recent times have placed pressure on the country's forest resources. From 1950 to 1995 the country's actual forest cover declined by approximately 50% and recent surveys indicate that the country now has less than 6 million hectares of natural forest cover (Umali-Garcia 1995). Of the country's 15 million ha of legally classified forest lands, it has been estimated that approximately 50% are now mostly barren and dominated by grasses — primarily cogon (*Imperata cylindrica*) — or scrub vegetation. As a result the proportion of the land area of the Philippines covered by cogon grasslands is one of the highest of all Asian countries (Garrity et al. 1997). This situation creates an urgent need for reforestation, to arrest further environmental degradation and to meet the country's increasing wood demands (de la Cruz 1993).

In recent years, initiatives to develop industrial tree plantations in the Philippines have focused on the southern island of Mindanao (95 000 km^2). This island lies outside the typhoon belt and has an evenly distributed rainfall of more than 2000 mm average annually. Also, it contains large areas which were once forested but are now barren and unproductive grasslands that are potentially available for timber plantations. Consequently, it is an ideal location for introduction and domestication for a wide range of fast growing exotic hardwoods and for industrial timber plantation development (Caguioa 1956; Williamson 1993).

A. spectabilis is thought to be the only Australian acacia introduced to Mindanao on any significant scale before 1956 (Caguioa 1956). It was only more recently in the 1980s that *A. mangium, A. aulacocarpa* and some of the other Australian tropical rainforest acacias were introduced there (Umali-Garcia 1995). However, despite large scale establishment of

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A. mangium in Mindanao since then, comprehensive provenance test results from the area for this or other exotic acacia species have not been reported (Umali-Garcia 1995; Wilcox 1996).

Some of the oldest *A. mangium* plantations in Mindanao are those of Provident Tree Farms Incorporated (PTFI) located at Zillavia, Talacogan, in the province of Agusan del Sur (Wilcox 1996). Approximately 4000 ha of the species have been established there primarily on lowland cut-over forest sites. *A. mangium* is well adapted to Talacogon with 10-year-old stands providing increments of up to 32 m3/ha/ year (Wilcox 1996). In support of their plantation program, PTFI allocated two blocks of their 1985 plantations of *A. mangium* for seed production; one of which is believed to be derived from an Olive River provenance in Queensland and the other from an Oriomo-Daru, Papua New Guinea provenance. PTFI's other major species include *Paraserianthes falcataria, Eucalyptus deglupta* and *Gmelina arborea.*

As a pioneering project of the Philippine Department of Environment and Natural Resources and the government of New Zealand, Bukidnon Forests Incorporated (BFI) was started in 1988. BFI covers 39 000 ha of government-managed land in the province of Bukidnon in the central northern region of Mindanao (Figure 1). Project sites typify a large proportion of the lands available in the Philippines for afforestation: degraded steep land with shallow soils that have long been dominated by tropical grasses (mainly cogon). Many such sites have also had a long history of frequent burning.

To the end of 1996, BFI had successfully established 6000 ha of their 21 000 ha of plantable land. The major species now being deployed are *A. mangium, E. urophylla, E. deglupta* and *Pinus caribaea.* On account of the achievements to date, the project is seen to be fulfilling one of its prime objectives — that of serving as a model project to demonstrate appropriate species use and practical plantation silviculture in the Philippines (Wilcox 1996).

In developing efficient technologies for re-establishing forests on grass-dominated upland areas a wide range of species, species/provenance, provenance/family and silvicultural trials have been conducted by BFI. Trials have included a large range of exotic acacias along with many other hardwood and pine species, as well as some species native to the Philippines. This research has brought the BFI into the forefront of exotic acacia domestication and silvicultural research in the Philippines, even though most results of the trial work remain unpublished to date. This paper presents some extracts from the results of three key trials involving *Acacia* species being conducted by BFI.

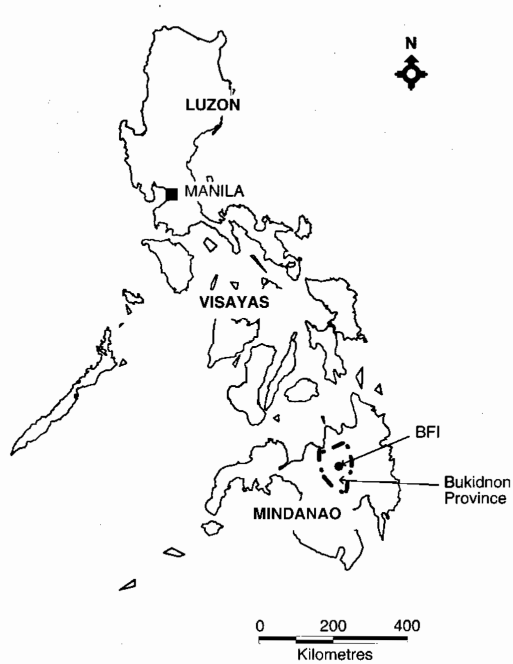

Figure 1. Location of Bukidnon Forests Incorporated in the Philippines.

Trials

Annual rainfall in Bukidnon is approximately 2800 mm with no distinct wet or dry season (all 12 months >100 mm rainfall). At Malaybalay, the provincial capital, the mean annual temperature is 23.5°C with the mean maximum of the hottest month being 30.2°C and the mean minimum of the coldest month being 17.5°C (Williamson 1993). Soils in BFI's plantation area are thin, predominantly ultisols and undifferentiated hill soils with heavier textures, reflecting their volcanic origin. Most of BFI's soils have been found deficient in boron. All trial sites are above 500 m asl. Details of the individual trials are as follows.

Species evaluation trial

This trial was established in August 1993 as a component of the project 'Tree Establishment Technology in the Philippines' (ACIAR FST/92/08). The site is situated approximately 625 m asl, in the Malaybalay section of BFI's estate. Soil is a mottled eutrophic brown chromosol (P. Dart pers. comm.) with pH from 4.5 to 6.5. The site was dominated by cogon grass *(I. cylindrica)* prior to trial establishment. The trial comprises 58 different species-provenances in total, 20 of which are acacias (Table 1). The trial was established in seven tree row plots, at 3 × 3 m spacing and with six replicates (Nicholls and Laureto 1995).

Table 1. Seed source details with their average growth and survival to age 30 months of acacias and other selected seedlots in the species evaluation trial at Malaybalay (Source of data: Nicholls and Laureto 1995).

Seedlot[a]	Species	Provenance details				Means and (rankings)[b]		
		Locality[c]	Lat. (° ′ S)	Long. (° ′ E)	Alt. (m asl)	DBH (cm)	Height (cm)	Mortality (%)
	Acacia							
17551	*aulacocarpa*	Bensbach-Balamuk WP, PNG	8 53	141 17	25	9.3 (16)	712 (18)	<10
17966	*auriculiformis*	Boggy Creek, Qld	15 52	144 53	240	9.2 (17)	773 (11)	<10
18601	*auriculiformis*	Seed Orchard (PNG source)	11 34	130 34	20	9.6 (14)	716 (17)	<10
14660	*colei*	Turkey Creek, WA	17 04	128 12	400	4.7 (45)	443 (42)	26
17948	*crassicarpa*	Chili Beach, Qld	12 38	143 23	3	6.5 (31)	602 (26)	14
17604	*crassicarpa*	Tokwa W. Morehead, WP, PNG	8 42	141 32	30	8.0 (21)	585 (29)	11
18092	*glaucocarpa*	Baralaba, Qld	23 30	140 49	200	7.0 (27)	897 (5)	33
18389	*holosericia*	WSW Kennedy Creek, NT	15 55	129 47	25	6.3 (33)	569 (31)	<10
17145	*irrorata*	Mt Mee, Qld	27 07	152 45	250	6.0 (40)	610 (24)	<10
18003	*leptocarpa*	Cooper Creek — Narbarlek, NT	12 19	133 19	60	6.7 (29)	573 (30)	<10
18079	*leptocarpa*	Oriomo, PNG	8 55	143 11	30	7.8 (24)	815 (8)	<10
14587	*longispicata*	Emerald, Qld	23 28	148 04	200	6.9 (28)	718 (16)	35
PTFI	*mangium*	Talacogan Seed Stand (ex Olive River, Qld)	—	—	—	9.1 (18)	664 (19)	<10
17550	*mangium*	Bensbach, WP, PNG	8 53	141 17	25	9.7 (12)	752 (14)	38
14735	*neriifolia*	N. of Toowoomba, QLD	27 24	152 00	500	4.2 (53)	425 (43)	76
18170	*neurocarpa*	S. of Attock Creek, NT	19 03	134 09	350	5.3 (43)	588 (28)	24
18543	*salicina*	Rollingstone, QLD	24 30	148 36	180	4.2 (52)	444 (40)	79
15654	*simsii*	Mata, PNG	8 40	138 18	100	4.3 (50)	501 (35)	75
18523	*stenophylla*	Georgina River, Qld	21 37	138 18	100	3.5 (55)	255 (56)	88
	Eucalyptus							
18604	*camaldulensis*	Petford — Emu Walsh River, Qld	17 20	144 57	580	12.3 (2)	1096 (1)	<10
18603	*tereticornis*	Luara River-Kennedy Creek, Qld	15 32	144 39	100	12.1 (3)	1074 (2)	<10
17859	*pellita*	NW of Kuranda, Qld	16 39	145 33	440	11.9 (4)	905 (4)	<10
14531	*urophylla*	Mt. Egon, Flores, Ind	8 38	122 27	515	10.9 (5)	766 (12)	<10
16927	*tereticornis*	50 km SSE of Moura, Qld	25 00	150 00	150	10.6 (6)	978 (3)	<10
15615	*deglupta*	Geshes Clonal SO, PNG	—	—	—	9.8 (11)	752 (15)	<10
CMU	*Gmelina arborea*	Philippines	—	—	—	10.3 (8)	543 (33)	<10
BFI	*Lagerstroemia speciosa*	Philippines	—	—	—	3.6 (54)	306 (52)	58
CMU	*Pterocarpus vidalianus*[d]	Philippines	—	—	—	3.1 (56)	323 (49)	57
BFI	*Shorea contorta*	Philippines	—	—	—	2.8 (57)	270 (54)	98

[a] Seedlots represented by 5 digit codes were supplied by the Australian Tree Seed Centre; seedlots represented by PTFI, CMU or BFI were supplied by Provident Tree Farms Incorporated, Central Mindanao University or Bukidnon Forests Incorporated respectively.
[b] Ranks are based on performance of all seedlots (58 in total) represented in the trial.
[c] WP: Western Province; PNG: Papua New Guinea; Ind: Indonesia; Qld: Queensland; WA: Western Australia; NT: Northern Territory.
[d] This species is also known under the synonym of *Pterocarpus indicus* var. *echinatus*.

Acacia species/provenance trial

This was established in August 1993 on two sites. The trial at the first site is on stony sandy clay soil, 650 m asl in the Malaybalay section of BFI's estate. It included 17 provenance lots of four *Acacia* species (*A. mangium*, *A. auriculiformis*, *A. aulacocarpa* and *A. crassicarpa* — Table 2) which were established in nine tree row plots, at 3 × 3 m spacing and with four replicates. At the second site, at 750 m asl on the highest plateau of the Abyawan section, the trial included 14 seedlots of the four species in nine tree row plots, at 3 × 3 m spacing and with eight replicates. Both sites were dominated by cogon grass prior to trial establishment.

Acacia mangium provenance trial

This was established in August 1991. This trial was established on an ex-agricultural site, unrepresentative of BFI's plantation estate. It lies 10 km west of the Malaybalay section of the project. Prior to

Table 2. Average growth by provenance in an acacia species-provenance trial at 2 sites in Bukidnon.

ATSC[a] seedlot #	*Acacia* species	Provenance locality[b]	Means and (rankings) at Malaybalay at 24 months		Means and (rankings) at Abyawan at 8 months	
			DBH (cm)	Height (cm)	DBH (cm)	Height (cm)
17551	*aulacocarpa*	Bensbach — Balamuk, WP, PNG	8.5 (11)	690 (15)	4.4 (7)	189 (12)
17873		Wipim — Oriomo, PNG	8.4 (12)	677 (16)	4.3 (8)	185 (13)
16644	*auriculiformis*	Holroyd R., Cape York, Qld	7.6 (16)	755 (9)	—	—
17553		Bensbach, WP, PNG	8.3 (14)	751 (10)	—	—
17966		Boggy Creek, Qld	7.6 (16)	655 (17)	3.1 (12)	211 (7)
18247		Wenlock River, Qld	7.8 (15)	739 (11)	3.0 (14)	196 (11)
18059		Pohaturi River, PNG	8.8 (9)	698 (14)	3.3 (11)	184 (14)
18601		Seed Orchard (PNG source)	8.6 (10)	718 (12)	3.1 (12)	228 (2)
17561	*crassicarpa*	Limal-Malam, PNG	8.4 (12)	713 (13)	4.3 (8)	227 (3)
17869		Morehead, PNG	9.0 (8)	772 (8)	4.2 (10)	229 (1)
16971	*mangium*	Wipim District, WP, PNG	10.4 (1)	793 (5)	5.1 (1)	221 (5)
16938		Kini, WP, PNG	10.0 (5)	837 (1)	5.1 (1)	212 (6)
16997		Boite NE Morehead, WP, PNG	10.4 (1)	789 (6)	4.5 (5)	210 (8)
17550		Bensbach, WP, PNG	10.4 (1)	813 (2)	4.7 (3)	222 (4)
17702		Pascoe River, Qld	9.6 (7)	785 (7)	4.7 (3)	209 (9)
17945		Olive River, Qld	9.8 (6)	806 (4)	4.5 (5)	220 (10)
18265		Claudie River, Qld	10.1 (4)	812 (3)	—	—

[a] ATSC: Australian Tree Seed Centre.
[b] WP: Western Province; PNG: Papua New Guinea; Qld: Queensland.

selection for this trial the site had been used for intensive cash cropping (mainly corn), but subsequently became colonised by scrub vegetation (*Chromolaena* community type) prior to establishment. This trial was established with six *A. mangium* provenances (Table 3) in 27 replicates with the objective of later conversion into a seed production area. Each replicate contained 12 trees per seedlot in non-contiguous plots of single trees with a spacing of 5 × 2 m.

Table 3. Height growth of six *Acacia mangium* provenances after one year at Malaybalay, Mindanao.

Seedlot[a]	Provenance locality[b]	Mean height and (rank) at 12 months (cm)
16997	Boite NE Morehead, WP, PNG	122 (2)
17550	Bensbach, WP, PNG	113 (3)
17607	Morehead District, PNG	100 (4)
17701	Claudie River & Iron Range, Qld	124 (1)
PTFI	Talacogan Seed Stand (ex. Oriomo River, PNG)	93 (6)
PTFI	Talacogan Seed Stand (ex. Olive River, Qld)	98 (5)

[a] Seedlots represented by 5-digit codes were supplied by the Australian Tree Seed Centre; seedlots represented by PTFI were supplied by Provident Tree Farms Incorporated.
[b] WP: Western Province; PNG: Papua New Guinea; Qld: Queensland.

All trials received intensive site preparation and weed control for the first two years. The species evaluation trial and the acacia species-provenance trial also received three or more fertiliser applications (diammonium phosphate) during the first two years.

Results

Species evaluation trial

Of the 15 acacia species represented in the species evaluation trial, *A. mangium* (Bensbach, WP, PNG) and *A. auriculiformis* (Seed Orchard ex PNG source) had the greatest diameter growth in 30 months (ranked 1st and 2nd of the acacias and 12th and 14th overall respectively — Table 1). *A. glaucocarpa* (Baralaba, Qld) was the tallest of all the acacias at the same age (ranked 5th overall) but had smaller average diameter (ranked 9th of the acacias and 27th overall) than the *A. mangium*, *A. aulacocarpa* and *A. auriculiformis* provenances. Second and third tallest of the acacias were *A. leptocarpa* (Oriomo, PNG; 8th overall) and *A. auriculiformis* (Boggy Creek, Qld; 11th overall).

On the basis of both diameter and height one of the *A. mangium* provenances (Bensbach, WP, PNG; 12th for diameter and 14th for height overall) showed superiority to all the other acacia material in the trial. This was followed by a small group of similar performing provenances which included *A. aulacocarpa* (Bensbach-Balamuk WP, PNG), *A. auriculiformis* (Boggy Creek, Qld, and Seed Orchard (PNG Source)), and *A. mangium* (Talacogan Seed Stand (ex Olive River, Qld)). Compared to these, even the best of the two *A. crassicarpa* provenances (Tokwa W. Morehead, WP, PNG), which was ranked 21st for diameter and 29th for height overall, proved relatively inferior.

A. stenophylla (Georgina River, Qld) and *A. neriifolia* (N. of Towoomba, Qld) ranked low at 55th and 53rd overall for diameter, and at 56th and 43rd overall for height respectively. The performances of *A. simsii* (Mata, PNG), *A. salicina* (Rollingstone, Qld) and *A. colei* (Turkey Creek, WA) were also relatively poor. In addition, these species with the exception of *A. colei* suffered very high mortalities (>75%) up to 30 months.

Of all 58 species/provenances represented in the trial the largest overall at 30 months was *Eucalyptus camaldulensis* from Petford, Emu Walsh River, Qld ranking 2nd for diameter and 1st for height overall. Similarly, most of the other top ranking species/provenances were also eucalypts including *E. tereticornis* (Laura River-Kennedy Creek, Qld, and 50 km SSE of Moura, Qld), *E. pellita* (NW of Kuranda, Qld) and *E. urophylla* (Mt Egon, Flores Ind). The exotic source (from Geshes Orchard, PNG) of the eucalypt *E. deglupta*, a species native to the Philippines, ranked 11th for diameter and 15th for height overall, making it comparable in size at 30 months to the best acacias.

The growth of three other native species included in the trial, namely *Lagerstroemia speciosa*, *Pterocarpus vidalianus* and *Shorea contorta*, was inferior (all ranked 54th or lower for diameter and 49th or lower for height overall) relative to the better acacias. Also, these three showed unacceptably poor survival (mortality >55%) under the trial conditions.

Acacia species/provenance trial

Of the four acacia species represented, *A. mangium* generally showed the best growth on both trial sites (Table 2). At the Malaybalay trial site, Bensbach, WP, PNG ranked 1st for diameter and 2nd for height overall at age 24 months. At the Abyawan trial site the provenance from Wipim District, WP, PNG ranked 1st for diameter and 5th for height at age 8 months.

Some provenances of *A. auriculifomis* and *A. crassicarpa* also performed well for growth. *A. crassicarpa* from the Morehead, PNG, provenance ranked 8th for both diameter and height at Malaybalay, and was outgrown only by provenances of *A. mangium*. It also showed good height growth to 8 months at the Abyawan trial site, ranking first overall, although its diameter at that early age was relatively small (10th for diameter).

The two *A. aulacocarpa* provenances were relatively slow growers early on at both sites (ranked 11th and 12th for diameter at Malaybalay and 7th and 8th for diameter at Abayan). However, since the early assessments reported, subjective observations at both sites at approximately 34 months indicate that their ranking for growth has improved and both provenances now appear equal or superior in size to most *A. auriculiformis* and *A. crassicarpa* provenances (Wilcox 1996). Although results on form traits are not presented, both provenances of this species showed superior stem form (straight trunks and fine branches) to all the other material in the trial (Wilcox 1996).

The poorest growth at both sites was by some of the *A. auriculiformis* provenances. At Malaybalay, the Boggy Creek, Qld provenance of this species was the poorest overall (16th for diameter and 17th for height) whilst at Abyawan the Wenlock River, Qld provenance had the smallest diameter and the Pohaturi River, PNG was shortest.

Acacia mangium provenance trial

The growth of *A. mangium* in this trial was relatively poor compared to the other trials (Table 3). The average height across all provenances in this trial at 12 months was 108 cm which was only approximately half that of the average height for the same species at 8 months at the Abyawan site of the species-provenance trial.

However, distinct differences between provenances in this trial were still apparent. Those from Claudie River, Iron Range, Qld, and from Boite NE Morehead, PNG, showed markedly better height growth than the other four provenances (Table 3). In contrast, seedlots from the two seed stands at Talacogan (Agusan del Sur, Mindanao) were outperformed by all provenances sourced from natural stands. The poorest provenance (Talacogan Seed Stand ex. Oriomo R., PNG) was less than 75% of the height of the tallest seedlot (Claudie River and Iron Range, Qld).

Discussion and Conclusions

The trials have shown that *A. mangium*, *A. crassicarpa*, *A. aulacocarpa* and *A. auriculiformis* are well adapted to the cogon dominated grass uplands of Bukidnon. These results will also have relevance to other industrial timber plantation initiatives on cogon-dominated grasslands in the region of Bukidnon and further afield in other parts of the Philippines.

Some of the best early-age tree growth in both plantations and trials at BFI has been produced by eucalypt species. Despite this, the project maintains a substantial acacia plantation program (i.e. up to 400 ha of *A. mangium* per year) as it has a policy of planting not just one or two but a range of fast-growing species. Also BFI recognise that good early performance of some eucalypts on cogon grasslands is no guarantee of rotation age success. Rapid decline of eucalypt plantations that have shown early promise has been observed in a number of situations elsewhere (Eldridge et al. 1994; Turvey 1995).

Even with the intensive silvicultural care applied to the species evaluation trial, the three species *P. vidalianus*, *S. contorta* and *L. speciosa*, performed comparatively poorly. Consequently, their potential for success in plantations on cogon-dominated grass uplands, given the intensive silvicultural management provided in the trial, is very limited in comparison to many of the exotic acacias and other species tested.

A. mangium generally proved superior for growth relative to the other acacia species tested. However, the trials do reinforce the importance of careful provenance testing and selection as an integral part of a major afforestation initiative. The better provenances of this species on BFI's sites have generally proved to be those from PNG, as has been found in many other countries (Otsamo et al. 1996; Harwood and Williams 1992).

The relatively poor performance of *A. mangium* seedlots from the Talacogan seed stands in the Bukidnon trials reinforces the value of testing a wide range of introduced material. Reasons for their relatively poor performance are not readily apparent. The original provenances from which seed stands originated (i.e. from Olive River, Qld and Oriomo-Daru, PNG) have generally performed well in exotic plantations elsewhere (e.g. see Harwood and Williams 1992). It is only possible to infer that the environment in Bukidnon is different from the adapted environment of the seed stands in Talacogon. The lack of data to compare the performance of materials from Talacogon in other trials limits further interpretation.

Despite the excellent growth shown by *A. glaucocarpa* to 30 months of age in the species evaluation trial, the species is unlikely to find application in plantation programs such as BFI's. This species is a bipinnate acacia that only grows to be a small (6–10 m) tree (Turnbull 1986). Whilst it could be useful for producing small round timbers such as posts and poles, it would be unable to produce large volumes of logs suitable for sawn timber and other solid wood applications, which is one of the prime plantation objectives for BFI.

On account of the foregoing plantation objective *A. aulacocarpa* is seen by BFI to be a species with real potential for larger scale establishment (Wilcox 1996). Combined with reasonable growth it has generally shown superior stem form (straight trunks and fine horizontal branching) to other acacia species in BFI's environment. To evaluate this species on a larger scale the project plans to establish up to 100 ha of it in the next few years.

A. auriculiformis may be of value to BFI as a hybrid parent despite having little potential in BFI's environments because its growth is inferior to *A. mangium* and its stem form is inferior to *A. aulacocarpa* (Wilcox 1996). Selected clones of the hybrid *A. mangium* × *auriculiformis* have shown faster growth than either parent species and intermediate wood density and morphological characteristics on many sites in Vietnam (Le Dinh Kha 1996; Harwood 1996). Although it has not been tested yet at BFI, trial plantings of this hybrid have shown good results elsewhere in the Philippines (Umali-Garcia 1995).

Although *A. crassicarpa* is not currently a priority species for BFI's sites, it is one of the priority species for the Philippines national reforestation program (Umali-Garcia 1995). Reasons for this include the expectation that *A. crassicarpa* will perform better than *A. mangium* on poorer planting sites in the Philippines (Williamson 1993).

A valuable outcome of BFI's acacia trials is the practical demonstration in the Philippines of the potential of exotic acacias such as *A. mangium* for establishment of highly productive timber plantations on lands considered by some nationals as seemingly impractical for plantation use. However, the very diverse geography and climatic characteristics of the Philippine archipelago will require more acacia trials similar to those conducted at BFI to be conducted across the country to achieve widespread replication of the project's achievements. Towards such ends the work reported by Jovanovic and Booth (1996) on development of climatic interpolation relationships for the Philippines could help identify other sites for trials and assist with transfer of information to other regions in the Philippines.

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References

Caguioa, V. 1956. Planting exotic species in the Philippines. Philippine Journal of Forestry. 12(1–2): 1–35.

de la Cruz, R.E. 1993. *Imperata cylindrica* Grasslands in the Philippines. In: Vandenbeldt, R.J. (ed.). Imperata Grasslands in Southeast Asia: Summary Reports from The Philippines, Malaysia, and Indonesia. Report Number 18. Forestry/Fulewood Research and Development (F/FRED) Project.

Eldridge, K.G., Davidson, J., Harwood, C.E. and van Wyk, G. 1994. Eucalypt domestication and breeding. Oxford University Press.

Garrity, D.P., Soekardi, M., van Noordwijk, M., de la Cruz, R., Pathak, P.S., Gunasena, H.P.M., van So, N., Huijun, G. and Majid, N.M. 1997. The *Imperata* grasslands of tropical Asia: area, distribution and typology. Agroforestry Systems. 16:3–29.

Harwood, C.E. 1996. Recent developments in improvement strategy for tropical tree species. In: Rimbawanto, A., Widyatmoko, A.Y.P.B.C., Suhaendi, H. and Furukoshi, T., ed., Tropical Plantation Establishment: Improving Productivity Through Genetic Practices. Proc. International Seminar. Yogyakarta, Indonesia. 19–21 December 1996.

Harwood, C.E. and Williams, E. R. 1992. A review of provenance variation in the growth of *Acacia mangium.* In: Carron, L.T. and Aken, K., ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37. Australian Centre for International Agricultural Research, Canberra, 22–30.

Jovanovic, T. and Booth, T.H.1996. The development of climatic interpolation relationships for the Philippines. In: Booth, T.H., ed., Matching Trees and Sites. ACIAR Proceedings No. 63. Australian Centre for International Agricultural Research, Canberra, 56–64.

Le Dinh Kha. 1996. Studies on natural hybrids of *Acacia mangium* and *A. auriculiformis* in Vietnam. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proc. QFRI-IUFRO Conf. Caloundra, Queensland, Australia. 27 October–1 November 1996.

Munro, D. 1988. Chamber's World Gazetteer: An A–Z of Geographical Information. Chambers and Cambridge University Press. Edinburgh and Cambridge.

Nicholls, J. and Laureto, E.S. 1995. Bukidnon Forests Incorporated 1995 Annual Report to ACIAR Project 9208. Bukidnon Forests Incorporated Internal Report. Malaybalay, Bukidnon, Philippines.

Otsamo, A., Nikles, D.G. and Vuokko, R.H.O. 1996. Species and provenance variation of candidate acacias for afforestation of *Imperata cylindrica* grasslands in South Kalimantan, Indonesia. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proc. QFRI-IUFRO Conf. Caloundra, Queensland, Australia. 27 October–1 November 1996.

Turvey, N.D. 1995. Afforestation of *Imperata* grasslands in Indonesia: results of industrial tree plantation research trials at Teluk Sirih on Pulau Laut, Kalimantan Selatan. ACIAR Technical Report No. 33. Australian Centre for International Agricultural Research, Canberra.

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

Umali-Garcia, M. 1995. Forest tree improvement in the Philippines: a baseline study. UNDP/FAO Regional Project on Improved Productivity of Man-made Forests through Application of Technological Advances in Tree Breeding and Propagation (RAS/91/004) (FORTIP). Los Baños, Philippines.

Wilcox, M. 1996. Tree Improvement Plan for the Bukidnon Industrial Plantation Project, Philippines. Report No. 151/1996. NZ Ministry of Foreign Affairs, Professional Forestry Services Limited and Groome Poyry Limited.

Williamson, M. 1993. Forest management in industrial forest plantations in the Philippines. TA No. 1578-PHI. Asian Development Bank, Manila and FORTECH, Canberra.

Acacia Species and Provenance Trials in Central Northern Vietnam

Huynh Duc Nhan and Nguyen Quang Duc[1]

Abstract

In 1990, 32 forest and agroforestry tree species/provenances were tested at three sites—Ham Yen (Tuyen Quang province), Phong Chau (Phu Tho province) and Tam Dao (Vinh Phuc province). Tree growth was best at Ham Yen, where *A. crassicarpa* reached a growth rate of 17.7 m^3/ha/year, while *A. mangium*, *A. aulacocarpa* and *A. auriculiformis* reached more than 12 m^3/ha/year. In Phong Chau, *A. aulacocarpa* grew best (13.8 m^3/ha/year) and in Tam Dao, *A. crassicarpa* (13.2 m^3/ha/year). The *Acacia* species were suitable on all three sites. *Eucalyptus* grew slower than *Acacia* (*E. tereticornis* in Phong Chau was the fastest eucalypt at 9.8 m^3/ha/year). Other species of the Fabaceae family and two indigenous species, *Manglietia* and *Melia*, were all unsuccessful.

THE research conducted by the Forest Research Centre within the Vietnam-Swedish Forestry Cooperation Programme includes testing and selecting timber and multipurpose tree species, bushes and herbs suitable for human utilisation. Since early 1980, the Centre has carried out a range of trials on tree species and provenances. It has selected suitable species and planted thousands of hectares of plantation forest and millions as scattered trees. This report presents the findings of recent trials on *Acacia* species and provenances.

Species Elimination Trials

Species tested

The trial involved 24 species. Most of them were exotics and only two were indigenous species—*Manglietia glauca* and *Melia azedarach*. Of the 22 exotics, six were represented by two provenances and one by three provenances—a total of 32 species and provenances (see Table 1). However, seedling limitations and planting conditions that were too harsh for some of the species meant that the trial was not completed for all species and provenances at every site. *Eucalyptus camaldulensis*, *E. urophylla*, *Acacia holosericea* and *A. mangium*, considered suitable species and popular throughout the region, were included in the test as a frame of reference.

Trial sites

The trials were established in Ham Yen (Tuyen Quang province), Phong Chau (Phu Tho province) and Tam Dao (Vinh Phuc province) (see Table 2).

Results from Ham Yen

In Ham Yen, the survival rate of the species was low. Of 29 species, 10 did not survive. After 18 months, 10 species survived at a rate of over 80%. This satisfies the minimum survival rate for a production plantation. After 42 months, only one species reached this standard and four species survived at a rate higher than 70%. All of them are *Acacia* (four species) or *Eucalyptus* (one species). The main reason for the poor survival rate was insect damage (crickets).

Average height and diameter of eight of the best species at 54 months are presented in Table 3. Among the 19 surviving species, acacias had a high average growth rate (2 m/year). The best species was *A. crassicarpa*, followed by *A. mangium*, *A. longispicata*, *A. aulacocarpa*, *A. auriculiformis* and *E. urophylla*. Others grew at a rate of nearly 2 m/year. A comparison of heights of the various species at 54 months revealed significant differences at the 5% level.

Although figures only cover 54 months, the species with the faster height growth rate were found

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Table 1. Species and provenances of multipurpose trees tested at three sites: (1) Ham Yen, (2) Phong Chau and (3) Tam Dao. Established 1990.

Source							Test site		
Species and provenance	Code	Seed lot	Locality	Latitude	Longitude	Alt. (m)	1	2	3
Acacia aulacocarpa	Aaul	CSIRO-16612	Hai kussa River WP PNG	9°29′S	142°25′E	15	+	+	+
A. auriculiformis	Aaur	Au-2-89	Archer River Qld	13°27′S	142°57′E	180	+	+	+
A. crassicarpa	Acra	CSIRO-16602	Dimisisi Village WP PNG	8°31′S	141°13′E	50	+	+	+
A. holosericea	Ahol	Ah-2h89	East Alligator NT	12°35′S	132°55′E	20	+	+	+
A. longispicata	Alon	CSIRO-14587	Emerald Qld	23°28′S	148°04′E	200	+		+
A. mangium	Aman	Am-7-89	Mossman Qld	16°22′–31′S	145°20′–24′E	5–40	+	+	+
A. platycarpa	Apla	CSIRO-14542	S.E. Katherine NT	14°35′S	132°30′E	190	+	+	+
Calliandra calothyrsus	Cal3	FAO-3/89					+	+	+
C. calothyrsus	Cal4	FAO-4/89					+	+	+
C. calothyrsus	Cal5	NFTA-495					+		
Cassia siamea	Cass	FAO-5/89					+		
Eucalyptus camaldulensis	Eca1	CSIRO-12964	Emu Creek Petford Qld	17°20′S	144°58′E	460	+	+	+
E. camaldulensis	Eca2	ECVN-1/89	Phó Kh,nh, ViÖt Nam					+	+
E. cloeziana	Ecl1	CSIRO-90	Gympie Qld	26°07′S	150°47′E	130	+		+
E. cloeziana	Ecl2	CSIRO-91	Cardwell Qld	18°22′S	146°03′E	100	+	+	+
E. pellita	Epel	CSIRO-14916	N.of Kuranda Qld	16°49′S	145°38′E	400	+	+	+
E. tereticornis	Eter	CSIRO-16646	Laura River Qld	15°41′S	144°37′E	120	+	+	+
E. urophylla	Euro	CSIRO-13827	Mt. Egon Flores Is., Ind.	8°40′S	122°30′E	900	+	+	+
Gliricidia sepium	Gli2	OFI-12/89					+	+	+
G. sepium	Gli3	OFI-13/89					+	+	+
Grevillea robusta	Gre1	Dendros-0541	Linville Qld	26°48′S	152°16′E	150	+	+	+
G. robusta	Gre6	Dendros-0546	Emu Vale Qld	28°13′S	152°17′E	550	+	+	+
Leucaena diversifolia	Ldi1	FAO-6/89					+	+	+
L. diversifolia	Ldi2	OFI-46/87					+	+	+
L. leucocephala	Lle7	FAO-7/89					+	+	+
L. leucocephala	Lle8	FAO-8/89					+	+	+
L. hybrid	Lhyb	K x 3C					+		
Manglietia glauca	Magl	Mg-1/89	Vinh Phu Viet Nam	21°25′N	105°04′E	60	+		
Melia azedarach	Mela	Ma-1/89	Phong Chau VP Viet Nam	21°22′N	102°20′E	30	+		
Paraserianthes falcataria	Para	FAO-9/89					+	+	+
Sesbania formosa	Sefo	CSIRO-16175	Annie Creek NT					+	+
S. grandiflora	Segr	NFTA-835							+

*Ind: Indonesia, NT: Northern Territory, PNG: Papua New Guinea, Qld: Queensland, WP: Western Province (PNG)

Table 2. Location of trial sites.

Trial sites	Lat. (N)	Long. (E)	Alt. (m)	Temp. (°C)	Rain. (mm)	Slope	Soil
Tam Dao	21°19′	105°36′	50	23	1600	15°	Red ferralitic
Phong Chau	21°05′	104°15′	40	23.1	1660	10°	Yellow-red ferr.
Ham Yen	22°05′	105°01′	100	22.7	1875	25°	Brown-red ferr.

Table 3. Ham Yen. Height, diameter, tree volume and annual growth rate after 54 months*.

Species	Height (m)	Diameter (cm)	Volume per tree (dm^3)	Yield (m^3/ha/year)
A. aulacocarpa	bcd 9.6	a 10.8	abc 29.7	12.2
A. auriculiformis	bc 10.1	a 10.2	bcd 27.4	12.0
A. crassicarpa	a 12.6	a 11.6	a 44.3	17.7
A. holosericea	e 6.6	a 7.9	d 11.3	5.1
A. mangium	ab 11.3	a 11.9	ab 42.5	15.8
E. camaldulensis Petford	cd 9.6	a 7.2	d 13.0	5.7
E. cloeziana Gympie	da 8.1	a 7.9	cd 14.2	3.2
E. tereticornis	bc 9.9	a 7.4	cd 14.2	4.8

* The difference in height, diameter and volume is significant at the 5% level for species not having the same letter in each column..

mostly to have a faster diameter increase. First was *A. mangium*, after that *A. crassicarpa*, *A. aulacocarpa* and *A. auriculiformis*. Variance analysis of diameters of eight species at 54 months represented by two replications show that the differences between species are not significant at the 5% level.

The variance analysis of the mean volume of the various species shows that the differences are significant at the 5% level (Table 3). *A. crassicarpa* and *A. mangium* show significantly better growth than the other species. With an initial tree density of 2500/ha and a survival rate of 72% the mean growth rate during the first 54 months of *A. crassicarpa* was 17.7 m^3/ha/year. *A. mangium*, with a survival rate of 67%, reached a growth rate of 15.8 m^3/ha/year, while *E. camaldulensis* (Petford), with a survival rate of 79%, reached a growth rate of only 5.7 m^3/ha/year.

Results from Phong Chau

The 24 species involved in the Phong Chau trial were all exotic. The survival rate was higher than in Ham Yen, however, there no species reached 100%. This percentage varied from 0 to 94%. Five species reached survival rate higher than 80% (four *Acacia* and one *Eucalyptus* species), and four species reached above 70%. Nine species died, and six others displayed a very low survival rate. The reasons are the same as in Ham Yen, mostly non-adaptation. Damage by crickets had little effect. As well, several species (*A. mangium*, *Paraserianthes falcataria*, *Gliricidium sepium*, *Leucaena leucocephala* and *Calliandra calothyrsus*) were killed by cattle.

The average height, diameter, volume and annual growth rate of the nine better surviving species are presented in Table 4. *A. aulacocarpa* was the tallest. *A. crassicarpa* ranked high but did not grow so well as at Ham Yen. *A. mangium* grew less than in Ham Yen and has a clear lower ranking regarding height growth (No. 6) in Phong Chau compared to being No. 2 in Ham Yen.

A. aulacocarpa had the largest diameter, *E. urophylla* came second and *A. crassicarpa* third, while *E. camaldulensis* and *E. tereticornis* dropped to 6th and 7th ranking in terms of diameter. *A. holosericea* had the lowest diameter among all with only 6.9 cm. Variance analysis showed that height and diameter differences were significant at the 1% level (Table 4).

Variance analysis of the mean volume of the species showed that the difference was significant at the 1% level. In comparison with Ham Yen, average annual growth in Phong Chau is not high. A comparison between species on the same topography shows that *A. aulacocarpa* grew better than all the other species. With a survival rate of 93% at 4.5 years, this species reached a growth rate of 13.8 m^3/ha/year. *A. crassicarpa* had a survival rate of 72%, and growth rate of 9.0 m^3/ha/year. The growth rate of *A. mangium* reached only 6.2 m^3/ha/year. *Eucalyptus* grew very well under these conditions. *E. tereticornis* had a growth rate of 9.9 m^3/ha/year and *E. camaldulensis* Petford 8.3 m^3/ha/year. As can be seen from these numbers, the average growth in the initial 4.5 years for *A. aulococarpa*, *A. crassicarpa*, *E. tereticornis* and *E. camaldulensis* make these species acceptable for plantation forestry.

Results from Tam Dao

In Tam Dao, 27 species were tested, 25 of which were planted in two plots. *A. longispicata* and *Sesbania grandiflora* were only present in the first block. Ten species were found unsuitable or did not survive. *A. auriculiformis* had 100% survival. Another nine species reached a survival rate of 90%, while only five species recorded a survival rate of less than 80%.

The ranking of tree height alternated between *Acacia* and *Eucalyptus*. *A. crassicarpa* ranked highest at 8.8 m, followed by *E. camaldulensis* Petford. Then came *A. longispicata*, *E. tereticornis*, *E. camaldulensis* from Phu Khanh and *E. urophylla* just above the average. In Tam Dao *A. holosericea* grew better than *A. mangium*, although it still lagged behind other *Acacia* and *Eucalyptus* species. *Grevillea robusta*, *A. mangium*, and *A. platycarpa* grew very poorly. Variance analysis based on height when 54 months old show that the differences were significant at the 1% level (Table 5).

Regarding diameter at 0.3 m above the ground, *A. crassicarpa* ranked first with 10.3 cm, 1.8 cm larger than *A. longispicata* and *A. aulacocarpa*.

Variance analysis based on mean volume showed that the differences between the various species were statistically significant at the 5% level. With a tree volume of 24.8 dm^3 and an annual average growth rate of 13.2 m^3/ha after 54 months *A. crassicarpa* is superior to all the other species, including the *Eucalyptus* species. The mean tree volume of *A. aulacocarpa*, *A. auriculiformis*, *E. tereticornis*, *E. camaldulensis* Petford, *E. urophylla* and *E. cloeziana* Cardwell showed no significant difference, ranging from 9.0 dm^3 (*A. auriculiformis*) to 14.4 dm^3 (*E. tereticornis*).

Discussion

On all three test sites and under similar conditions, *Calliandra calothyrsus*, *Leucaena diversifolia*, *L. leucocephala*, *L.* hybrid, *Gliricidia sepium*, *Melia*

Table 4. Phong Chau. Height, diameter, tree volume and annual growth rate after 54 months*.

Species	Height (m)	Diameter (cm)	Volume per tree (dm^3)	Yield (m^3/ha/year)
A. aulacocarpa	b 8.0	a 11.3	a 26.7	13.8
A. auriculiformis	b 7.8	bcd 8.4	bc 14.3	7.5
A. crassicarpa	bc 7.8	b 9.3	b 17.6	9.0
A. holosericea	e 5.8	de 6.9	d 7.3	3.4
A. mangium	bcd 7.1	b 9.2	b 15.5	6.2
E. camaldulensis Petford	a 9.3	b 9.0	b 19.5	8.3
E. camaldulensis Phó Kh,nh	cde 6.7	e 5.7	d 5.6	1.7
E. pellita	de 6.5	cd 7.3	cd 9.0	3.9
E. tereticornis	a 9.3	bc 8.7	b 18.7	9.8

* The difference in height, diameter and volume is significant at the 1% level for species not having the same letter in each column.

Table 5. Tam Dao. Height, diameter, tree volume and annual growth rate after 54 months*.

Species	Height (m)	Diameter (cm)	Volume/tree (dm^3)	Yield (m^3/ha/year)
A. aulacocarpa	abcd 7.3	ab 8.5	bc 14.0	7.7
A. auriculiformis	bcd 6. 8	bc 7.6	bcde 10.1	5.6
A. crassicarpa	a 8.8	a 10.3	a 24.8	13.2
A. holosericea	d 5.6	cd 6.3	ef 5.7	3.0
A. mangium	ef 4.9	cd 6.2	ef 5.3	2.0
A. platycarpa	f 3.3	d 4.3	f 1.7	0.5
E. camaldulensis Petford	a 8.8	bc 7.7	bcd 13.5	7.0
E. camaldulensis PhóKh,nh	cde 6.5	cd 6.3	cdef 6.7	3.5
E. cloeziana Cardwell	abc 7.5	ab 8.4	bcd 13.8	5.7
E. cloeziana Gympie	cde 6.3	bc 7.4	bcdef 9.0	4.5
E. pellita	de 5.7	c 6.5	def 6.3	3.3
E. tereticornis	ab 8.6	bc 7.9	b 14.3	7.7
E. urophylla	bcd 7.0	ab 8.5	bcd 13.3	6.4

* The difference in height, diameter and volume is significant at the 1% level for species not having the same letter in each column.

azedarach, *Sesbania formosa* and *S. grandiflora* all appeared to adapt poorly to the sloping hill conditions in the plantation sites. Many of the species died, had a low survival rate, or grew very poorly.

A. platycarpa, *E. cloeziana* Cardwell, *E. pellita*, *Paraserianthes falcataria*, and *Manglietia glauca* were not very successful either, and their survival rates were low.

A. aulacocarpa, *A. auriculiformis*, *E. urophyll*a and *E. cloeziana* Gympie grew better than the species in the two groups just mentioned. These species can be planted in Ham Yen if cared for and protected against animals and competition from grass.

In Ham Yen, *A. crassicarpa* and *A. mangium* grew very well. They were superior to the others in terms of height, diameter of the major stem, diameter of the crowns, survival rate and wood volume. *A. mangium* is especially suitable on good soil and in areas of high rainfall like in Ham Yen. It is necessary to develop this species in such areas, because it grows fast, stabilises the soil's nitrogen content, has a large, thick canopy, and yields construction timber, pulpwood and fuelwood. *A. crassicarpa* can grow on dry and less fertile soil. While *A. mangium* dropped from second to ninth position in Phong Chau and twelfth in Tam Dao, *A. crassicarpa* still ranked highly in those areas.

Northern Phu Tho and southern Tuyen Quang, where the soil layer is still thick and not yet severely depleted, may be suitable for *E. teretocornis*, *E. urophylla* and *A. aulacorcarpa*. *A. crassicarpa*, *E. camaldulensis*, *E. cloeziana*, *A. longispicata*, and *A. holosericea* appear to have a high tolerance for poor and dry soils. These species grew better on the southern sites (Phong Chau and Tam Dao) than in Ham Yen. As a result of these tests, many new species have been identified that with further research could be introduced for mass production.

General Conclusion

In Ham Yen, besides *A. mangium* and *E. urophylla* that are alrealy popular species, the most promising species is *A. crassicarpa*, followed by *E. tereticornis*, *A. longispicata*, *E. camaldulensis* Petford, *E. cloeziana* and *A. auriculiformis*. These species should be introduced for seed production on an experimental basis. At the same time, research on suitable silvicultural methodologies should be performed for each region. The research findings also give evidence of the large potential of *Acacia*. These species should be prioritised for research regarding site matching and plantation establishment, so that the most suitable species, provenances and the ones with the best development of multipurpose products could be selected for every region.

Acacia Species and Provenance Performance in Southwest Victoria, Australia

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Abstract

Trials were undertaken to identify Australian acacias with potential for planting in areas perhaps marginal for plantation forestry. Sites in southwest Victoria at Gringegalgona (near Coleraine) and Dunkeld were used to test 36 acacia seedlots, in a cool-temperate climate with an annual rainfall of 700 mm and a drier 3–4 month summer-autumn.

The Gringegalgona site is a sloping bank near a creek, on laterised Tertiary sediments (sandy loam over clay). The topsoil is mildly acidic and infertile but well drained. The Dunkeld site is on basaltic soil that becomes waterlogged in late winter. The soil is gravelly clay-loam over clay, mildly acid and infertile.

Seedlings were planted in September 1994. At 34 months, the poorest survival was 65% at Gringegalgona and 77.5% at Dunkeld. *A. mearnsii* (Tuross River), *A. dealbata* (Errinundra) and *A. decurrens* (Picton-Mittagong) were the tallest at Gringegalgona (510, 495 and 483 cm, respectively). *A. mearnsii* (Tuross River), *A. decurrens* (Picton-Mittagong) and *A. trachyphloia* (Monga) were the tallest at Dunkeld (405, 394 and 376 cm, respectively). In terms of stem volume, the best at Gringegalgona was *A. mearnsii* from Tuross River (ranked third at Dunkeld). The best at Dunkeld was *A. decurrens* from Picton-Mittagong (ranked eighth at Gringegalgona). Only *A. mearnsii* (Tuross River) and *A. dealbata* (Errinundra) ranked in the first six at both sites.

THE Victorian component of this project is part of the Australian Centre for International Agricultural Research (ACIAR) Project FST/92/27, sub-project A, containing acacia species/provenances represented in plantings in the Australian Capital Territory (Kowen and Uriarra), New South Wales (Eden), China and Vietnam (Brown 1996). The objective in Victoria is to identify Australian acacias with potential for planting in areas considered marginal for commercial forestry. This project is a first step in the screening process.

Apart from firewood, post or pulp wood production, we want to identify material that is suitable for appearance-grade sawlog production. For that purpose, as well as having fast growth, these trees should be small-branched, erect and straight. The wood must also have desirable properties, including decorative aspects. There is potential for the use of such trees for timber production in the 400–700 mm rainfall zone, where they will contribute significantly to sustainable land management (Bird et al. 1992). The trees would require intensive pruning to produce clearwood of high value (Bird et al. 1996a). This would be necessary where transport costs are high and/or where long distances from a port precludes sale of species such as *Eucalyptus globulus* for chipwood, even given that they can be grown.

Methods and Materials

Production of seedlings

Seedlots of acacia species were obtained from Australian Tree Seed Centre (ATSC) — see Table 1. Pre-germination treatment was by immersion of the seed for 1 minute in water at 100°C, our usual practice for acacias, except for seedlots *A. schinoides* (No. 12) and *A. nanodealbata* (No. 24, from Mt Macedon, Vic). An ATSC database error in the consignment note indicated no heat treatment was required but the seed failed to germinate. These

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Table 1. Origin of *Acacia* seedlots, range in height (cm) of seedlings at planting in September 1994 and mean survival (Sv, %) and height (Ht, cm) in January 1996 at Gringegalgona, or November 1995 at Dunkeld.

No.	*Acacia* species	ATSC No.#	Provenance	Lat (deg-min)	Long (deg-min)	Alt (m)	Seed-ling ht	Gringegalgona		Dunkeld	
								Sv	Ht	Sv	Ht
1	*blayana*	18068	Brogo, NSW	36–29	149–40	500	7–10	97	135	100	98
2	*chrysotricha*	18620	Newry State Forest, NSW	30–32	152–55	50	7–10	80	114	97	86
3	*dangarensis*	18608	Mt. Dangar, NSW	32–20	150–28	600	10–15	97	148	100	93
4	*dealbata*	16269	26 km S of Cooma, NSW	36–28	149–07	910	10–15	100	247	100	137
5	*dealbata*	16271	Errinundra Plateau, Vic	37–11	148–52	960	10–15	100	280	100	173
6	*dealbata*	16376	18–22 km WNW Bemboka, NSW	36–37	149–26	1035	7–10	95	229	100	141
7	*dealbata*	16384	18.6 km S Orford, Tas	42–41	147–52	120	10–15	95	251	100	154
8	*dealbata*	18024	Captains Flat, NSW	35–37	149–26	700	10–15	100	174	100	125
9	*decurrens*	14726	SW of Goulburn, NSW	34–53	149–17	685	10–15	95	193	100	147
20	*decurrens*	15847	Picton–Mittagong, NSW	34–17	150–35	380	10–15	97	208	100	164
21	*elata*	18243	Mt. Boss State Forest, NSW	31–14	152–22	800	7–10	95	136	100	88
23	*elata*	18252	Mt. Wilson, NSW	33–30	150–21	650	7–10	97	140	97	86
10	*filicifolia*	15841	19 km SW of Singleton, NSW	32–41	151–01	150	7–10	90	176	100	132
11	*filicifolia*	17893	Yadboro Flat, NSW	35–19	150–14	60	7–10	97	213	100	155
35	*implexa*	18019	Pyalong, Vic	37–08	144–53	200	5–7	97	114	100	65
36	*implexa*	15832	Swansea, NSW	33–05	151–37	10	7–10	95	106	97	67
13	*irrorata*	15840	Craven–Stroud, NSW	32–10	151–57	110	5–7	100	194	97	121
14	*irrorata*	18619	Bodalla, NSW	36–08	150–02	20	5–7	87	172	100	135
15	*mearnsii*	15329	Apsley River Bridge, Tas	41–56	148–14	10	7–10	100	216	100	161
16	*mearnsii*	16246	10 km S of Nowra, NSW	34–59	150–36	10	10–15	97	240	100	194
17	*mearnsii*	16621	Tuross River, SW Bodalla, NSW	36–11	149–58	15	10–15	97	225	100	187
18	*mearnsii*	17928	Tarpeena, SA	37–36	140–58	70	10–15	90	197	100	168
19	*mearnsii*	17933	Wattle Circ, Omeo Hwy, Vic	37–27	147–50	200	10–15	95	226	100	173
37	*mearnsii* §	PVI	Byaduk, Vic	38–55	142–00	175	5–7	—	—	—	—
33	*melanoxylon*	16526	25 km SE Mount Gambier, SA	37–57	140–56	40	7–10	97	131	100	73
34	*melanoxylon*	15863	Blackwood Park Lileah, Tas	40–57	145–10	250	7–10	97	147	97	87
38	*melanoxylon*	PVI	Crawford River, Vic	37–56	141–30	150	10–15	100	149	92	92
39	*melanoxylon*	PVI	Mt Napier State Park, Vic	37–53	142–08	200	7–10	92	124	100	72
25	*nanodealbata*	17940	Lavers Hill, Vic	38–45	143–15	200	5–7	90	240	100	129
26	*parramattensis*	17711	Tarago, NSW	35–10	149–35	740	7–10	100	171	100	125
27	*parramattensis*	17925	Umaralla, NSW	36–11	149–18	900	5–7	80	165	100	122
28	*parramattensis*	14723	SW of Bungendore, NSW	35–19	149–25	730	7–10	100	137	100	131
12	*schinoides*	18258	Watagan State Forest, NSW	33–00	151–18	300	5–7	97	133	100	101
29	*silvestris*	15852	Deua River, Deua NP, NSW	35–58	149–45	350	5–7	95	204	100	138
30	*silvestris*	17939	Bruthen, Vic	37–35	147–54	200	7–10	95	226	100	132
31	*trachyphloia*	14229	Monga State Forest, NSW	35–36	149–55	710	5–7	100	166	97	151
32	*trachyphloia*	17894	Currowan Creek, NSW	35–35	150–03	100	5–7	97	158	100	140

Australian Tree Seed Centre seedlot number (PVI collections not numbered)
§ Seedlings used only in guard row

seedlots were resown on 29 April, after heat treatment for 30 sec at 100°C. Seedlot 12 responded but germination of Seedlot 24 was too slow to allow its use in the project.

On 28 Mar 1994, for each seedlot, two or three seeds were sown in individual pots, 150 mm deep and 50 × 50 mm at the top. The best seedling was retained in situ. The potting mixture was 53% Debco potting mix (pine bark and sand), 23.5% coarse sand, 23.5% loamy sand with 0.6 g of Osmocote slow release (270 day) fertiliser (1.6% P, 17% N, 8.7% K, 4.5% S). A soluble fertiliser (Aquasol) was given on 24 June (8 g/9 L), 22 July and several weeks before planting (16 g/9 L), applied liberally with a watering can.

All seedlots were left in the open for the first two months. Frosts in June were quite severe, including four consecutive mornings, two of them having temperature below −2°C, and growth was slow. Seedlots 1–2, 4, 7–8, 12, 22, 24–26, 30–34, 36 and 38 were put in a solar-heated glasshouse on 27 May. Seedlots 15, 27–29 were included on 27 June. Seedlots 3, 5–6, 9–11, 13–14, 16–21, 23, 35 and 37 were added on 22 July. All seedlings were removed from the glasshouse to harden 2 weeks before planting.

Field sites

The regional climate is cool-temperate, with a mean annual rainfall of 703 mm and a 4-month summer-autumn period, which is drier and hotter. The long-term rainfall/evaporation data for months April–Nov and Dec–March at Hamilton are 555/588 mm and 148/728 mm, respectively.

The Gringegalgona site (T. and A. Johnston) is 22 km north of Coleraine, latitude 37°25′, longitude 141°44′, altitude 300 m — laterised Tertiary sediments forming the Dundas Tableland. The site is on a slope above a slightly saline creek. The plots are on sandy loam over clay. The grey topsoil has a moderate depth (30 cm) and is mildly acid and infertile, but the site is generally well drained and sheltered.

The Dunkeld site (W. and H. Funk) is 6 km east of Dunkeld, latitude 37°39.5′, longitude 142°25′, altitude 200 m — volcanic plains with basaltic soil that becomes waterlogged in late winter. The site has a slight slope. Soil texture is a gravelly clay-loam over clay. A few boulders are present. The topsoil is mildly acid and infertile.

Site preparation

At Gringegalgona, rows were pegged at 2.75 m apart and ripped to 40–50 cm in late autumn. Columns were pegged at 2.75 m but not ripped because this was an erodible sandy slope. At Dunkeld, columns were pegged at 3 m spacing and rows at 2.5 m spacing. Both columns and rows were ripped to a depth of 50–60 cm on 27 May 94. Columns were mounded with a three-furrow mouldboard plough on 6 July 94.

Glyphosate was applied at 1080 g active ingredients (a.i)/ha in a 1.5 m wide strip along proposed planting lines on 18 Aug 94, to control weeds at Gringegalgona. Repeat application of this herbicide (720 g a.i./ha) plus chlorsulfuron (22.5 g a.i./ha) was given a few days before planting. Simazine (2 kg a.i./ha) was applied along lines on 28 March 95. Glyphosate (360 g a.i./ha) and chlorsulfuron (22.5 g a.i./ha) was applied in a 75 cm wide band along either side of each row on 10 Oct 96.

Weed control at Dunkeld was planned initially by mounding of the lines. Trees on replicates 1–3 had been planted on small spots cleared of weeds with a mattock, but this was not completely satisfactory. Mounds on replicate 4 were sprayed with glyphosate (1080 g a.i./ha) on 22 Sep 94 just before planting; lines on other replicates were sprayed with glyphosate (360 g a.i./ha) on 1 Dec 94, using a shield to protect the trees. Simazine (3 kg a.i./ha) was applied along the mounds on 24 March 95, in an effort to prevent weed germination in autumn and winter. In Nov 1995 fluazifop-p (1060 g a.i./ha) was applied along the mounds to check the grass. Control was not satisfactory in 1996 and on 5 Nov 96 glyphosate (720 g a.i./ha) and chlorsulfuron (19 g a.i./ha) was applied in a 75 cm wide band along either side of each row, taking care to avoid the trees.

Planting

The Gringegalgona site was planted on 21–22 Sep 94. Soil conditions were ideal and seedlings required no watering in. A Hamilton Treeplanter was used to make holes for the seedlings. No fertiliser was applied. A conventional wire fence afforded protection from livestock. Plastic sleeves, 46 cm tall × 40 cm diameter with three bamboo stakes, were used to protect trees from rabbits, hares and wingless grasshoppers. Seedlings were replaced on 24 Oct 94 — one from Seedlot 9 and one from Seedlot 23.

The Dunkeld site was planted 19–23 Sep 94. The dry winter and spring of 1994 resulted in mounds being dry, less than ideal planting conditions. The weather at planting was also windy. Trees on replicate 1 were given a little water after planting. All planting holes for remaining replicates were given approximately 100 ml of water before planting. No fertiliser was applied. The site was fenced from livestock. Hares were present so all seedlings were guarded individually. Seedlings were replaced on 21 Oct 94 — one each from Seedlots 2, 3, 6, 11, 20, 35 and 36.

Experimental design

A partially balanced 6 × 6 quadruple lattice design was used, with 10 seedlings per plot (two adjacent columns each with five seedlings). Two shelter rows were used around the site; *A. mearnsii* (No. 37) as an outer row and an inner row comprising seedlots the same as in adjacent plots. No buffer trees were used between plots.

Tree measurements

Survival was recorded when tree heights were measured. Heights were measured to the nearest cm on all trees at 14–16 months (Nov 1994–Jan 1995), 22 months (July 1996) and 34 months (July 1997). Diameter was measured on the main stem of all trees, to the nearest mm at 10 cm above ground, at 22 months and 34 months. At 34 months, the diameter of the main stem was also measured at 1.3 m above ground for all trees greater than 2.9 m tall. We also recorded the number of branches (stems) at the 1.3 m level that were 50% or more of the diameter of the main stem. The 1996 and 1997 data for diameter at 1.3 m are not reported here. Tree volume data for 1997 are based on tree height and diameter of the main stem at 10 cm above ground, using the cone formula. This value does not represent wood biomass because minor stems and branches are ignored. Plot data reported are the mean of all trees present.

Project scientists are yet to assess tree form. Their objective will be to grade each tree once it has attained a height of 4–8 m, based on a 5-point scale: (1) erect, straight stem with very light branching on the base 4–6 m, (2) fairly straight and erect stem, light basal branching, (3) stem crooked, or forked above 1 m, or heavy branched, (4) two or more stems forking within 1 m from ground, (5) stunted or deformed.

Results

Survival and height growth at 15 months

At Gringegalgona, survival and height on 5 Jan 1996 is given in Table 1. Survival was 90% or more for all except *A. chrysotricha* (No. 2), *A. irrorata* (No. 14) and *A. parramattensis* (No. 27). Few weeds were present along the planting rows in Nov 1995. Grasshoppers were present in one corner of replicate 4 on Jan 1995 but not in numbers to warrant spraying. Some browsing damage by rabbits occurrred in late 1994 and summer 1995 and this also accounted for most of the losses. *A. dealbata* (Errinundra) attained 2.8 m. Growth was poorer on the wetter lower edge.

At Dunkeld, survival and height of trees at 21 Nov 1995 is also given in Table 1. Survival was 92% or more for all species. Weed control on the mounds was not optimal, with grass in abundance in Nov 1995. *A. mearnsii* (Nowra) was the fastest growing species (1.9 m).

Survival, height and diameter growth at 34 months

These data are presented in Table 2. Survival at 34 months was excellent, with 65% the lowest at

Table 2. Mean survival, height growth and main stem diameter (measured 10 cm above ground) in July 1997 of *Acacia* seedlots planted at Gringegalgona and Dunkeld in September 1994.

No.	*Acacia* species	Provenance	Gringegalgona			Dunkeld		
			Survival %	Diameter (mm)	Height (cm)	Survival (%)	Diameter (mm)	Height (cm)
1	*blayana*	Brogo, NSW	92.5	46	287	87.5	43	241
2	*chrysotricha*	Newry State Forest, NSW	67.5	41	218	77.5	20	129
3	*dangarensis*	Mt. Dangar, NSW	97.5	53	302	100	41	228
4	*dealbata*	26 km S of Cooma, NSW	100	66	453	100	48	311
5	*dealbata*	Errinundra Plateau, Vic	100	79	495	100	64	362
6	*dealbata*	18-22 km WNW Bemboka, NSW	65	70	380	100	57	335
7	*dealbata*	18.6 km S Orford, Tas	90	76	439	97.5	58	323
8	*dealbata*	Captains Flat, NSW	97.5	58	347	100	46	266
9	*decurrens*	SW of Goulburn, NSW	95	78	451	97.5	64	350
20	*decurrens*	Picton-Mittagong, NSW	97.5	70	483	97.5	66	394
21	*elata*	Mt. Boss State Forest, NSW	92.5	56	254	90	37	144
23	*elata*	Mt. Wilson, NSW	97.5	56	245	97.5	38	142
10	*filicifolia*	19 km SW of Singleton, NSW	90	55	398	100	42	303
11	*filicifolia*	Yadboro Flat, NSW	97.5	65	467	100	52	301
35	*implexa*	Pyalong, Vic	97.5	45	216	100	30	131
36	*implexa*	Swansea, NSW	92.5	32	150	95	24	112
13	*irrorata*	Craven-Stroud, NSW	100	74	425	97.5	46	293
14	*irrorata*	Bodalla, NSW	85	64	411	100	48	282
15	*mearnsii*	Apsley River Bridge, Tas	100	76	454	100	68	365
16	*mearnsii*	10 km S of Nowra, NSW	97.5	84	482	100	62	370
17	*mearnsii*	Tuross River, SW Bodalla, NSW	97.5	84	510	100	65	405
18	*mearnsii*	Tarpeena, SA	90	71	423	100	65	353
19	*mearnsii*	Wattle Circ, Omeo Hwy, Vic	95	76	474	100	61	369
33	*melanoxylon*	25 km SE Mount Gambier, SA	92.5	44	205	97.5	32	141
34	*melanoxylon*	Blackwood Park Lileah, Tas	97.5	39	198	92.5	28	145
38	*melanoxylon*	Crawford River, Vic	97.5	42	203	87.5	31	141
39	*melanoxylon*	Mt Napier State Park, Vic	85	46	181	95	31	121
25	*nanodealbata*	Lavers Hill, Vic	87.5	74	441	92.5	55	310
26	*parramattensis*	Tarago, NSW	100	56	369	97.5	51	308
27	*parramattensis*	Umaralla, NSW	80	56	366	100	47	288
28	*parramattensis*	SW of Bungendore, NSW	97.5	46	339	100	50	317
12	*schinoides*	Watagan State Forest, NSW	95	61	322	97.5	41	232
29	*silvestris*	Deua River, Deua NP, NSW	95	58	426	100	50	315
30	*silvestris*	Bruthen, Vic	95	63	409	95	44	305
31	*trachyphloia*	Monga State Forest, NSW	97.5	54	413	97.5	55	376
32	*trachyphloia*	Currowan Creek, NSW	97.5	57	417	95	51	352

Gringegalgona (Seedlot 6) and 77.5% the lowest at Dunkeld (Seedlot 2). Seedlots having a survival less than 90% at Gringegalgona were Seedlots 2, 6, 14, 25, 27 and 39; at Dunkeld these were Seedlots 1, 2 and 38. Since assessment at 15 months (Table 1), there was a further loss of 10% or more with only four seedlots; Seedlots 2 and 6 at Gringegalgona and Seedlots 1, 2 and 21 at Dunkeld.

A. mearnsii (Tuross River), *A. dealbata* (Errinundra) and *A. decurrens* (Picton-Mittagong) were the tallest seedlots at Gringegalgona (510, 495 and 483 cm, respectively). *A. mearnsii* (Tuross River), *A. decurrens* (Picton-Mittagong) and *A. trachyphloia* (Monga) were the tallest at Dunkeld (405, 394 and 376 cm, respectively).

Stem volume at 34 months

The data for Gringegalgona are shown in Figure 1 and for Dunkeld in Figure 2.

A. mearnsii (Tuross River), *A. mearnsii* (Nowra), *A. dealbata* (Errinundra), *A. dealbata* (S Orford), *A. mearnsii* (Wattle Circ) and *A. decurrens* (SW Goulburn) had the greatest stem volume at Gringegalgona (10.1, 9.4, 8.6, 8.2, 8.1 and 8.0 dm3, respectively). *A. decurrens* (Picton-Mittagong), *A. mearnsii* (Apsley River), *A. mearnsii* (Tuross River), *A. mearnsii* (Tarpeena), *A. dealbata* (Errinundra) and *A. mearnsii* (Nowra) had the greatest stem volume at Dunkeld (4.7, 4.6, 4.6, 4.5, 4.3 and 4.0 dm3, respectively).

Species having slow growth at both sites include *A. melanoxylon*, *A. implexa*, *A. chrysotricha* and *A. elata*. *A. blayana* and *A. dangarensis* were a little better. Frost damage to some species was extensive, particularly to *A. elata* but also *A. implexa* (No. 36) and *A. melanoxylon*. In one instance, frosts were experienced on seven consecutive nights in June 1996, with screen temperatures to –3.8°C and ground temperatures to –4.9°C. This suppressed the growth of those groups. Rainfall at Hamilton during the 11 months Oct 1996–Aug 1997 is the lowest recorded (401 mm compared with the long term average of 625 mm).

Stem form

No detailed assessment has been made yet but several seedlots indicate straight, erect stems with relatively light branching. These include *A. dealbata* (South Cooma and Errinundra Plateau) and *A. filicifolia* (Singleton). July 1995 was very wet (111 mm) and some wind tilt was evident throughout the Gringegalgona site in Nov 1995. Wet and windy conditions from July to September 1996 (355 mm rain and 13.5 km/hour mean windspeed, compared with the long-term mean of 253 mm and 12.2 km/hour) have resulted in some wind tilt and lean in many trees, particularly at Dunkeld.

Discussion

Early establishment was excellent at both sites, despite dry conditions in spring of 1994. Early growth across all species was consistently slower at Dunkeld than at Gringegalgona. Over all seedlots, stem volume from Dunkeld was only 47% that of Gringegalgona, reflecting poorer site condition (clay loam compared with sandy loam) and poorer initial weed control. An unusually wet July in 1995 and winter in 1996 created a degree of waterlogging at Dunkeld, despite the use of mounds at this site. Poorer weed control at Dunkeld would certainly also have reduced growth. This was due partly to failure of spray lines prior to mounding, and even extra use of herbicide later failed to retrieve the situation.

The most productive species at both sites, ranked in descending order of stem volume, were: *A. mearnsii*, *A. decurrens*, *A. dealbata* (excluding Captains Flat seedlot), *A. nanodealbata*, *A. trachyphloia*, *A. silvestris* and *A. filicifolia* (Yadboro Flat). In terms of stem volume, the best seedlot at Gringegalgona was *A. mearnsii* from Tuross River (ranked third at Dunkeld). The best at Dunkeld was *A. decurrens* from Picton-Mittagong (ranked eighth at Gringegalgona). *A. mearnsii* (Tuross River) and *A. dealbata* (Errinundra) were the only two seedlots to rank in the first six at both sites.

The degree to which nutrients may be limiting growth at either site is unknown. To help resolve this question, trees on two of the four replicates at each site were each given 150 g of Pivot 800 fertiliser (8% N, 10.6% P, 10% K, 7.1% S) in May 1997. Project scientists will assess the effects of this treatment by comparing replicate overall means in relation to performance before any treatment was applied. However, it is not expected that any fertiliser effect would alter ranking of seedlots at either site.

Further assessment is required to determine the best seedlots for purposes other than biomass production. In this region, Blackwood (*A. melanoxylon*) and lightwood (*A. implexa*) are slow growing in the first few years. Their potential can not be adequately assessed from the early results in this project. A larger project, with 20 provenances of blackwood, was established in the region in 1993 (Bird et al. 1996b).

For sawlog production, the form of the tree will greatly influence the outcome. Trees which are amenable to pruning to produce clearwood appearance-grade timber (Bird et al. 1996a) will be noted. Severe between-tree competition will soon be experienced in these woodlots. Thinning of the stand by at least 50% would be required to reduce stress and consequent mortality and to produce sawlogs from the trees retained.

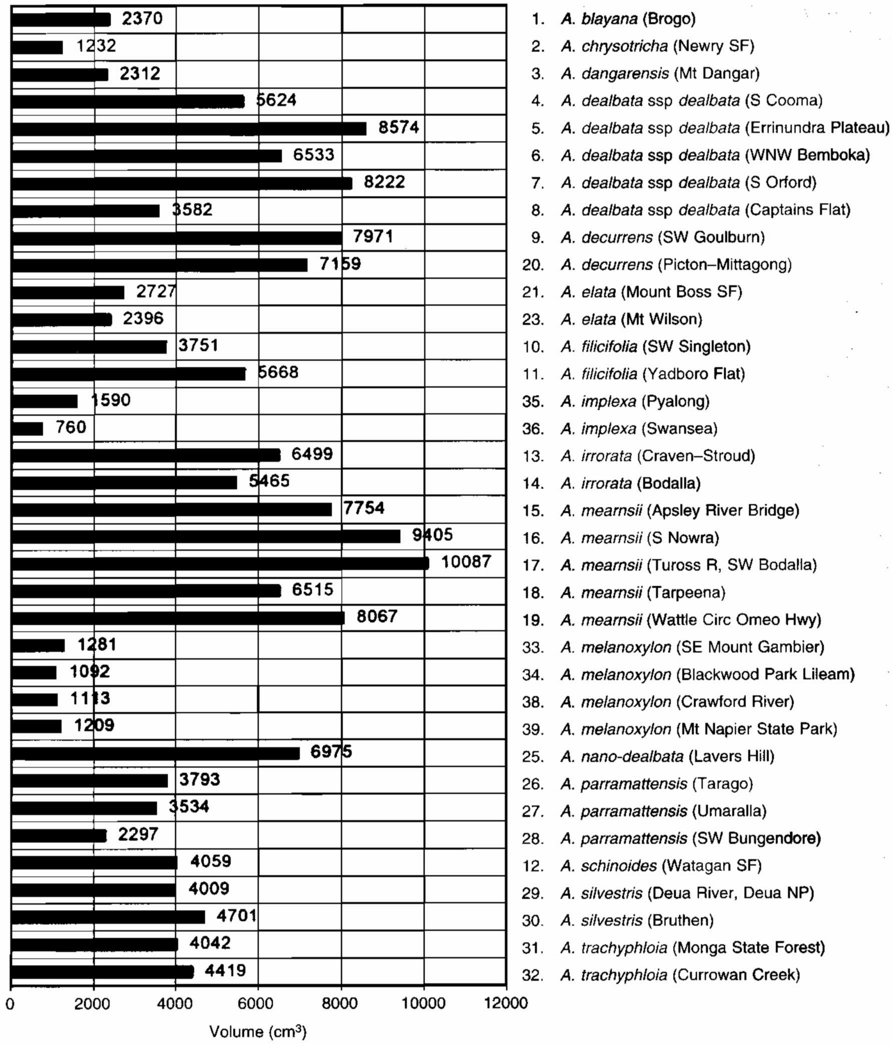

Figure 1. Mean stem volume in July 1997 of *Acacia* species and provenances planted at Gringegalgona in Sept 1994.

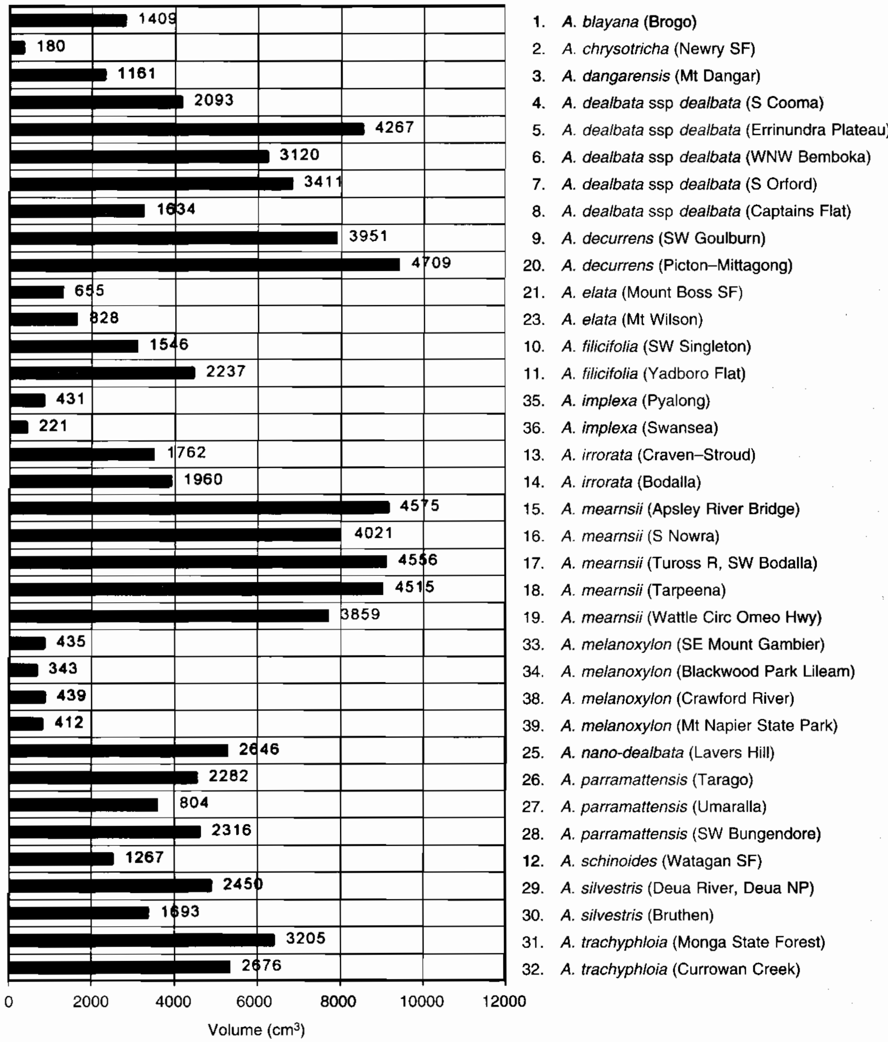

Figure 2. Mean stem volume in July 1997 of *Acacia* species and provenances planted at Dunkeld in Sept 1994.

References

Bird, P.R., Bicknell, D., Bulman, P.A., Burke, S.J.A., Leys, J.F., Parker, J.N., van der Sommen, F.J. and Voller, P. 1992. The role of shelter in Australia for protecting soils, plants and livestock. Agroforestry Systems, 18, 59–86.

Bird, P.R., Jowett, D.J. and Kearney, G.A. 1996a. Farm forestry for clearwood production in southern Australia. Technical Report series, Agriculture Victoria, Australia, p. 86.

Bird, P.R., Jowett, D.W., Aldridge, K. and Raleigh, R. 1996b. Hamilton 1993 Blackwood Provenance Project Update. Page 20 in SW Agroforestry Network section, Agroforestry News, Vol 5, Issue 4.

Brown, A.G. 1996. ACIAR Project 9227 — Australian acacias for sustainable development in China, Vietnam and Australia. Second Annual Report, CSIRO Forestry and Forest Products, Canberra, Australia.

Selected Wood Properties of *Acacia auriculiformis* and *A. crassicarpa* Provenances in Malaysia

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Abstract

A study on genetic variation of some selected physical and mechanical properties of *Acacia auriculiformis* and *A. crassicarpa* provenances was carried out. Nine provenances of *A. auriculiformis* and six provenances of *A. crassicarpa* from Australia (Northern Territory, Queensland), Papua New Guinea and Indonesia (Irian Jaya) were selected and further classified into best, medium and poor performer classes based on growth performance. Provenances of *A. auriculiformis* showed significant differences at $p \leq 0.05$ for specific gravity but not for tangential and radial shrinkage. Provenances of *A. crassicarpa* also differed markedly at $p \leq 0.01$ for tangential and radial shrinkage but not for specific gravity. Similar significant differences at $p \leq 0.01$ were obtained for compression parallel to the grain and shear parallel to the grain but not for static bending. Heritability estimates for *A. crassicarpa* varied from 0.06 for specific gravity to 0.81 for shear parallel to the grain. The *A. auriculiformis* provenances from Wenlock River, Queensland and East Alligator and Howard Springs, Northern Territory, and the *A. crassicarpa* from Samlleberr, Irian Jaya and Olive River, Queensland were identified as the most promising in terms of growth and wood properties for industrial planting purposes.

THE Malaysian government is striving to establish plantations of fast-growing trees to ensure sound forest management and an adequate log supply to sustain the operations of the existing wood-based industries in the country. Early reports on the evaluation of several acacia provenances in Thailand (Chittachumnonk and Sirilak 1991), Malaysia (Sim and Gan 1991), Sri Lanka (Weerawardane and Vivekanandan 1991), Hainan Island, China (Yang and Zeng 1991), Vietnam (Kha and Nghia 1991) and Laos (Latsamay 1991) indicated that *Acacia auriculiformis* and *A. crassicarpa* have proven to be truly multipurpose trees, being fast growing and suitable for timber and pulp production (Harwood 1992).

However, the introduction and work on improving these species have been limited in Malaysia (Nor Aini et al. 1994). Any information on these two species, such as their basic wood properties, is important to ensure appropriate plantation requirement and utilisation purposes. Wood properties such as wood-specific gravity are strongly related to both growth and quality and are subject to large variance and high heritability (Zobel 1963; Barefoot et al. 1970; Kano and Saiki 1970; Van Buijtenen 1982). It is important to consider these relationships, since poor growth may not be accompanied by poor strength and vice versa. Apart from that, the influence of the geographic source of seed and species used in plantations upon the wood produced should be considered as well. Differences between plantations can have genetic origins or can arise when the same species/provenances are grown in diverse environments.

Hence, this study was carried out to investigate the genetic variation of some selected physical and mechanical properties of *A. auriculiformis* and *A. crassicarpa* provenances.

Materials and Methods

Study site

Acacia auriculiformis and *A. crassicarpa* trees planted in adjacent trial plots at Universiti Putra Malaysia, Serdang were chosen for this study. Both stands were planted with a planting distance of

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3×3 m and were established in 1989 for *A. auriculiformis* and in 1992 for *A. crassicarpa*. There are 28 provenances of *A. auriculiformis* and eight provenances of *A. crassicarpa* collected from Australia (Northern Territory and Queensland), Papua New Guinea and Indonesia (Irian Jaya), examples of a major part of the species natural distribution.

Selection of materials

Wood samples were gathered from nine provenances of *A. auriculiformis* and six provenances of *A. crassicarpa*. The selection of trees was based on the growth performance in terms of height and diameter, from provenances classified as best, medium and poor performers. Details on the provenances for both species are shown in Table 1.

Wood properties determination

Specific gravity and shrinkage were the only physical properties determined for both species. Mechanical properties tests, namely static bending (MOR and MOE), compression parallel to the grain and shear parallel to the grain, were conducted only on *A. crassicarpa*.

Statistical analysis and broad-sense heritability estimation

The data were analysed for variance among the provenances. Differences arising from the analysis were further characterised by using Duncan's mean separation test. Finally, broad-sense heritability values (h^2) were estimated for *A. crassicarpa* utilising data from Anova based on the relationship given by Burley and Wood (1976).

Results

The results obtained for *A. auriculiformis* indicate that the provenances were significantly different at $p \leq 0.05$ in their specific gravity (Table 2). The East Alligator provenance from the best performer classes possessed the highest mean specific gravity of 0.85 (Table 3). On the other hand, North Mibini provenance and South Alligator River, both from the poor performer classes, produced the lowest mean specific gravity of 0.73 (Table 3).

Similarly, the best grown provenances outperformed other provenances in both tangential and radial shrinkage. However, no significant difference was detected among the provenances for either form of shrinkage. Howard Springs provenance from the best performer class possessed the highest mean tangential and radial shrinkages of 4.77% and 2.99% respectively. However, the lowest means of 4.10% and 2.05% were recorded in Morehead River, which is from the medium performer class (Table 3).

The results for *A. crassicarpa* indicate that there was no significant difference among the provenances in their specific gravity but marked differences at $p \leq 0.01$ in both tangential and radial shrinkage (Table 2). Samlleberr provenance of Irian Jaya from the best performer classes possessed the highest mean specific gravity (0.48) and tangential and radial shrinkage with values 3.69% and 1.78% respectively (Table 3). However, these values are lower than obtained by the best-grown provenance of *A. auriculiformis*. In terms of mechanical properties, the best-grown provenances also outperformed the others in all traits tested. Compression parallel to the grain and shear parallel to the grain differed significantly at $p \leq 0.01$ among the provenances while only a small variation was detected for MOR and MOE (Table 2). The provenance of Samlleberr obtained the highest measurements for mean MOR, MOE, compression parallel to the grain and shear parallel to the grain, while Bimadebun Village from Papua New Guinea possessed the lowest mean (Table 4).

The heritability values estimated for physical and mechanical properties of *A. crassicarpa* ranged from 0.06 to 0.81. Specific gravity, MOR and MOE exhibited low heritability values of 0.06, 0.12 and 0.11 while a high heritability of 0.81 was found for shear parallel to the grain (Table 5).

Discussion and Conclusion

The results demonstrated that all provenances differed significantly in specific gravity for *A. auriculiformis* and in both tangential and radial shrinkage for *A. crassicarpa*. Similar results have been found for *A. auriculiformis* by Chomcharn et al. (1986) in other plantation areas in Thailand. These differences were very much associated with both inter- and intra-variations from the species' main geographical region, encompassing Australia (Queensland and Northern Territory), Papua New Guinea and Indonesia. Actually, all wood properties are determined by an interaction of the genetic potential of the tree with the environment in which the tree grows. Thus, the significant differences in specific gravity in *A. auriculiformis* and shrinkage in *A. crassicarpa* in this study show that these physical properties were under environmental control and varied considerably with a change in the environment.

According to Zobel and van Buijtenen (1989), anything that affects the growth of a tree can also affect its wood properties. This is true when trees are grown within a normal forest environment, in a

Table 1. Selected provenances for wood properties determination.

	Provenances	G. reg.	Mean height (m)	Mean DBH (cm)	Performer classes
A. auriculiformis	Wenlock River	Qld	11.88	13.25	BEST
	East Alligator River	NT	11.86	12.40	
	Howard Springs	NT	11.48	12.27	
	Reynolds River	NT	11.32	12.44	MEDIUM
	Morehead River	Qld	11.20	11.55	
	Old Tonda Village	PNG	10.41	11.30	
	South Coen	Qld	10.52	10.33	POOR
	North Mibini	PNG	10.08	10.61	
	South Alligator	NT	9.32	10.15	
A. crassicarpa	Samlleberr	Ind	19.54	15.37	BEST
	Olive River	Qld	18.51	15.14	
	Jardine River Bamaga	Qld	17.88	13.95	MEDIUM
	Bensbach WP	PNG	17.43	13.58	
	Bimadebun Village	PNG	14.94	10.98	POOR
	Claudie River	Qld	12.48	10.07	

Note: Ind-Indonesia, Qld-Queensland, PNG-Papua New Guinea, NT-Northern Territory

Table 2. Analysis of variance of wood properties of *A. auriculiformis* and *A. crassicarpa.*

Species	Parameter	Source of variation	DF	F value	CV (%)
A. auriculiformis	Specific gravity	Provenance	8	4.19*	
		Performer classes	2	8.40	
		Error	52		29.83
	Tangential shrinkage (%)	Provenance	8	1.37	
		Performer classes	2	0.67	
		Error	52		11.50
	Radial shrinkage (%)	Provenance	8	2.21	
		Performer classes	2	1.08	
		Error	52		28.71
A. crassicarpa	Specific gravity (SG)	Provenance	5	1.31	
		Performer classes	2	0.62	
		Error	52		10.93
	Tangential shrinkage (%)	Provenance	5	4.71**	
		Performer classes	2	9.00**	
		Error	52		17.27
	Radial shrinkage (%)	Provenance	5	5.91**	
		Performer classes	2	12.57**	
		Error	52		21.54
	Static Bending MOR (N/mm^2)	Provenance	5	2.82	
		Performer classes	2	1.80	
		Error	52		23.95
	Static Bending MOE (N/mm^2)	Provenance		0.23	
		Performer classes		0.45	
		Error			21.11
	Compression parallel to the grain (N/mm^2)	Provenance	5	14.25**	
		Performer classes	2	6.76**	
		Error	52		6.35
	Shear parallel to the grain (N/mm^2)	Provenance	5	26.30**	
		Performer classes	2	38.85**	
		Error	52		5.96

Note: * — significant at p 0.05, ** — significant at p 0.01

Table 3. Mean value of physical properties for *A. auriculiformis* and *A. crassicarpa.*

Species	Performer classes	Provenances	Specific gravity	Tangential shrinkage (%)	Radial shrinkage (%)
Acacia auriculiformis	Best	Wenlock River, Qld	0.84[a]	4.56[a]	2.58[a]
		East Alligator, NT	0.85[a]	4.66[a]	2.67[a]
		Howard Springs, NT	0.83[a]	4.77[a]	2.99[a]
	Medium	Reynolds River, NT	0.80[b]	4.22[a]	2.12[a]
		Morehead River, Qld	0.78[b]	4.10[a]	2.05[a]
		Old Tonda Village, PNG	0.78[b]	4.11[a]	2.06[a]
	Poor	South Coen, Qld	0.76[c]	4.33[a]	2.33[a]
		North Mibini, PNG	0.73[c]	4.38[a]	2.35[a]
		South Alligator, NT	0.73[c]	4.29[a]	2.29[a]
	Overall mean		0.78	4.38	2.38
Acacia crassicarpa	Best	Samlleberr, Ind	0.48[a]	3.69[a]	1.78[a]
		Olive River, Qld	0.48[a]	3.21[ab]	1.76[a]
	Medium	Jardine River Bamaga, Qld	0.48[a]	3.19[ab]	1.63[ab]
		Bensbach WP, PNG	0.46[a]	2.93[b]	1.44[bc]
	Poor	Claudie River, Qld	0.46[a]	2.79[b]	1.37[bc]
		Bimadebun Village, PNG	0.45[a]	2.67[b]	1.13[c]
	Overall mean		0.47	3.08	1.52

Note: Ind-Indonesia, Qld-Queensland, PNG-Papua New Guinea, NT-Northern Territory
Means with the same letter are not significantly different at p = 0.05

Table 4. Mean value of mechanical properties for *A. crassicarpa.*

Performer classes	Provenances	MOR (N/mm²)	MOE (N/mm²)	Compression parallel to grain (N/mm²)	Shear parallel to the grain (N/mm²)
Best	Samlleberr, Ind	79.61[a]	6700.30[a]	43.83[a]	18.92[a]
	Olive River, Qld	66.81[ab]	6636.10[a]	42.39[ab]	18.17[ab]
Medium	Jardine River, Bamaga, Qld	66.76[ab]	6617.80[a]	41.44[abc]	17.72[bc]
	Bensbach WP, PNG	64.13[ab]	6503.80[a]	40.34[bc]	15.17[c]
Poor	Claudie River, Qld	61.56[b]	6414.80[a]	39.71[cd]	16.86[d]
	Bimadebun Village, PNG	61.25[b]	6124.00[a]	37.73[d]	14.87[d]
Overall mean		66.69	6499.45	40.91	16.95

Note: Ind-Indonesia, Qld-Queensland, PNG-Papua New Guinea
Means with the same letter are not significantly different at p = 0.05

different geographic region within their species range or as exotics. The results for specific gravity of *A. auriculiformis* in this study, compared to other studies of the same species grown in other countries, highlight the effects of different environments. It varies from 0.55 to 0.57 in Indonesia (Hazani 1994), 0.57 to 0.64 in Queensland (Keating and Bolza 1982), 0.59 to 0.66 in Thailand (Hazani 1994), 0.72 in India (Kumar et al. 1987) and 0.73 to 0.85 in Serdang, Malaysia (Fred 1994). Thus, the wood produced can vary by latitude, elevation, soil or rainfall differences, depending upon where the trees are grown.

Table 5. Heritability values estimated for wood properties of *A. crassicarpa.*

Wood properties	Parameters	Heritability value
Physical properties	Specific gravity	0.06
	Tangential shrinkage	0.38
	Radial shrinkage	0.44
Mechanical properties	MOR	0.12
	MOE	0.11
	Compression parallel to grain	0.49
	Shear parallel to grain	0.81

On the other hand, *A. crassicarpa* indicates highly significant differences in compression strength parallel to the grain and shear strength parallel to the grain but only a small variation was detected in MOR and MOE. The result of the mechanical tests exhibits a clear relationship with the physical properties whereby the provenances with high values of physical properties also produced high values of strength properties (Abel 1997). Therefore, factors affecting the wood specific gravity for instance, will undoubtedly have a pronounced effect on strength (Haygreen and Bowyer 1982). The heritability estimated for wood properties of *A. crassicarpa* exhibits a wide range—0.06 for specific gravity and 0.81 for shear strength parallel to the grain. The low heritability detected for specific gravity, MOR and MOE in this study indicated that little of the variation was attributable to genetics, whereas most variation in shear strength parallel to the grain was due to genetics.

Although both species were only 4 years of age when this study was conducted, the results provide a preliminary basis for making a selection of the better provenances, especially if wood quality is of major concern. For *A. auriculiformis*, the provenances of Wenlock River, East Alligator and Howard Springs are prime candidates due to the generally faster growth rate and good wood properties. Similar considerations should also be given to *A. crassicarpa* Samlleberr and Olive River provenances. The high heritability value for shear strength parallel to the grain justifies the use of this trait for further improvement work. This trait is not as important as MOR and MOE in selecting provenances for sawn timber, but is important if the end purposes are for the manufacturing of composite panel products.

Since the results for wood properties of both species obtained in this study vary considerably according to where the trees are grown, further planting of the provenances recommended here should be restricted to sites similar to the trial site and selection of stable genotypes across site should also be identified. Apart from that, it is evident that wood differences occur not only because of the influence of provenance or the exotic environment, but also because these trees are fast growing and thus harvested at a young age, resulting in trees with a high proportion of juvenile wood. More research is needed to clarify these matters and this should be devised from the results obtained here and those reported from similar trials by researchers in other countries.

References

Abel, N.N. 1997. Growth performance and genetic variation of selected physical and mechanical properties of *Acacia crassicarpa* A. Cunn ex. Benth provenances. A Project Report. Faculty of Forestry, Universiti Putra Malaysia, Serdang.

Barefoot, A.C., Hitchings, R.G., Ellwood, E.L. and Wilson, E. 1970. The relationship between loblolly pine fiber morphology and kraft paper properties. Bulletin of the North Carolina Agricultural Experiment Station, North Carolina State University, Raleigh, North Carolina Technical Bulletin, 202, 88 p.

Burley, J. and Wood, P.J. 1976. A manual on species and provenance research with particular reference to the tropics. Department of Forestry, CFI. University of Oxford, 7–47.

Chittachumnonk, P. and Sirilak, S. 1991. Performance of *Acacia* species in Thailand. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research, ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 153–158.

Chomcharn, A., Visuthidepakul, S. and Hortrakul, P. 1986. Wood properties and potential uses of 14 fast-growing tree species. Report, Division of Forest Product Research, Royal Forest Department, Thailand.

Fred, T. 1994. Growth performance and selected physical properties of *Acacia auriculiformis* provenances. A Project Report. Faculty of Forestry, Universiti Putra Malaysia, Serdang.

Harwood, C. 1992. Spotlight on species: *Acacia crassicarpa*. Farm Forestry News, 5 (3), 10–11.

Haygreen, J.G. and Bowyer, J.L. 1982. Forest Product and Wood Science. An Introduction. The Iowa State University Press-Mes, 219–225.

Hazani, O. 1994. Physical and mechanical properties of *Acacia mangium* Willd. and *A. auriculiformis* A. Cunn ex. Benth from different sites and provenances. A Project Report. Faculty of Forestry, Universiti Putra Malaysai, Serdang.

Kano, T. and Saiki, H. 1970. On the selection of the basic density in the Japanese red pine wood. Mokuzai Gakkaishi, 16, 305–306.

Keating, W.G. and Bolza, E. 1982. Characteristics, properties and uses of timbers Southeast Asia, Northern Australia and Pacific. Vol. 1. Gordian Productions, Singapore.

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

Kollman, F.F.P. and Cote, W.A.J. 1968. Principles of Wood Science and Technology. Volume I. Springer-Verlag. 592 p.

Kumar, P., Anathanaraya, A.K. and Sharma, S.N. 1987. Physical and mechanical properties of *Acacia auriculiformis* from Karnataka. Indian Forester, 113, 8, 567–573.

Latsamay, S. 1991. Australian acacias in Laos. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 227–228.

Nor Aini A.S., Kamis A. Venkateswarlu, P. and Abdul Latib 1994. Three-year performance of *Acacia auriculiformis* at Serdang, Malaysia. Pertanika. Faculty of Forestry, Universiti Putra Malaysia, Serdang. 7 p.

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

Van Buijtenen, J.P. 1982. Fiber for the Future. TAPPI 65 (8), 10–12.

Weerawardane, N.D.R. and Vivekanandan, K. 1991. Acacia species and provenance trials in uplands of Sri Lanka. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 166–169.

Yang, M. and Zeng, Y. 1991. Results from four-year-old tropical *Acacia* species/provenance trial on Hainan Island, China. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 170–172.

Zobel, B.J. 1963. Improving wood qualities through use of seed from selected parents and the effect of different environmental and growth conditions. Symposium on Wood Quality. North Carolina State Univ. Raleigh, North Carolina, 10 pp.

Zobel, B.J and van Buijtenen, J.P. 1989. Wood Variation. Its Causes and Control. Springer Series in Wood Science.

Results from an *Acacia ampliceps* Provenance–Family Trial on Saltland in Pakistan

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Abstract

Salinity is a serious threat to agricultural production in Pakistan. Several tree and shrub species have been evaluated for survival and growth on salt-affected land in Pakistan, particularly over the last ten years or so, and *Acacia ampliceps* (salt wattle) has proven to be one of the best performing species.

This paper summarises results from a provenance-family trial of *A. ampliceps* conducted on moderately saline-sodic land near Faisalabad (Punjab province) in Pakistan. Significant differences were found both between provenances and between families within provenances for height, crown diameter and crown volume (calculated) at 28 months of age. In addition, there were differences between families within provenances in frost susceptibility. These results indicate significant potential for improving growth traits by selection and breeding.

Good agreement was found between ranking of provenances at seedling stages (glasshouse), 9 months and 28 months (field). This suggests that glasshouse screening is a useful means for selecting potential candidates for field evaluation.

IN Pakistan, approximately 6.5 million ha of agricultural land is adversely affected by soil salinity (Anon. 1996). Ansari et al. (these Proceedings) have provided some background to the causes and possible management options to the salinity problem in Pakistan. Planting trees and shrubs is likely to be a logical choice for salt-affected land because many tree and shrub species are moderately to highly salt-tolerant (Marcar et al. 1995) and most crop plants are not (Maas and Grieve 1994).

Results from several tree species evaluation trials in Pakistan have indicated the existence of significant inter- as well as intra-specific variation in survival and growth for several Australian species. It was considered important that the extent of this variation should be more fully documented by planting provenance–family trials of the most promising species, including *Acacia ampliceps* Maslin and *Eucalyptus camaldulensis* Dehn. In this way appropriate recommendations for which seed sources to use for large-scale planting could be developed. With the use of suitable designs such trials could also later be converted to seedling seed orchards by removal of inferior families and individuals, thus providing improved seed for future plantings.

Acacia ampliceps is a potentially valuable fuelwood and fodder species for the drier subtropics. It produces abundant leaf (phyllode) biomass. It has been shown to be very productive in Pakistan, Thailand, Indonesia and India on neutral to very alkaline/sodic (pH 7–11) and saline soils (EC_e up to 20–30 dS m^{-1}) (McKinnell and Harisetijono 1991; Hussain and Gul 1993; Ansari et al. 1993). *A. ampliceps* is, however, sensitive to periodic waterlogging and flooding. If these conditions prevail, other acacias, such as *A. stenophylla* A. Cunn. ex Benth. and *A. nilotica*, an indigenous species to Pakistan, perform better (Ansari et al. these Proceedings).

This paper reports on the performance of 75 seedlots of *A. ampliceps* included in a provenance-family trial conducted on a saline-sodic site near Faisalabad (Punjab province) in Pakistan.

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Materials and Methods

An *A. ampliceps* provenance-family trial was planted on moderately saline-sodic land at the Nuclear Institute for Agriculture and Biology (NIAB) Bio-saline Research Station (BSRS), Pacca Anna, about 30 km NW of Faisalabad (Punjab province) in late April 1995. Annual average rainfall is moderate (up to 500 mm per year), with the majority falling during July and August. The average summer temperatures are very high (35–40°C) and with high humidity. Soils are generally silty clay loams, sodic (pH range of 8–9) and variably saline. Soil salinity is variable (EC_e (estimated) in the root-zone (0–60 cm) ranges from 5 to 15 dS m^{-1}) but mostly high (>10 dS m^{-1}).

Just prior to initiation of the trial the land was cleared of natural vegetation, leveled and developed into experimental plots. A plot of 100 × 200 m (2 ha) was prepared. Rapid assessments of soil salinity across the experimental site (5 × 5 m grid) were conducted using a hand-held electromagnetic induction device (EM model 38). Using this device, apparent conductivity (EC_a) values were calculated for the 0–60 cm horizon (refer Ansari et al. these Proceedings). In addition, four soil cores (0–60 cm) were taken in each replicate and the $EC_{1:1}$ determined for the 0–30 cm and 30–60 cm depths, for later estimation of EC_a.

Seventy-five families of *A. ampliceps* were planted in the trial (Table 1). Sixty of these families were from five provenances in northern Australia and 15 Pakistani families. The latter are from trees (orginal seed source 80 Mile Beach, WA — CSIRO seedlot number 15762) growing in field trials at BSRS, Pacca Anna and Lahore (Table 1). The Australian provenances represented were chosen on the basis of earlier work conducted by Marcar and others in trials in Pakistan and elsewhere, and in a provenance–family × salinity glasshouse experiment conducted in Australia to select for superior salt and waterlogging tolerance. Seeds were pretreated with hot water and directly sown into polythene bags filled with a silty loam soil/sand mix. Seedlings were established in a nursery at NIAB and were ready for planting out after 5 months.

The trial was laid out as a randomised complete block design with five replicates. Each seedlot was represented by a 5 tree-row plot in each replicate. Thus there were 375 trees per replicate and 1875 trees in total. Trees were spaced at 3 m distance between rows and 2 m spacing within rows. A small amount of gypsum (c. 250 g $plant^{-1}$) was mixed into the soil at the time of planting. Seedlings were planted on the sides of c. 30 cm high ridges and soil around each tree was mulched with kallar grass (*Diplachne fusca*) straw. Irrigation with poor quality canal water (EC of 4–6 dS m^{-1}, sodium adsorption ratio (SAR) about 30–40, residual sodium carbonate (RSC) up to 20 with major ions being sodium, chloride and bicarbonate) has been applied in furrows about five times per year since planting.

Table 1. Identification of provenances used in an *A. ampliceps* provenance–family trial planted on moderately saline-sodic soil near Faisalabad (Pakistan) in April 1995. Provenance ex 15762 refers to seed sampled from trees established from this provenance in earlier trials in Pakistan.

Provenance (CSIRO no.)	No. of families	Location and altitude
Pakistan		
Ex 15762 (LH)	6	seed from 6 experimental trees (15762) at BSRS, Lahore (LH)
Ex 15762 (P)	9	seed from 9 experimental trees (15762) at BSRS, Pacca Anna (P)
	15	
Australia		
14631	10	NE Wave Hill, NT* (17°26′, 130°56′, 230 m)
15735	12	Lake Nongra, NT (18°10′, 129°45′, 300 m)
15738	8	150 km E Hall's Creek, WA (18°8′, 128°43′, 350 m)
15762	23	80 Mile Beach, WA (19°46′, 120°41′, 5 m)
15769	7	Karratha, WA (20°43', 116°51', 1 m)
	60	

* NT is Northern Territory, WA is Western Australia

Mean survival in the trial at three weeks after planting was 94%. Dead seedlings were replaced at this time but not thereafter. Survival, height, crown diameter and stem number were recorded at 3, 9 and 28 months after planting. Crown diameter was determined as the average of measurements in two directions. Crown volume index (CVI) was calculated as

$$CVI = \pi * H * (CD/2)^2$$

where CD is the mean crown diameter and H is the canopy height (i.e. difference between tree height and distance from the ground to the base of the canopy). Stems were counted if they originated close to (within 10 cm) the ground. In addition, frost damage at 28 months was rated subjectively on a four point scale:

1. >75% foliage killed;
2. 75% killed;
3. 50% killed;
4. <25% killed.

The presence (score of 1) or absence (score of 0) of flower buds, flowers and/or seed capsules was also noted at 28 months.

Data were analysed using procedures given in Williams and Matheson (1994). Plot means were subject to analyses of variance using the FIT procedure of the statistical package GENSTAT 5 (Payne et al. 1987) to evaluate magnitude and significance of both provenance and family within provenance variation.

Results

Overall survival at 3, 9 and 28 months was excellent (97, 95 and 92% respectively) and reasonably stable after replanting of dead plants during the first month following initial establishment. At 9 months, mean family survival ranged from 52 to 100% (data not shown) and this situation was unaltered at 28 months (Table 2). Survival at 28 months varied significantly ($p < 0.05$) between provenances but not between families within provenances (Table 3).

Significant differences ($p < 0.05$) were found both between provenances and between families within provenances for the three growth variates, viz. height, crown diameter and CVI, at age 28 months (Table 3). For height and CVI, provenances ranked similarly at both 9 and 28 months (Fig. 1). The Wave Hill (NT) provenance (14631) was clearly the most vigorous, while those from 80 Mile Beach (WA, 15762) and Karratha (WA, 15769) were the least vigorous (Fig. 1). The two provenances from Pakistan, Lahore (ex 15762) and Pacca Anna (ex 15762) both proved intermediate for growth traits to other provenances (CVIs of 34 and 26 m^3 respectively). However, both

Table 2. Mean (and standard error) and range (in parentheses) at 28 months for several growth and morphological variates of *A. ampliceps* provenances and families planted on a moderately saline-sodic site near Faisalabad, Pakistan. Details of measurements made are provided in the text.

Provenance	Survival percentage	Height (m)	Crown volume index (m^3)	Number of stems	Frost damage rating (1–4)
Pakistan					
Ex 15762 (LH)	93±4	3.5±0.1	34±4	2.4±0.1	3.7±0.1
	(76–100)	(3.2–3.9)	(23–36)	(2.0–2.8)	(3.6–3.9)
Ex 15762 (P)	96±1	3.3±0.1	26±2	2.4±9.1	3.7±0.1
	(92–100)	(2.9–3.8)	(20–39)	(1.8–2.9)	(3.5–3.9)
Australia					
14631	93±2	3.9±0.2	46±4	2.6±0.1	3.6±0.1
	(80–100)	(2.8–4.5)	(25–62)	(2.1–2.9)	(2.9–4.0)
15735	92±2	3.1±0.2	26±2	2.7±0.1	3.5±0.1
	(76–100)	(2.1–4.0)	(14–42)	(2.3–3.6)	(3.0–3.8)
15738	96±2	3.5±0.1	36±3	2.3±0.1	3.6±0.2
	(80–100)	(2.7–3.9)	(25–45)	(1.9–2.5)	(2.6–4.0)
15762	89±2	2.9±0.1	23±2	2.5±0.1	3.4±0.1
	(52–100)	(1.8–4.0)	(8–38)	(1.9–3.5)	(2.5– 4.0)
15769	96±2	2.9±0.1	23±1	2.7±0.1	3.3±0.2
	(88–100)	(2.7–3.2)	(20–26)	(2.3–3.2)	(2.7–3.8)

Table 3. Mean squares for analyses of variance based on plot means for height, crown diameter, crown volume index, number of stems and frost damage of *A. ampliceps* at 28 months on a moderately saline-sodic site near Faisalabad, Pakistan.

Source of Variation	Height	Mean crown diameter	Crown volume index	Number of stems	Frost damage	Survival
Provenance	4.19 *	4.69 *	2550.1 *	1.35 ns	0.54 ns	0.11 *
Family within provenance	1.08 *	0.70 *	306.2 *	0.57 ns	0.38 *	0.03 ns
Residual	0.80	0.41	227.7	0.60	0.26	0.03

Note: " * " indicates the factor (*ie.* source of variation) proved to have a significant effect (p 0.05) in an analysis of variance; " ns " indicates the factor did not have a significant effect ($p > 0.05$).

did show superior growth to the trees in the trial sourced directly from the provenance (80 Mile Beach, WA, 15762) from which they originated.

At 9 months mean family heights ranged from 0.8 to 1.8 m, with the tallest individual tree (from Halls Ck provenance, 15738) measured at 2.6 m. At 28 months the range was 1.8 to 4.5 m (Table 2), with the tallest individual tree (from Wave Hill provenance, 14631) measured at 6.0 m. Trees which performed well at 9 months also ranked highly at 28 months. This is demonstrated by the high regression coefficients for the linear regression between heights of individual trees at 9 and 28 months ($r^2 = 0.63$, $p < 0.001$). At 9 months mean family CVI ranged from to 1.1 to 5.8 m^3 and the tree with the greatest crown volume index (from Wave Hill provenance) measured at 15.9 m^3. At 28 months the range was 7.8 to 61.5 m^3 (Table 2) and the tree with the greatest crown volume (also from Wave Hill provenance) measured at 127.9 m^3.

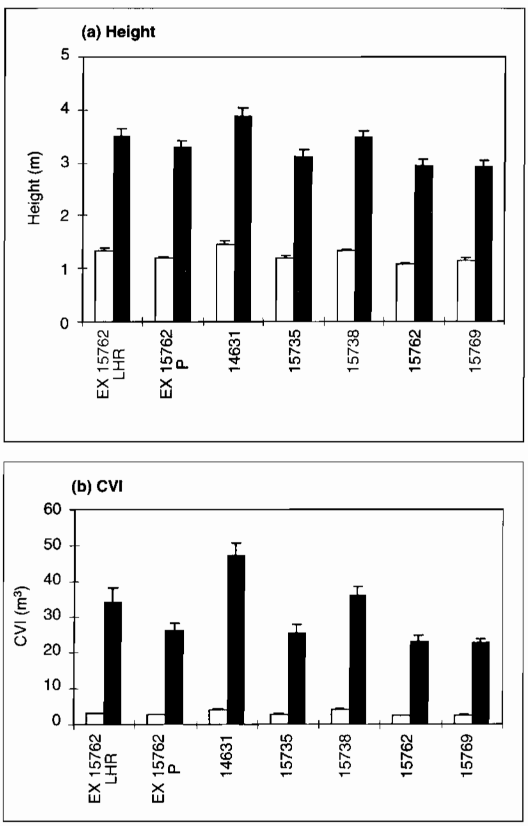

Figure 1. Mean height and crown volume index (CVI) for *A. amliceps* provenances at 9 (clear bar) and 28 months (black bar) on a moderately saline-sodic site near Faisalabad, Pakistan.

Although mean stem number varied both between provenances and between families within provenances, the differences were not significant ($p > 0.05$ — Table 3). Provenances from 80 Mile Beach (WA) and Wave Hill (NT) tended to have the least number of stems (Table 2). The range of mean stem numbers for all families was 1.8–3.6, with the range of actual stem numbers for individual trees being 1 to 7.

Differences in frost susceptibility on a provenance basis proved non-significant ($p > 0.05$). However, families within provenances did show significant differences in this trait (Table 3). The range of mean frost damage ratings for all families was 2.6–4.0 (Table 2) with the most sensitive trees within families (mainly from 80 Mile Beach and Karratha provenances) rating at 1 (greater than 75% of foliage killed by frost). The two Pakistani provenances tended to show less frost damage than the other provenances (average frost damage rating for both was 3.7) including 80 Mile Beach, WA (15762) (average frost damage rating of 3.4) from which they were originally derived.

Discussion

The root-zone salinities at this experimental site were in the moderate to high range (estimated average EC_e (0-60 cm) approximately 5–15 dS m^{-1}) and, since the soils were well drained, there was little opportunity for waterlogging to occur. Under these conditions overall survival was high (greater than 90%), even though some families had low mean survival percentages. The generally high survival at this site accords well with results from other studies (Marcar et al. 1995), however, it would be expected that in the presence of seasonal waterlogging survival might have been much lower (Ansari et al. these Proceedings). This is because *A. ampliceps* has a shallow root system, a feature that prevents it avoiding wet, surface soil conditions that often prevail on sodic sites during monsoonal periods or under excessive irrigation. Under these situations *A. stenophylla* and *A. nilotica* perform better. *A. ampliceps* is also sensitive to long dry spells, because of its surface rooting habit; Marcar (unpubl.) notes that yellowing and premature shedding of phyllodes are common under such conditions in trials in northeast Thailand.

This study has confirmed the very vigorous growth that *A. ampliceps* can achieve on moderate to highly saline land. For example, between 9 and 28 months of age mean CVI across the trial increased from 3.0 to 29.3 m^3 per tree. CVI provides a measure of canopy growth and has been used as a measure of tree leaf area for estimating potential transpiration (e.g.

Biddiscombe et al. 1985). Significant variation in the height growth performance between provenances and between families within provenances of *A. ampliceps* was also revealed. The superior growth performance of the Wave Hill and Halls Creek provenances accords with results from other trials in Pakistan (Ansari et. al. these Proceedings).

The two Pakistani land races proved to be superior to the seed from the natural provenance (seed source 15762) from which they themselves were derived. Seed trees from which seed was collected in Pakistan were chosen with some bias towards healthier, more productive trees. It is not possible to determine what the result would have been if these trees were chosen at random. Despite the good performance of the Pakistani seedlots, they still proved inferior (in all traits) to the best Australian provenance.

Reasons for the better performance of particular seedlots cannot be directly deduced from this study but warrant further investigation, especially specific aspects of their better adaptation to the climates and soils (including salinity). It is likely that their better performance is related in part to their greater frost tolerance. It is of interest that some seedlots and individual trees suffered extensive frost damage (score of 1) whereas the majority were little affected under the prevailing winter minimum temperatures of around 1–2°C. The relationship between growth of individual trees and soil salinity/sodicity has also not yet been determined.

Rankings of provenances based on growth were similar for this field trial to those from a glasshouse experiment conducted in Canberra (Australia) with 28 (seven provenances each with four families) *A. ampliceps* families (N. Marcar et al. unpubl.). In both cases, provenances from Wave Hill (14631) and Halls Creek (15738) were consistently the tallest whereas those from Karratha (15769) and 80 Mile Beach (15762) were the shortest.

Data for shoot dry weights (glasshouse) and crown volume (field) produced similar rankings. Provenance rankings in the glasshouse experiment were not affected by treatments (i.e. salt, waterlogging) imposed. In both cases there was also significant variation between families. This outcome, coupled with the good agreement between 9- and 28-month-old data, suggests that screening of seedling material under controlled conditions can provide a useful and efficient means of predicting later-age field performance.

The high degree of variation in growth traits between families within provenances found in this trial suggests that substantial progress can be made in producing genetically improved seed by converting this trial into a seedling seed orchard through thinning to remove poorer-performing trees. However, a complementary, longer-term approach would be to introduce many families from the best provenances for evaluation and later seed production. The high rates and early onset of flowering will ensure that cross-pollination and therefore high rates of outcrossing can be achieved from relatively early ages. There is already evidence of heavy seed crops in this and other plantings (i.e. age 2 years). Meanwhile the identification of the superior families and provenances is important, as these should be used in farm planting programs until the orchards are producing significant quantities of seed. Whilst the demand for *A. ampliceps* seed is low at present, the developmental work conducted so far will go a long way towards ensuring superior seed is in good supply whenever demand increases.

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References

Anon. 1996. Agricultural Statistics of Pakistan, 1994–95 Government of Pakistan, Ministry of Food, Agriculture and Live Stock, Islamabad.

Ansari, R., Khanzada, A.N. and Khan, M.A. 1993. Acacias for rural, industrial and environmental development in Pakistan. In: Awang, K. and Taylor, D.A, ed., Acacias for Rural, Industrial and Environmental Development. Winrock International and FAO, Bangkok, Thailand, 63–70.

Biddiscombe, E.F., Rogers, A.L., Greenwood, E.A.N. and De Boer, E.S. 1985. Growth of tree species near salt seeps, as estimated by leaf area, crown volume and height. Australian Forest Research, 15, 141–154.

Hussain, A. and Gul, P. 1993. Selection of tree species for saline and waterlogged areas in Pakistan. In: Davidson, Neil and Galloway, Richard, ed., Productive Use of Saline Land. ACIAR Proceedings No. 42, Australian Centre for International Agricultural Research, Canberra, 53–55.

Maas, E.V. and Grieve, C.M. 1994. Salt tolerance of plants at different stages of growth. In: Naqvi, S.S.M, Ansari, R., Flowers, T.J. and Azmi, A.R., ed., Current Developments in Salinity and Drought Tolerance of Plants. AEARC, Tandojam, Pakistan, 181–197.

Marcar, N.E., Crawford, D.F., Leppert, P., Jovanovic, T., Floyd R. and Farrow, R. 1995. Trees for Saltland: a guide to selecting native species for Australia. CSIRO Press, Melbourne, Australia.

McKinnell, F.H. and Harisetijono 1991. Testing *Acacia* species on alkaline soils in West Timor. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35, Australian Centre for International Agricultural Research, Canberra, 183–188.

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. Oxford University Press, New York.

Williams, E.R. and Matheson, A.C. 1994. Experimental Design and Analysis for Use in Tree Improvement. CSIRO, Canberra. 169 p.

Performance of *Acacia auriculiformis* in Second-generation Progeny Trials in Thailand

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Abstract

Two progeny trials of *Acacia auriculiformis* were established using open-pollinated seed from selected trees in first-generation seedling seed orchards. In total there were 106 families of which 13 came from three original Thai land races, 47 from four original Papua New Guinea provenances, 25 from six original Queensland provenances and 21 from seven original Northern Territory provenances. In addition, two local unimproved seed trees were included. Height and diameter assessed 24 months after planting confirmed the very poor growth rate of all Thai selections compared with families from Papua New Guinea and from Queensland and Northern Territory, Australia. Families from the Queensland provenance region were generally more productive than their counterparts from Papua New Guinea and Northern Territory. On the basis of these results it is proposed to focus on selected genetic material from Australia and Papua New Guinea for the improvement program of this species in Thailand.

ACACIA *auriculiformis* was first introduced into Thailand from Australia in 1935. It has since been planted widely for ornamental and rehabilitation purposes, due to its rapid early growth and adaptability to a wide range of climatic and soil conditions. However, plantations of *A. auriculiformis* have never been seriously adopted by farmers because of the propensity of the species to produce multiple leaders and crooked stems, restricting its use as poles or other forms of timber that require reasonable length. In 1984, a tree improvement program for *A. auriculiformis* was initiated by the Royal Forest Department with a specific objective to improve the stem form, while at the same time maintaining or increasing vigour (Pinyopusarerk 1987). Candidate plus trees based on vigour, single and straight stem (bole length exceeding 6 m) and freedom from pests and diseases were selected from all major plantations in Thailand during 1983–1987.

In 1989 open-pollinated seed from these candidate plus trees and from the natural populations in Australia and Papua New Guinea were planted in three progeny trials (which were later to be converted to seedling seed orchards), using five-tree row plots in six replicates, for assessment of genetic variation. Results from these trials revealed considerable variation in growth traits and stem form among families and different provenance origins (Luangviriyasaeng et al. 1995). All provenances from Papua New Guinea and Australia were found to out-perform all Thai selections in height and diameter growth.

After the first major growth assessment at 24 months, the progeny trials were thinned to only one best (largest and straightest) tree per family plot. The first major seed collection was carried out in 1993, focusing, in general, on the best two or three trees in each family to form the basis for a new breeding population. Selected families, representing most of the original provenances, were planted in two second-generation progeny trials/seedling seed orchards. Height and diameter growth measured 24 months after planting is reported in this paper.

Materials and Methods

Seedlots

One hundred and six families in the first-generation progeny trials/seedling seed orchards were selected. The selection was based on better-than-average

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vigour and good stem form (long bole and straight stem) for each of the respective provenance origins. The 106 trees were made up of 13 trees descended from three original Thai candidate plus trees, 47 trees from four original Papua New Guinea provenances, 25 trees from six original Queensland provenances and 21 trees from seven original Northern Territory provenances. The details of these families and their original mother trees are shown in Table 1. In addition, two local unimproved seed trees were included in one of the two trials to compare their performance with the improved material from the first-generation seedling seed orchards.

Table 1. List of families of *Acacia auriculiformis* planted in second generation progeny trials in Thailand.

Group		Seedlot No.	Origin of mother trees	No. of families
1	Thailand region	1	Prachuap Khirikhan	7
		2	Nakhorn Ratchasima	1
		3	Rayong	5
			Subtotal	13
2	Papua New Guinea region	4	Bensbach	3
		5	Balamuk	5
		6	Mibini	36
		7	Old Tonda Village	3
			Subtotal	47
3	Queensland, Australia	8	SW of Coen River	3
		9	WNW of Coen River	5
		10	S of Coen	5
		11	Wenlock	8
		12	Morehead River	1
		13	Kings Plain	3
			Subtotal	25
4	Northern Territory, Australia	14	Manton River	1
		15	Douglas River	5
		16	Goomadeer River	3
		17	Mann River	2
		18	Alligator River	8
		19	Elizabeth River	1
		20	Melville Island	1
			Subtotal	21
5	Local unimproved seed trees	21*	Kuiburi	2
			Total	108

*Local unimproved seed trees planted at one site only

Planting sites

Two replicated trials were established in the provinces of Chanthaburi and Prachuap Khirikhan (Kuiburi) in August 1994.

The Chanthaburi site (latitude 13°N, longitude 102°15′E, altitude 200 m) has a mean annual rainfall of 1400 mm and mean annual temperature 27°C. The soil is dark yellow brown, sandy loam, pH 5.5–6.5.

The Kuiburi site (latitude 12°05′N, longitude 99°45′E, altitude 30 m) has a mean annual rainfall of 1180 mm and mean annual temperature 27.4°C. The soil is sandy loam, pH 7.3.

The planting sites were disc-ploughed twice before the rainy season. Within two months after planting and following cultivation, 100 g of complete fertiliser (15:15:15) was applied to each plant. Weed competition was controlled by manual weeding.

Experimental design

Resolvable row-column designs were employed for both experiments. The design generation package ALPHA+ (Williams and Talbot 1993) was used to produce randomisations for eight replicates each containing 14 rows and eight columns. Each family plot consisted of a row of four trees spaced at 1.5 m intervals. The space between rows was 3 m.

To further increase the effectiveness in the randomisation, the families from the 21 seed sources were grouped into five regions. These were Thailand, Papua New Guinea, Queensland (Australia), Northern Territory (Australia) and local (for Kuiburi site only).

Measurement

Trees were measured for height (*H*) and diameter (*D*) at 1.3 m from ground level. Volume of individual trees (V) was calculated using the expression

$$V = 1/3\pi(D/2)^2H$$

Statistical analysis

Data analyses were carried out following the methods described by Williams and Matheson (1994). Plot means were analysed using a mixed model where replicates and families were treated as fixed effects and row and column within replicates as random effects. Residual maximum likelihood (REML) analysis within the statistical package Genstat 5 (Payne et al. 1987) was used for estimation of family means of height, diameter and volume. Estimated family means were then analysed to incorporate the treatment structure present in the families, namely five regions and seed sources within regions.

An analysis across the two sites was performed to examine the significance of the site × family interaction, following the procedures set out in Williams and Matheson 1994, Chapter 5.

By treating family, row and column within replicate as random effects and replicate, seed source and region as fixed effects (Williams and Matheson 1994, p 100), narrow-sense heritabilities (h^2) were

Table 2. Mean squares for analysis of variance for mean height, diameter and volume at 24 months of *Acacia auriculiformis* in the second generation of progeny trials in Thailand.

Source	df	Height (m)	Diameter (cm)	Volume ($m^3 \times 10^{-4}$)
Chanthaburi region	3	24.9677***	72.4906***	59810.3***
Region.seedlot	16	1.3960^{ns}	2.3530^{ns}	2358.1^{ns}
Region.seedlot.family	86	1.047***	1.8472***	1797.5***
Residual	734	0.4686	0.723	675.2
Kuiburi region	4	44.5661***	87.4160***	80732.0***
Region.seedlot	16	1.8559^{ns}	2.7688^{ns}	3392.7*
Region.seedlot.family	85	1.2075***	1.6144***	1913.8***
Residual	734	0.7144	0.7496	878.2

* and *** indicate significant differences at 5 and 0.1% respectively
ns indicates not significant differences at 5% level

Table 3. Mean height, diameter at breast height and volume per tree at 24 months of *Acacia auriculiformis* in the second generation progeny trials in Thailand.

No.	Chanthaburi			Kuibuir		
	Height (m)	Diameter (cm)	Volume ($m^3 \times 10^{-4}$)	Height (m)	Diameter (cm)	Volume ($m^3 \times 10^{-4}$)
Thailand region						
1	6.5	5.1	49.4	7.3	5.5	65.6
2	6.3	5.5	50.7	7.0	5.3	59.8
3	6.5	5.3	54.0	7.2	5.6	69.6
Mean	6.5	5.2	51.3	7.2	5.5	66.7
Papua New Guinea region						
4	6.9	6.5	81.2	7.7	7.0	110.7
5	6.9	6.4	81.7	7.9	7.3	119.3
6	7.0	6.5	85.4	7.8	6.9	109.1
7	7.1	6.6	89.2	7.8	7.0	110.6
Mean	7.0	6.5	85.0	7.8	7.0	110.4
Queensland region						
8	7.7	7.2	114.3	8.3	6.9	115.5
9	7.6	7.2	109.7	8.2	7.1	116.5
10	7.1	6.6	88.9	8.3	7.2	125.5
11	7.4	6.8	96.0	8.0	7.1	118.4
12	7.6	7.2	108.3	8.7	7.7	145.4
13	7.7	7.0	105.4	8.7	7.6	138.9
Mean	7.4	6.9	101.0	8.3	7.2	122.8
Northern Territory region						
14	7.0	6.8	87.9	8.1	7.1	113.7
15	7.0	6.0	73.7	7.9	6.6	94.9
16	7.3	6.7	88.3	7.8	6.7	102.0
17	7.7	7.0	103.3	8.5	7.5	135.8
18	7.1	6.1	72.6	7.7	6.5	97.1
19	7.0	6.0	72.7	8.3	6.9	106.4
20	6.4	5.4	52.4	7.0	5.3	63.0
Mean	7.1	6.2	77.8	7.9	6.7	100.6
Local						
21	*	*	*	5.3	3.9	21.1
Grand mean	7.0	6.4	83.2	7.8	6.8	106.0
LSD	0.97	1.35	40.78	1.03	1.23	41.37
H^2	0.26	0.27	0.28	0.10	0.15	0.15

estimated for height and diameter using the expression

$$h^2 = 3.5\sigma_f^2/(\sigma_f^2 + \sigma_m^2 + \sigma_t^2)$$

where σ_f^2, σ_m^2 and σ_t^2 are variance components for families within provenances, between plots within rows and columns (within replicates) and between trees within plots, respectively (Williams and Matheson 1994, Chapter 6).

Results

There was significant variation ($p < 0.001$) in height, diameter and volume per tree between regions and between families within seed sources whilst the differences between seed sources within regions were significant ($p < 0.05$) for volume per tree only at one site (Table 2). The overall growth performance on regional basis was similar at both sites although the growth rate at Kuiburi was greater than that at Chanthaburi.

Despite considerable variation among families within seed sources, the results show clear evidence of variation among regions. Trees descended maternally from the original Queensland provenance region were clearly the fastest growing while those from Thai selections were the slowest. At Chanthaburi the means for Queensland region for height, diameter and stem volume were 7.4 m, 6.9 cm and 101.0 $m^3 \times 10^{-4}$ respectively, compared with 6.5 m, 5.2 cm and 51.3 $m^3 \times 10^{-4}$ respectively for Thai selections (Table 3). Similarly at Kuiburi, the means for Queensland region for height, diameter and stem volume were 8.3 m, 7.2 cm and 122.8 $m^3 \times 10^{-4}$ respectively, compared with 7.2 m, 5.5 cm and 66.7 $m^3 \times 10^{-4}$ respectively for Thai selections (Table 3).

The mean values recorded for Papua New Guinea and the Northern Territory regions were intermediate, and both were also significantly greater than that of the Thai selections. The trees originated from Thai land races, though being the poorest among the material from the first generation were much more productive than unimproved seed from local source; this was evident at the Kuiburi planting site (Table 3).

The differences in height and diameter growth among seed sources within regions were relatively small, and non-significant at both planting sites. There did not appear to be a consistent trend of provenance ranking within a given region at both sites. Nevertheless, it is noted for the Northern Territory region that the family of Melville Island provenance (No. 20) was the slowest growing, and trees from Mann River (No. 17) were most vigorous at both planting sites (Table 3).

Estimates of narrow-sense heritabilities for height and diameter differed between planting sites (Table 3). The heritability estimates for height at Chanthaburi and Kuiburi were 0.26 and 0.10 respectively, and for diameter the values were 0.27 and 0.15 respectively.

An analysis of variance across sites revealed a significant family × site interaction for diameter and volume but not for height (Table 4).

Table 4. Mean squares for family × site interaction for mean height, diameter and volume per tree.

Source	Df	Height (m)	Diameter (cm)	Volume ($m^3 \times 10^{-4}$)
Site	1	32.756	8.225	27375.5
Family	105	0.359	0.817	801.9
Site.family	103	0.084^{ns}	0.162**	155.1**
Residual (pooled)	1448	0.074	0.092	96.9

** indicates significant differences at p < .01
ns indicates not significant differences at p < .05

Discussion

Despite a significant improvement in growth rate of the Thai selections as compared with local unimproved seed, they are still out-performed by families which have their original mother trees from Australia and Papua New Guinea. The persistently inferior performance of Thai land races compared to exotic sources, carrying over from the first generation, suggests a high degree of inbreeding and perhaps negative selection that has built up over many generations. There are no records of new imports of germplasm of *A. auriculiformis* between the first introduction to Thailand in 1935 and when the Royal Forest Department embarked on a tree improvement program for the species in 1984. On the basis of these results, it is proposed to remove all the remaining Thai families in the first generation progeny trials in a process of conversion to seedling seed orchards.

Provenance variation in growth and form of *A. auriculiformis* has been examined in many countries, including Australia (Harwood et al. 1991), Indonesia (Otsamo et al. 1996), Malaysia (Nor Aini et al. 1994; Bernard 1996), Thailand (Luangviriyasaeng et al. 1991), Vietnam (Nguyen Hoang Nghia and Le Dinh Kha 1996) and Zaire (Khasa et al. 1995). In general, provenances from Papua New Guinea have been shown to be more productive than those from Queensland and Northern Territory, Australia. In addition, provenances from Queensland have the lowest occurrences of multistemmed trees. However, the results obtained in the second generation progeny trials in Thailand showed that material from female parents originating from Queensland provenance performed better than their counterparts from Papua New Guinea and Northern Territory. The vigorous growth rate of the trees from Queensland parents is an encouraging result because of their potential to produce single stemmed trees. Stem form has not yet been assessed for these second generation trials and will be included in future measurements.

Differences between seed sources within regions appeared to be small. This is most likely due to the fact that only the best families of each provenance growing in the first generation progeny trials were planted in these trials. More than half of the original provenances were represented only by the best one to three trees, which appears to account for the small variation within each region.

Estimates of individual heritability for height and diameter for *A. auriculiformis* in this study are within the range reported for open-pollinated progeny trials of fast-growing hardwood species such as *Eucalyptus tereticornis* (Kedharnath and Vakshasya 1978) and *E. camaldulensis* (Pinyopusarerk et al. 1996). The trial at Kuiburi gave lower narrow-sense heritability estimates than at Chanthaburi. This is due to the more variable growth of trees at the former site. The results suggest that further improvement can be made through selection within the best families from the best provenance regions.

Rapid early growth is a desirable characteristic for growing *A. auriculiformis* in Thailand. Young trees are susceptible to a beetle, *Sinoxylon* sp. which girdles the leading shoot and small branches up to 1.5 cm in diameter, causing the stem or branches to break at the point of attack (Pinyopusarerk 1990). This is of concern because if the main stem is broken at low height the tree will develop multiple leaders and reduce the length of clear bole. Therefore the faster the young tree can grow the lesser chance its main stem will be broken by *Sinoxylon* beetle. Most of the trees from Queensland, Papua New Guinea and Northern Territory parents appear to meet this important criterion, and will form the basis for the genetic improvement program of *A. auriculiformis* in Thailand. The program will also introduce new genetic material from Australia and Papua New Guinea to maintain a broad genetic base in future breeding populations.

Although the second-generation progeny trials were planted on two sites only, i.e. one each in eastern and southwestern Thailand, these sites are very different in the climate and soil conditions. The results of the analysis across sites (Table 4) showed that the mean square values for site × family were much less than that for family, even for diameter and volume where site × family interaction was significant. This indicates that it will not be necessary to have separate breeding programs for this species for eastern and southwestern Thailand.

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References

Bernard, A. 1996. Provenance trial of *Acacia auriculiformis* A. Cunn. Ex Benth.: the Sabah experience. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings QFRI-IUFRO conference, Caloundra, Queensland, Australia, 27 October–1 November 1996. Gympie: Queensland Forest Research Institute, 182–184.

Harwood, C.E., Matheson, A.C., Gororo, N. and Haines, M.W. 1991. Seed orchards of *Acacia auriculiformis* at Melville Island, Northern Territory, Australia. In Turnbull, J.W., ed., Advances in Tropical Acacia Research. Proceedings of an international workshop held in Bangkok, Thailand, 11–15 February 1991. ACIAR Proceedings No. 35, 87–91.

Kedharnath, S and Vakshasya, R.K. 1978. Estimates of components of variance, heritability and correlations among some growth parameters in *Eucalyptus tereticornis*. Proceedings. FAO Third World Consultation on Forest Tree Breeding Vol. 2, CSIRO, Canberra, 667–676.

Khasa, P.D., Cheliak, W.M. and Bousquet, J. 1995. Early evaluation of *Racosperma auriculiformis* and *R. mangium* provenance trials on four sites in Zaire. Forest Ecology and Management, 78, 99–113.

Luangviriyasaeng, V., Pinyopusarerk, K and Williams, E.R. 1991. Results at 12 months of *Acacia auriculiformis* trials in Thailand. In: Turnbull, J.W. ed., Advances in Tropical Acacia Research. Proceedings of an international workshop held in Bangkok, Thailand, 11–15 February 1991. ACIAR Proceedings No. 35, Australian Centre for International Agricultural Research, Canberra, 77–81.

Luangviriyasaeng, V., Pinyopusarerk, K., Pitpreecha, K. Simsiri, A. and Kiatvuttinand, B. 1995. Early growth of *Acacia auriculiformis* progeny trials. Thai Journal of Forestry, 14, 81–93.

Nguyen Hoang Nghia and Le Dinh Kha 1996. *Acacia* species and provenance selection for large-scale planting in Vietnam. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings QFRI-IUFRO conference, Caloundra, Queensland, Australia, 27 October–1 November 1996. Gympie: Queensland Forest Research Institute, 443–448.

Nor Aini, A.S., Awang, K., Venkateswarlu, P. and Abd Latib Senin. 1994. Three-year performance of *Acacia auriculiformis* provenances at Serdang, Malaysia. Journal of Tropical Agricultural Science, 17, 95–102.

Otsamo, A.O., Nikles, D.G. and Vuokko, R.H.O. 1996. Species and provenance variation of candidate acacias for afforestation on *Imperata cylindrica* grassland in South Kalimantan, Indonesia. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings QFRI-IUFRO conference, Caloundra, Queensland, Australia, 27 October–1 November 1996. Gympie: Queensland Forest Research Institute, 46–50.

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, W.G. 1987. Genstat 5 Reference Manual, Oxford University Press, Clarendon, 749 p.

Pinyopusarerk, K. 1987. Improving *Acacia auriculiformis* through selection and breeding in Thailand. In: Turnbull, J.W. ed., Australian Acacias in Developing Countries. Proceedings of an international workshop held at the Forestry Training Centre, Gympie, Queensland, Australia, 4–7 August 1986. ACIAR Proceedings No. 16, Australian Centre for International Agricultural Research, Canberra, 147–148.

Pinyopusarerk, K. 1990. *Acacia auriculiformis*: An Annotated Bibliography. Winrock International and Australian Centre for International Agricultural Research, 154 p.

Pinyopusarerk, K., Doran, J.C., Williams, E.R. and Wasuwanich, P. 1996. Variation in growth of *Eucalyptus camaldulensis* provenances in Thailand. Forest Ecology and Management, 87, 63–73.

Williams, E.R. and Matheson, A.C. 1994. Experimental Design and Analyses for Use in Tree Improvement. CSIRO, Melbourne.

Williams, E.R. and Talbot, M. 1993. ALPHA + : Experimental Design for Variety Trials. Design User Manual. CSIRO, Canberra and SASS, Edinburgh.

Variation in Growth Traits of a Six-year *Acacia aulacocarpa* Progeny Trial in Thailand

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Abstract

Variation in growth and stem form of 169 open-pollinated families from 15 natural provenances of *Acacia aulacocarpa* distributed in Papua New Guinea (PNG) was assessed at 6 years of age. The 15 provenances came from three broad regions, namely PNG north of the Fly River (PNG-N), PNG southwest of the Fly River (PNG-SW) and PNG southeast of the Fly River (PNG-SE). There were marked differences between provenances in height, diameter, stem volume and stem form with the provenances from PNG-SE, especially those distributed along the Oriomo River, being more productive. Trees of all provenances were typically single-boled up to 75% of total height, although stem straightness varied substantially between families. The results indicate a great potential for selection of the best families as well as the best individuals within each family for next generation breeding populations.

THE potential of *Acacia aulacocarpa* as a plantation species has been recognised. It is one of the four tropical acacias (the others being *A. auriculiformis*, *A. crassicarpa* and *A. mangium*) which have received the highest priority for genetic assessment and improvement in the humid and subhumid tropics by the Consultative Group for Research and Development of Acacias (COGREDA) (Awang and Taylor 1992).

Four provenances of *A. aulacocarpa*, two each from Papua New Guinea (PNG) and Queensland, Australia, were introduced to Thailand in 1985. The species was among more than 60 Australian tree and shrub species which were planted in collaborative species trials between the Royal Forest Department and CSIRO Forestry and Forest Products supported by Australian Centre International Agricultural Research (ACIAR) during 1985–86 (Pinyopusarerk 1989). *Acacia aulacocarpa* was found to survive well but growth rate and form varied considerably between provenances (Pinyopusarerk 1989; Chittachumnonk and Sirilak 1991). The two provenances from PNG grew much faster than those from Queensland. Many individuals of the PNG provenances were also reported to exhibit excellent stem form and strong apical dominance. In contrast, the Queensland provenances grew as large shrubs, placing them in a less favourable position as plantation candidates. The better growth performance of PNG over Australian provenances has also been reported in Australia (Ryan and Bell 1989) and China (Pan et al. 1988; Yang et al. 1989).

For the purpose of further assessing the genetic variability of *A. aulacocarpa* and to set up a base population of the species, a progeny trial (later to be converted to a seedling seed orchard) was established with seed from natural populations in PNG. Queensland provenances were excluded because of their shrub form and slower growth. This paper reports some of the results at 6 years of age.

Materials and Methods

Seed and seedlings

There were in total 15 provenances comprising 169 families (open-pollinated seed from 169 trees) from trees growing naturally in PNG (Table 1). Figure 1 shows locations of these provenances. The 15 provenances came from three broad regions, namely:

PNG-N: PNG north of the Fly River
PNG-SW: PNG southwest of the Fly River
PNG-SE: PNG southeast of the Fly River

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Table 1. Detail of provenances of *Acacia aulacocarpa* in a progeny trial in Thailand. All seedlots are from Western Province, Papua New Guinea.

CSIRO Seedlot No.	Location	Latitude (S)	Longitude (E)	Altitude (m)	No. of families
PNG-N					
16946	Balimo	8° 05′	142° 58′	12	20
16947	Makapa	7° 56′	142° 35′	15	16
16948	Isago	8° 01′	142° 41′	10	8
16949	Duaba	8° 13′	142° 58′	25	11
16950	Wasua	8° 17′	142° 52′	10	20
PNG-SW					
16988	Pongaki	8° 40′	141° 51′	30	4
16989	Derideri	8° 40′	141° 50′	30	5
16995	Arufi	8° 43′	141° 55′	25	8
16996	Bimedebun	8° 38′	142° 03′	40	12
17560	Dimisisi	8° 31′	142° 13′	50	15
PNG-SE					
16976	Wipim	8° 47′	142° 52′	50	17
16981	Kapal	8° 37′	142° 47′	40	5
16985	Woroi, Oriomo River	8° 52′	143° 08′	20	3
16998	Sawmill, Oriomo River	8° 49′	143° 06′	10	15
17549	Old Zim, Oriomo River	8° 48′	143° 06′	20	10
	Total				169

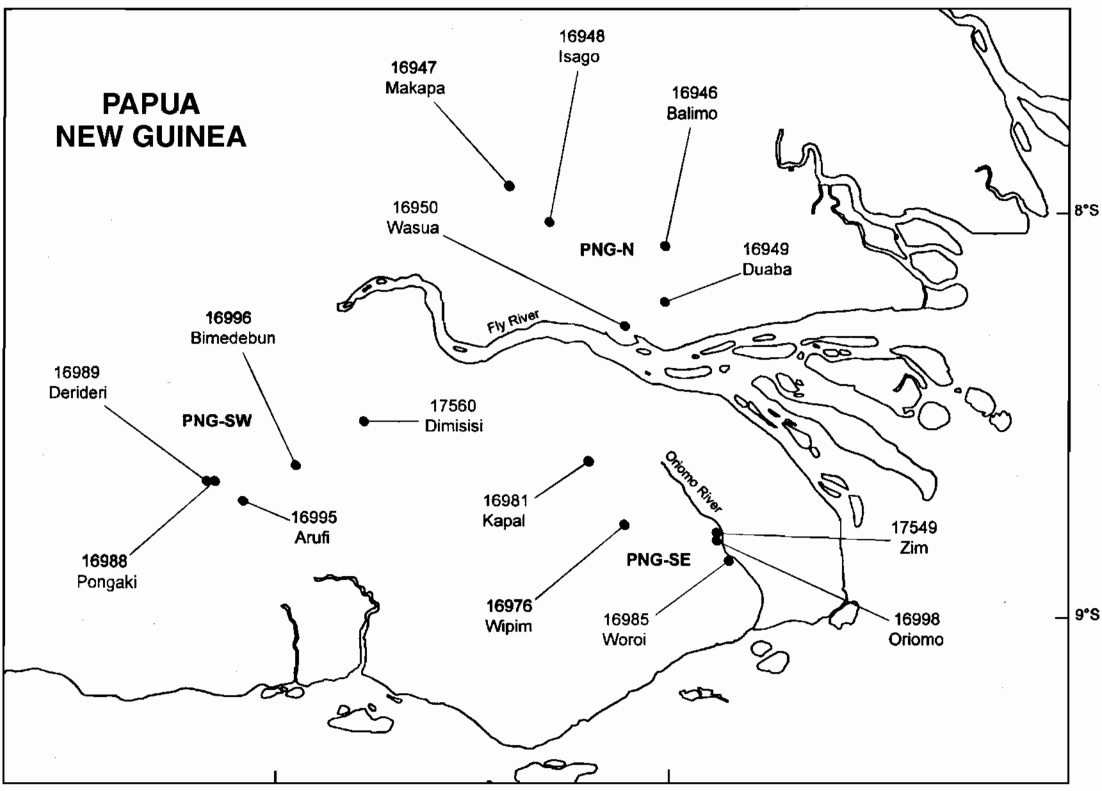

Figure 1. Location of *Acacia aulacocarpa* seedlots in Papua New Guinea.

The seedlings were raised as tubed stock in a nursery for 5 months before outplanting in July 1990.

Planting site

The planting site is located at Sakaerat, Nakhon Ratchasima province (latitude 14°58′N, longitude 120°05′E, altitude 540 m). The area receives a mean annual rainfall of 1300 mm. The mean annual temperature is 25.9°C. The soil is dark reddish brown, sandy to clay loam, pH 5–6. The site was formerly a dry evergreen forest that had been cleared for agriculture. *Imperata cylindrica* grass is prevalent.

The site was fully cultivated prior to planting. Weed competition was controlled by manual weeding and weedicide application. Soil cultivation between tree rows to reduce fire hazard was also carried out in the dry season during the first 3 years.

Experimental design

The trial was established using an incomplete block design, with the randomisation being generated following alpha designs described in Williams and Matheson (1994). There were six replicates, each consisting of 13 incomplete blocks of 13 plots. Each plot consisted of a row of five trees. The spacing was 1.5 m between trees within rows and 3 m between rows.

The trial was thinned to one tree per plot 2 years after planting by removing four trees in each family row plot, retaining only the tallest and straightest tree in each plot.

Measurement and assessment

Ten growth traits were assessed for this trial at 6 years after planting. Only five, however, are addressed in this paper. These are:

- Height (H (m))
- Diameter at breast height (D (cm))
- Overbark volume per tree ($m^3 \times 10^{-4}$)
- Axis persistence (1–6)
- Stem straightness (1–4)

Height refers to the total tree height. If there was more than one stem, the tallest was measured.

Diameter at breast height refers to the stem diameter 1.3 m from ground level. For multistemmed trees, diameter was measured on all stems if forking or multiple leaders originated less than 1.3 m above the ground. A branching bole is considered a stem if its diameter was equal to or greater than half of the diameter of the principal bole at the same height. The diameter was calculated using the following equation

$$D = (d_1 2 + d_2^2 + \ldots d_n^2)^{1/2}$$

Where $d_1, d_2 \ldots d_n$ are the diameter of the stems taken at 1.3 m from ground level.

Individual tree volume was calculated for each tree using the equation

$$V = 1/3\pi(D/2)^2 H$$

Axis persistence reflects the ability of the tree to retain its primary axis. It was scored on a scale of 1–6.

1 Double or multiple stems from ground level
2 Axis loses persistence in the first (lowest) quarter of the tree
3 Axis loses persistence in the second quarter of the tree
4 Axis loses persistence in the third quarter of the tree
5 Axis loses persistence in the fourth quarter of the tree
6 Complete persistence

Stem straightness was scored on a scale of 1–4. It was recorded only for the trees which scored 4–6 in the axis persistence.

1 Very crooked, > two serious bends
2 Slight crooked, > two small bends and < two serious bends
3 Almost straight, one–two small bends
4 Completely straight

Statistical analysis

Analysis of variance for plot values of all five variates was carried out using the statistical package Genstat 5 (Payne et al. 1987). The following linear model was fitted to plot mean data:

$$Y_{ijkl} = \mu + \text{replicate}_i + \text{region}_j + \text{region}_j.\text{provenance}_k + \text{region}_j.\text{provenance}_k.\text{family}_l + \varepsilon_{ijkl}$$

where Y_{ijkl} = plot mean, μ = overall mean and ε_{ijkl} = residual

Results

Table 2 summarises the results of statistical analyses. There were significant differences between the three broad provenance regions in all growth parameters. Differences between provenances within regions were significant in diameter, axis persistence and stem straightness whilst differences between families with provenances were significant for all growth parameters except for individual tree volume.

Despite variation among families within provenances the results show clear evidence of variation between regions and between provenances within regions in most growth parameters. Of the three broad provenance regions, provenances from PNG-SE were generally more productive than those from PNG-N and PNG-SW (Table 3). The means for PNG-SE region for height, diameter and stem volume for PNG-SE were 12.5 m, 17.7 cm and 106.9 $m^3 \times 10^{-4}$ respectively, compared to 12.2 m, 17.0 cm and 95.8 $m^3 \times 10^{-4}$ respectively for PNG-N, and 12.1 m, 16.6 cm and 90.9 $m^3 \times 10^{-4}$ respectively for PNG-SW. Growth rates of provenances from PNG-SW region were all below the overall means (Table 3).

Whilst axis persistence differed markedly between families and between regions, most provenances appeared to have the first fork at 75% of total height, thus no significant difference in this trait. It is noted that provenances along the Oriomo River (Woroi (16985), Oriomo Sawmill (16998) and Old Zim (17549)), which were among the fastest growers, also had very strong apical dominance. PNG-N had the lowest regional mean.

Stem straightness differed considerably between provenances within and between regions. PNG-SE recorded the highest regional mean and the fast-growing provenances along the Oriomo River all had better-than-average stem straightness (Table 3). Provenances from Pongaki (16988) in PNG-SW and Isago (16948) in PNG-N recorded the poorest stem straightness.

Table 2. Mean squares for analysis of variance of *Acacia aulacocarpa* progeny trial at 6 years in Thailand.

Source	Df	Height	Diameter	Volume	Df	Axis persistence	Df	Stem straightness
Replicate	5	53.478	80.376	25140	5	9.406	5	11.715
Region	2	10.084**	84.999***	19770***	2	5.313**	2	2.113**
Region.provenance	12	2.074^{ns}	49.155***	8376***	12	1.759^{ns}	12	1.115***
Region.prov.family	154	1.516*	9.394*	1449^{ns}	154	2.176**	154	0.686***
Residual	775	1.209	7.686	1266	763	1.586	553	0.387

*, ** and *** indicate significant differences at P < 0.05, P.01 and P < .001 respectively
ns indicates not significant differences at P < 0.05

Table 3. Mean height, diameter, volume per tree, axis persistence and stem straightness at age 6 years of *Acacia aulacocarpa* in progeny trial in Thailand.

CSIRO Seedlot No.	Location	Height (m)	Diameter (cm)	Volume ($m^3 10^{-4}$)	Axis persistence	Stem straightness
PNG-N						
16946	Balimo	12.1	16.7	91.0	4.28	2.08
16947	Makapa	12.3	17.5	101.4	4.18	2.06
16948	Isago	12.3	17.4	101.6	4.43	1.98
16949	Duaba	12.1	16.7	93.2	4.24	2.03
16950	Wasua	12.2	16.9	95.3	4.47	2.28
Mean		12.2	17.0	95.8	4.31	2.11
PNG-SW						
16988	Pongaki	12.1	16.8	93.4	4.39	1.88
16989	Derideri	12.0	16.7	91.5	4.77	2.06
16995	Arufi	12.2	16.6	90.7	4.29	2.30
16996	Bimedebun	12.3	15.8	81.6	4.57	2.07
17560	Dimisisi	12.1	17.0	97.5	4.55	2.30
Mean		12.1	16.6	90.9	4.49	2.17
PNG-SE						
16976	Wipim	12.2	16.2	88.3	4.47	2.11
16981	Kapal	12.5	17.7	108.6	4.08	2.15
16985	Woroi, Oriomo River	12.5	17.9	108.2	4.46	2.27
16998	Sawmill, Oriomo River	12.7	19.4	129.6	4.64	2.33
17549	Old Zim, Oriomo River	12.6	17.4	103.5	4.71	2.38
Mean		12.5	17.7	106.9	4.53	2.26
Overall mean		12.3	17.1	97.8	4.43	2.17
LSD (provenances with region)		0.55	1.37	17.6	0.63	0.31
LSD (region)		0.17	0.42	5.4	5.4	0.09

Discussion

The results indicate marked genetic variation in both growth and stem form between provenances of *A. aulacocarpa* in Papua New Guinea with the provenances in the southeastern occurrence being most productive among the three broad provenance regions. The fast-growing provenances are those which occur along the Oriomo River (seedlots 16985, 16998 and 17549), the most eastern part of the natural occurrence in Papua New Guinea. In addition, two provenances in PNG-N region, i.e. Makapa (16947) and Isago (16848) also grew well. Pan et al. (1988) have found Oriomo provenance to be more productive than other western provenances in trial planting in southern China. However, a trial in Fiji using a subset of families of the same provenances reported here showed that the fastest provenance was from Isago, north of the Fly River (Thomson 1992). Nevertheless, both the trials in Thailand and Fiji revealed that trees were typically single-boled although stem straightness varied substantially between families. These results thus indicate a great potential for selection of the best families as well as the best individuals within each family for next generation breeding populations.

Acacia aulacocarpa is a species with good potential for planting as a producer of quality wood for sawn timber and veneer. In addition, it is a suitable pulpwood species and compares favourably with *A. auriculiformis* and *A. mangium* in terms of pulp yield per cubic metre of wood (Clark et al. 1991). The propensity of Papua New Guinea provenances to produce single-boled trees is encouraging but stem straightness needs to be improved. The rate of growth of *A. aulacocarpa* over a range of sites in earlier trials in Thailand suggests that it is possible to grow this species for sawn timber over a 15-year rotation.

Acacia aulacocarpa occupies a wide geographic and climatic range in four states in Australia, Western Province, Papua New Guinea and Irian Jaya, Indonesia, and populations encompass a wide range of ecological, physiological and morphological variation. An informal taxonomic assessment by Thomson (1994) suggested that the species comprises five subspecies. A formal taxonomic revision is currently in progress and, therefore, the understanding of the taxonomy of this species will change.

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References

Awang, K. and Taylor, D.A., ed. 1992. Acacias for Rural, Industrial and Environmental Development. Proceedings of the second meeting of the Consultative Group for Research and Development of Acacias (COGREDA) held in Udorn Thani, Thailand, February 15–18, 1993. Winrock International Institute for Agricultural Research and FAO. 258 p.

Chittachumnonk, P. and Sirilak, S. 1991. Performance of *Acacia* species in Thailand. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. Proceedings of an international workshop held in Bangkok, Thailand, 11–15 February 1991. ACIAR Proceedings No.35, Australian Centre for International Agricultural Research, Canberra, 153–158.

Clark, N.B., Balodis, V., Fang Guigan and Wang Jingxia 1991. Pulping properties of tropical acacias. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. Proceedings of an international workshop held in Bangkok, Thailand, 11–15 February 1991. ACIAR Proceedings No.35, Australian Centre for International Agricultural Research, Canberra, 138–144.

Pan, Z. and Lu, P. and Yang, M.C. 1988. Preliminary report on the 3-year-old provenance tests of tropical acacias in China. Forestry Research, Chinese Academy of Forestry, Beijing, 553–558.

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, W.G. 1987. Genstat 5 Reference Manual, Oxford University Press, Clarendon, 749 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: Growing Multipurpose Trees and Shrubs in Developing Countries. ACIAR Monograph No. 10, Australian Centre for International Agricultural Research, Canberra, Australia, 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 Multipurpose Trees and Shrubs in Developing Countries. ACIAR Monograph No. 10, Australian Centre for International Agricultural Research, Canberra, Australia, 49–68.

Thomson, L.A.J. 1992. Summary of *Acacia* performance at Lau Lau, Viti Levu, Fiji. Consultant report to Pacific Australia Reforestation Company, Canberra, Australia.

Thomson, L.A.J. 1994. *Acacia aulacocarpa*, *A. cincinnata*, *A. crassicarpa* and *A. wetarensis*: an Annotated Bibliography. CSIRO Forestry and Forest Products, Canberra, 131 p.

Williams, E.R. and Matheson, A.C. 1994. Experimental Design and Analysis for Use in Tree Improvement. CSIRO, Melbourne and ACIAR, Canberra, 174 p.

Yang Minquan, Bai Jaiyu 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: Growing Multipurpose Trees and Shrubs in Developing Countries. ACIAR Monograph No. 10, Australian Centre for International Agricultural Research, Canberra, Australia, 89–96.

Approaches to Breeding Acacias for Growth and Form: the Experience at PT. Musi Hutan Persada (Barito Pacific Group)

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Abstract

This paper describes approaches to breeding acacias at PT Musi Hutan Persada (Barito Pacific Group) — a forestry company producing wood materials for a pulp mill in South Sumatra, Indonesia. Breeding programs have been developed with *Acacia mangium* as a principal species. Seed production area and seedling seed orchards are established to obtain genetically improved seed for interim and long-term seed sources, respectively.

The breeding population (progeny test) of *A. mangium* is grouped into 11 sublines containing more than 650 families; each subline is gradually converted into a seedling seed orchard. A composite seed orchard using the best tree from each subline is being planned. Programs on inter-specific hybrids, clonal forestry and other acacias are also discussed.

PT. Musi Hutan Persada (MHP) is a joint company between PT. Enim Musi Lestari (a subsidiary of the Barito Pacific Group) and PT. Inhutani V (a Forest State Enterprise operating in Southern Sumatra). In the last 7 years the Government of Indonesia has been promoting the establishment of industrial plantation forests in the outer island of Java. Thirteen forest companies including MHP have been granted concession right for establishing pulp plantations. In this regard the government of Indonesia has allocated a total area of 2.625 million ha.

The MHP's plantation project covering a total area of 193 500 ha is primarily to supply wood materials for a pulp mill expected to produce 1.2 million tonnes of bleached kraft pulp annually. It is indeed one of the largest pulp plantations managed by a single company, not only in Indonesia but also in the world. By the end of 1997 the allotted plantation area will be fully planted with *Acacia mangium* as the major species, occupying about 90% of the total area. Other species include *Paraserianthes falcataria*, *Eucalyptus urophylla*, *Peronema canescens* and *Hevea brasiliensis*.

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Since the beginning of the plantation project MHP has developed breeding programs with primary emphasis on *A. mangium*. This paper describes this company's approach to breeding acacias for growth and form.

Base Population

At the beginning of the plantation project MHP relied on the seed of *A. mangium* from the local seed source (Subanjeriji land race) derived from four seed sources in Queensland Cairns Region (QCR), (Cassowary, Jullaten, Mossman, and Daintree). The genetic base of Subanjeriji land race is certainly quite narrow.

QCR seed sources have demonstrated suboptimal growth compared to the seed sources from Far North Queensland (FNQ) and Papua New Guinea (Harwood and Williams 1991). A provenance study of *A. mangium* conducted at the MHP's plantation site confirmed further that the seed source from FNQ, PNG and Muting (southeast Irian Jaya) out-performed that of Subanjeriji and QCR (Hardiyanto et al. 1997). The large size of plantation forest being developed by MHP is certainly at high risk if it is developed using the very narrow genetic base of the Subanjeriji land race. Subsequently MHP has broadened its genetic base of *A. mangium* by introducing new genetic materials either in the form of bulk or individual tree seedlots from known good provenances, mainly from PNG, FNQ and southeast Irian Jaya for its breeding programs.

Breeding Population

MHP has realised that an efficient breeding program is of paramount importance to support its objectives, namely producing high quality wood materials for bleached kraft pulp in adequate quantities and on a sustainable basis. To obtain good quality seed in sufficient quantities as quickly and cost effectively as possible, the company established unpedigreed seed-producing areas (SPA).

In 1990 a SPA of *A. mangium* totaling 17 ha was established, using seed from 79 plus trees collected from the local seed source. This SPA is essentially similar to an extensive seedling seed orchard described by Nikles et al. (1984). More than 60 ha of SPAs (provenance resource stands) from four seed sources (Claudie River, Gubam, Wipim-Oriomo, Wando-Bensbach, and Deri-Deri) were established at the end of 1991. The number of parent trees used to set up these SPAs varied from 15 to 140. The bulk seedlots for establishing the SPAs were obtained from the CSIRO Australian Tree Seed Centre.

The unpedigreed SPAs were subjected to three selective thinnings, leaving 125–130 trees from initial stocking of 1111–1250 per ha. Phenotypic selection of SPAs is based mainly on growth and stem form. Genetic gain achieved by phenotypic thinning of this kind of SPA is reported to be quite satisfactory (Harwood et al. 1995). A genetic gain trial using seed from *A. mangium* SPAs will be carried out at the end of 1997.

Since 1995 seed collection has been carried out from some of the SPAs, producing more than 700 kg seed annually. This makes MHP not only self-sufficient on improved seed for its own plantation establishment, but the company could also provide *A. mangium* seed for other plantation projects.

In the long term genetically improved seed is gradually obtained from seed orchards with expected greater genetic gain and eventually the use of seed from the SPAs will be phased out. The strategy being taken is the establishment of open-pollinated progeny trials and gradually converting them into seedling seed orchards by selective thinning. It is essentially similar to what Barnes (1995) described as a breeding seedling orchard in that it combines the conventional hierarchy of sequential testing, selection and seed production in a single planting. The adoption of this strategy depends upon the fact that *A. mangium* has rapid growth and starts flowering and producing seed at an early age, and the practical difficulty of a large-scale controlled pollination. This simple, low-cost approach has already been applied with considerable success in the breeding program of *Eucalyptus grandis* in southern Florida (Franklin 1989) and South Africa (Eldridge et al. 1993).

The breeding population (progeny test) is divided into sublines (breeding groups) with half-sib pedigree instead of having a large interbreeding population as described, among others, by McKeand and Beineke (1980), Burdon and Namkoong (1983) and White (1992). In this breeding scheme selection and mating to produce seed for the next generation breeding population are confined within sublines. Relatedness will build up among members within sublines; however members from different sublines will always be unrelated. Mating between members from different sublines will result in outcrossed progeny that will not suffer from inbreeding depression. Matheson (1990) elucidated the advantages of this breeding strategy.

The grouping is principally based upon the natural provenance or region of seed collection. As of April 1997 11 sublines containing more than 650 families had been put in the field. Each subline comprises around 60 families (except one subline of 100 families) isolated from one another physically in the field by more than 100 m and a buffer planting of non-hybridising species. The new genetic materials used to develop the sublines are from known good provenances of *A. mangium* (PNG, QFN and southeast Irian Jaya). At least four checklots from the local seed source were included in every subline to permit estimation of genetic gain and comparison between sublines.

All sublines are eventually converted into seedling seed orchards by selective thinning. Composite seed orchards are also being planned by mixing progenies of open-pollinated seeds collected from the best tree in the very best families from each subline. This type of orchard could have substantial genetic gain, be relatively cheap and involve simple technology (Shelbourne 1992; Cannon and Shelbourne 1993). The scheme can be seen in Figure 1.

Experimental Design and Selection

Most of the progeny tests have been established by using four-tree row plots arranged in a randomised complete block design with restriction in the randomisation, in that siblings from the same family do not occur close each other in neighbouring blocks; this design is similar to forward selection plots introduced by Cannon and Shelbourne (1993). The number of replicates varies from 8 to 20; this

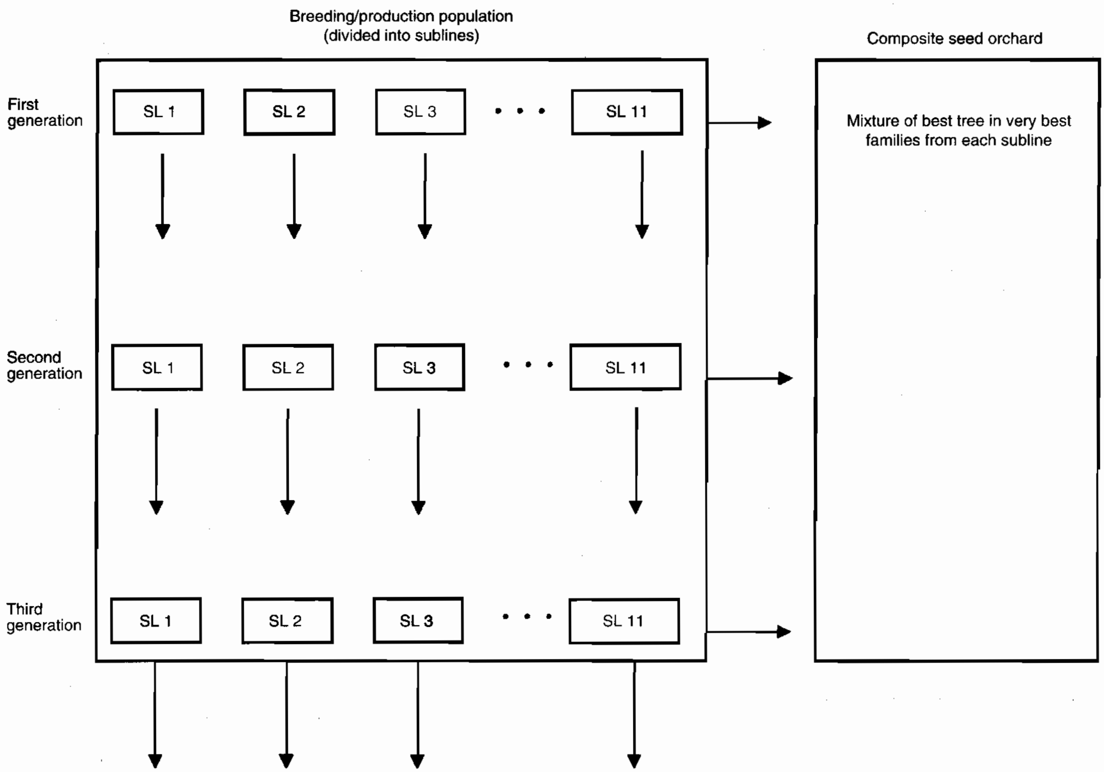

Figure 1. Schematic representation of *Acacia mangium* breeding population and seed orchards.

large number of replications is mainly due to the need for larger areas of seed orchards to produce adequate quantities of seed. The initial spacings are 4 × 2 m or 4 × 3 m. Some of the progeny tests are also replicated in space. Recent evaluation of some of the tests revealed that genotype–environment interactions in growth of *A. mangium* seem to be important (Hardiyanto 1997).

Recently an incomplete block design generated by the program Alpha+ (Williams and Talbot 1991) has also been applied for establishing progeny tests at MHP. Incomplete block design in most cases is believed statistically to be more efficient than randomised complete block design, particularly for progeny trials having a large number of families to be included in the tests. This makes ranking of individuals and families more precise. Replications often are too large to be effective in removing the environmental effects (Williams and Matheson 1994). Incomplete block design was reported to have about one-third less residual error in an international provenance study of *Casuarina equisetifolia* compared with the analysis that is based on a randomised block design (Williams 1995 pers. comm.).

Thinning to convert progeny trials into seedling seed orchards is done by a two-stage process. The first stage is a within-family selection while the second stage involves individual and family evaluation. Some of the progeny tests of *A. mangium* at MHP have undergone the first stage of thinning. It is done at about 2 years of age by culling phenotypically the two worst trees in every plot and the following year the poorest tree in each plot is also removed, retaining only the best tree in every plot.

So far no progeny test has gone through the second stage of thinning. This last thinning is planned to remove the worst individual trees and all checklots to reduce stand density to a level conducive to seed production (about 120–150 trees per hectare). However, only a certain number of best trees from the same family will be permitted in order to avoid having a very narrow genetic base and a lot of inbreeding in the seed orchard. The seed from seedling seed orchards which relatively has a narrow genetic base resulting from the second stage of thinning will be used solely for plantation establishment.

The final thinning will be based on combined index, which combines individual phenotypic observation and family mean. Combined index is considered to be a very efficient selection method (Cotterill and Dean 1990). The following characteristics have been used to evaluate individual trees in the progeny tests: stem volume, stem straightness, and axis persistence.

The strategy of developing the seedling seed orchard of *A. mangium* is principally taking the generation interval as quickly as possible. By so doing the cumulative genetic gain per unit time is expected to be high. Seed collection for providing the basis of the next generation breeding population will commence after the completion of the second thinning, provided that the majority of trees in the seed orchards already produce seeds. It will ensure that the offspring of the most recently produced seed is predominantly outcrossed between unrelated selected families in the trial.

Seeds will be collected from the best tree in each family (family identity retained) and therefore the second generation breeding population will essentially comprise all families in the first generation breeding population. Progeny tests using open-pollinated seed collected from native stands are not reliable in assessing the genetic values of families due to the existence of inbreeding among parents used for the test. Better estimates of genetic parameter and more precise selection will be obtained at the second and later generation of progeny test in which high inbreeding is overcome (Eldridge et al. 1993; Hodge et al. 1996). Therefore, all families in the first progeny test will be carried over in the second generation's breeding population

Hybrid Breeding Program

MHP has been developing interspecific hybrids between *A. mangium* and *A. auriculiformis*. Due to the difficulty of carrying out controlled pollination, interspecific hybrids are developed by establishing open-pollinated hybrid seed orchards. In south Sumatra there are overlapping periods of flowering of these two species. Exceptional natural hybrids of *A. mangium* × *A. auriculiformis* have been recorded at the MHP plantation established using seed from the local seed source.

Around 2 ha of a hybrid seed orchard of *A. mangium* × *A. auriculiformis* from unimproved parents were established in 1996. The orchards were planted on a 10 × 10 m triangular spacing between four-square plots of *A. mangium* and each of these plots surrounded by trees of *A. auriculiformis*. The spacings within plot of *A. mangium* and also between *A. auriculiformis* trees are 3 × 3 m. Thinning will be conducted to remove phenotypically poor trees in the orchard both for *A. mangium* and *A. auriculiformis*. Seed will be collected from *A. mangium* parents, and interspecific hybrids expected from this natural hybridisation in the orchard will be identified at nursery stage using Rufelds's method described by Gan and Liang (1991).

In future, the hybrid seed orchard will comprise selected and improved parents for both *A. mangium* and *A. auriculiformis* selected from progeny tests. The approach is essentially a hybrid program through co-improvement of the parental species using recurrent selection for general combining ability within species and crossing between selected individuals from each species (Nikles and Griffin 1991; Nikles 1993). For this purpose in early 1996 a progeny test of *A. auriculiformis* containing 139 families from Papua New Guinea and Queensland was established, and two more sublines will be planted at the end of 1997.

Plus Tree Selection and Vegetative Propagation

Vegetative propagation from selected plus trees of *A. mangium* has been carried out by marcotting, and subsequent cuttings grown in the mist propagation chamber. An attempt to propagate plus trees (no more than 4 years old) from shoot cuttings harvested from the coppice sprout after felling the plus trees did not yield satisfactory results. Out of 97 trees felled, only 30 were successfully vegetatively propagated.

Over the last 3 years 1044 plus trees have been selected from the existing plantations; 179 plus trees were effectively propagated and put in the hedge garden. However, in the near future the search for plus trees will be carried out more on SPAs and progeny trials. Clonal tests replicated at a number of sites, to select best clones for establishing clonal plantations, will be conducted soon after sufficient materials become available for testing.

Breeding Program for Other Acacias

As mentioned before, more than 90% of the total area of MHP consists of *A. mangium*. A plan to find backup species suitable for pulp production has been carried out; one of these species is *Acacia crassicarpa*. A species trial conducted at the project site in 1980s revealed that *A. crassicarpa* had reasonable growth.

The breeding strategy and test design used for *A. crassicarpa* is similar to those of *A. mangium*. The breeding population of *A. crassicarpa* is also divided into sublines. So far six sublines containing 261 families originating from Papua New Guinea, Queensland and southeast Irian Jaya have been established. The oldest progeny tests comprising three sublines were established in 1994. One and two sublines were planted in 1995 and 1996, respectively. Growth of these tests has been good, except for the subline containing families from Queensland, which showed slower growth.

The 1994 progeny tests were thinned at 2 years of age, removing the poorest 50% of trees within each plot. These trials will be thinned again in 1998 leaving only the best tree in every plot. The strategies of thinning and seed collection for the next generation breeding population are similar to those of *A. mangium*.

A provenance resource stand of *A. crassicarpa* with a total area of 13 ha has been established at a number of sites. Provenance resource stands for *A. aulacocarpa* and *A. leptocarpa*, covering a total area of 14.5 and 15.5 ha respectively, were also established in 1996. No progeny tests have been carried out for the last two species.

Future Directions

The genetic base of *A. mangium* breeding program at MHP has been increased quite substantially. It provides a vast opportunity to exploit the genetic variation existing in the species to increase its productivity. The first breeding population will be brought to the next generation breeding populations as fast as possible to maximise genetic gain per unit time by having a short generation turn over. In the next generation open-pollinated seedling seed orchards and composite seed orchards will still be the methods used to produce genetically improved seeds.

The hybrid breeding program of *A. mangium* × *A. auriculformis* will continue and there is a possibility of using controlled pollination to obtain interspecific hybrid seeds in the future. Extra effort will be devoted to the program of vegetative propagation of selected plus trees and interspecific hybrids, as well as clonal tests to support clonal forestry programs. In the clonal test wood properties will be evaluated in addition to growth and stem form.

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References

Barnes, R.D. 1995. The breeding seedling orchard in the multiple population breeding strategy. Silvae Genetica, 44, 81–88.

Burdon, R.D. and Namkoong, G. 1993. Multiple population and sublines. Silvae Genetica, 32, 221–222.

Cannon, P.C. and Shelbourne, C.J.A. 1993. Forward selection plots in breeding programmes with insect-pollinated tree species. New Zealand Journal of Forestry, 23, 3–9.

Cotterill, P.P. and Dean, C.A. 1990. Successful tree breeding with index selection. CSIRO, Melbourne.

Eldridge, K., Davidson, J., Harwood, C., and van Wyk, G. 1993. *Eucalyptus* Domestication and Breeding. Clarendon Press. Oxford, England.

Franklin, E.C. 1989. Selection strategies for eucalyptus tree improvement — four generations of selection in *Eucalyptus grandis* demonstrate valuable methodology. In: Proceedings of the IUFRO Conference on breeding tropical trees: population structure and genetic improvement strategies in clonal and seedling forestry. Pattaya, Thailand, 197–209.

Gan, E. and Liang, S.B. 1991. Nursery identification of hybrid seedlings in open pollinated seedlots. In: Caron, L.T. and Aken, K.M., ed., Breeding Technologies for Tropical Acacias.. ACIAR Proceedings No. 37, Australian Centre for International Agricultural Research, Canberra, 76–87.

Hardiyanto, E.B. 1997. Genotype–environment interactions in *Acacia mangium* progeny tests. Technical Notes Vol. 3, No. 6. Dep. R&D PT. Musi Hutan Persada.

Hardiyanto, E.B., Siregar, S.T. and Chandralika. 1997. Results of the provenance test of *Acacia mangium* at 28 months old at Setuntung. Technical Notes Vol. 3, No. 4, Dep. R&D PT. Musi Hutan Persada.

Harwood, C.E., Nikles, D.G., Pomroy, P. and Robson, K. 1995. Impact of thinning via phenotypic selection on the genetic bases of planted seed production area. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry, Proceedings of the Queensland Forest Research Institute-IUFRO Conference, Caloundra, Queensland, Australia, 148–153.

Harwood, C.E. and Williams, E.R. 1991. A review of provenance variation in growth of *Acacia mangium*. In: Caron, L.T. and Aken, K.M., ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37, Australian Centre for International Research, Canberra, 22–30.

Hodge, G. R., Volker, P.W., and Potts, B.M. 1996. A comparison of genetic information from open-pollinated progeny tests in two eucalypt species. Theoretical Applied Genetics, 92, 53–63.

Matheson, A.C. 1990. Breeding strategies for MPTS. In: Glower, N. and Adams, N., ed., Tree Improvement of Multipurpose Tree Species. Network Technical Series, 2. Winrock International Institute for Agriculture Development, USA.

McKeand, S. and Beineke, F. 1980. Sublining for half-sib breeding population of forest trees. Silvae Genetica, 29, 14–17.

Nikles. D.G. 1993. Breeding methods for production of interspecific hybrids in clonal selection and mass propagation programmes in the tropics and sub-tropics. In: Davidson, J., ed., Proceedings. of the regional symposium on recent advances in mass clonal multiplication of forest trees for plantation programmes, Cisarua, Bogor, Indonesia, 1–8 December 1992. FAO, Los Baños Philippines, 218–261.

Nikles, D.G. and Griffin, A.R. 1991. Breeding hybrids of forest trees: definitions, theory, some practical examples, and guidelines on strategy with tropical acacias. In: Caron, L.T. and Aken, K.M., ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37, 101–109.

Nikles, D.G., Spidy, T., Bowyer, P.C. and Newton, R.S. 1984. Seedling seed sources of *Pinus caribaea* var. *hondurensis* in Queensland. In: Barnes, R.D. and Gibson, G.L., ed., Provenance and genetic improvement strategies in tropical forest trees, Mutare, Zimbabwe, April 1984. Commonweath Forestry Institute, 579–581.

Shelbourne, C.J.A. 1992. Genetic gains from different kinds of breeding population and seed or plant production population. African Forestry Journal, 160, 49–65.

White, T. 1992. Advanced-generation breeding populations: size and structure. In: Lambeth, C and Dvorak, M., ed., Proceedings of the IUFRO conference on resolving tropical forest resource concerns through tree improvement, gene conservation and domestication of new species. Cartagena, Cali, Colombia, 208–222.

Williams, E.R. and Matheson, A.C. 1994. Experimental Design and Analysis for Use in Tree Improvement. CSIRO, Melbourne, and ACIAR, Canberra, 174 p.

Williams, E.R. and Talbot, M. 1993. Alpha+: Experimental Designs for Variety Trials and Many-treatment Experiments. CSIRO, Canberra and SASS, Edinburgh.

Management and Use of Ex Situ Genetic Resources of some Tropical *Acacia* Species in Queensland*

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Abstract

Genetic advancement of tropical *Acacia* species can be undertaken quickly with only limited resource inputs. Open-pollinated seedling seed orchards constituting conservation/breeding populations of *Acacia aulacocarpa* and *A. mangium* in north Queensland have been cycled within 6 years. Even after heavy phenotypic thinning, the first-generation seed orchards remain genetically diverse and constitute a valuable source of genetic material for several purposes. Realised genetic gain is already apparent for *A. mangium*, especially in reduced incidence of low forking. Promising *A. aulacocarpa* clones have been identified and are to be further evaluated; their rankings are stable across two very different trial environments. The genetic resources accumulated have also enabled exploratory production and testing of interspecific hybrids of *A. auriculiformis* and *A. mangium*.

Alternative strategies for hybrid development are outlined. The methods developed for population improvement and use of hybridisation could be applied in all countries planting these species. Suggestions are made on measures required to ensure long-term conservation of genetic diversity ex situ.

SOME of the best provenances of four commercially important tropical acacias (*Acacia aulacocarpa, A. auriculiformis, A. crassicarpa* and *A. mangium*) occur predominantly in remote areas of northern Australia and central-southern Papua New Guinea, making seed collection difficult and expensive (Gunn and Midgley 1991). By the late 1980s, demand for seed of these provenances was increasing steadily. In 1988, in anticipation of an on-going demand for seed for research and development, CSIRO's Australian Tree Seed Centre (ATSC), the Queensland Forest Service, the Conservation Commission of the Northern Territory and Melville Forest Products Ltd jointly decided to establish ex situ conservation stands and seedling seed orchards (SSOs) in the Northern Territory (NT) and Queensland. Between 1989 and 1992, one SSO of *A. crassicarpa* and seven of *A. auriculiformis* were established in the NT and 10 SSOs of *A. mangium* and four of *A. aulacocarpa* in north Queensland (Harwood et al. 1994). Each SSO was initially a replicated progeny trial, testing from 20–30 plants from each of 33–170 open-pollinated, natural-stand families from several provenances within a single (apart from one exception) provenance region.

Provenance regions in Papua New Guinea and northern Australia were defined as shown in Figure 1.

The aims of the present paper are to describe aspects of the management and utilisation of the SSOs and their products, including: deployment of seed produced, preliminary results of genetic gain trials and clonal trials, further genetic resource development, production and testing of interspecific *Acacia* hybrids in Queensland and alternative hybrid breeding strategies.

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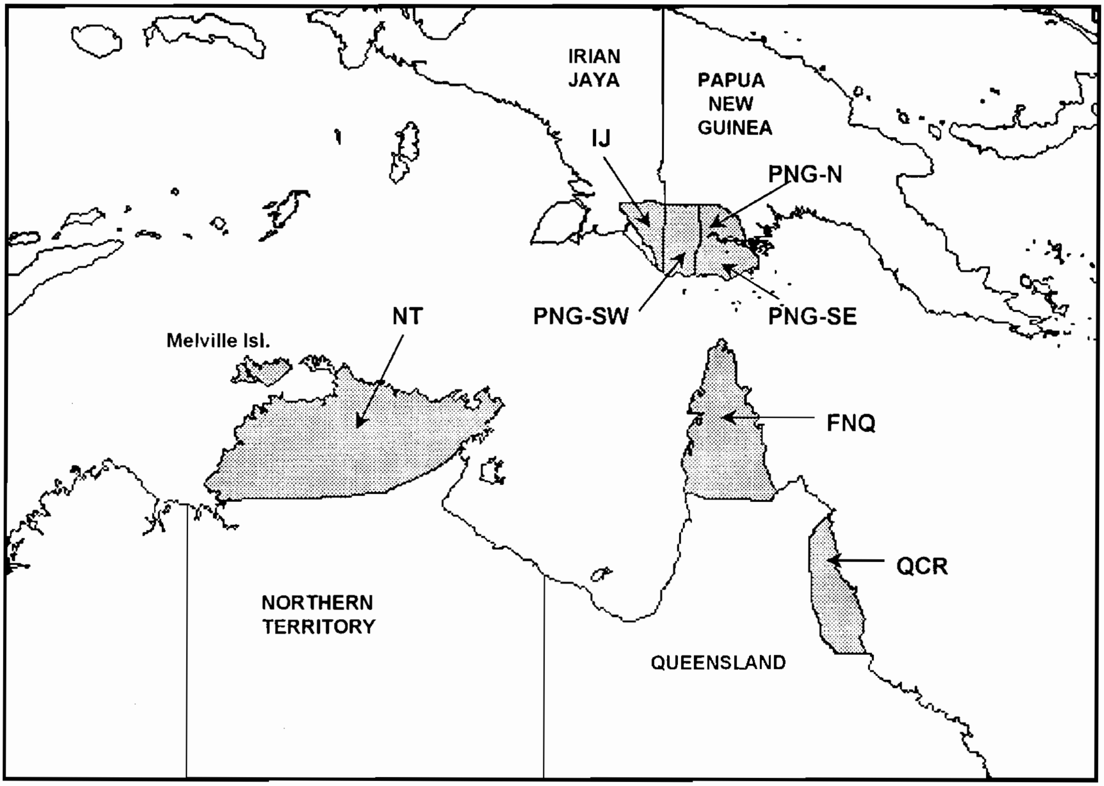


IJ	Southeastern Irian Jaya
PNG-N	Western Province, Papua New Guinea north of the Fly River
PNG-SE	Western Province, PNG south of the Fly River and east of 142°E
PNG-SW	Western Province, PNG south of the Fly River and west of 142°E
NT	Northern Territory
FNQ	Far North Queensland, north of latitude 13°S
QCR	Queensland Cairns Region, latitude 15–18°S

Figure 1. Provenance regions of tropical *Acacia* species.

Establishment and Thinning of the SSOs in North Queensland

Harwood et al. (1994, 1996) give details of the establishment and composition of the 10 SSOs of *A. mangium* and four SSOs of *A. aulacocarpa* planted in north Queensland in 1990 or 1991. Most orchards were situated on either coarse-textured soils derived from granitic parent materials or finer textured soils derived from old, metamorphosed sediments. These soils are generally classified as Kandosols under the new Australian system (Isbell 1996) or Ultisols in the US systems (Soil Survey Staff 1975). Mean annual precipitation ranges from over 2000 mm at Cardwell to around 1500 mm north of Kuranda. The location of the orchards was generally not the most suitable for growth of these species, but orchard location was restricted by land availability and the need to isolate orchards some distance from natural occurrences of the species.

Cyclones are relatively common in this region crossing the coast, on average, every 10 years or so. Cyclone Justin passed over the Kuranda, Damper and Lannercost areas in March 1997 bringing strong winds and heavy rain. It destroyed two *A. mangium* SSOs established at Kuranda in 1990, damaged or felled a small proportion of trees in some other SSOs, and damaged many trees in the *A. aulacocarpa* clone trial at Danbulla.

Initial orchard stocking was either 1250 or 1850 stems ha^{-1}. All of the SSOs have been progressively thinned selectively, leaving trees of superior form (single, straight bole) and above average vigour (Harwood et al. 1996). The approximate current stockings of all 12, presently viable orchards in north Queensland are given in Table 1.

Table 1. Current composition of remaining seedling seed orchards of *Acacia* species in north Queensland following selective thinning and cyclone losses.

Species and planting year	Location	Provenance region	Area (ha)	No. of families		Current stocking (stems per ha)	No. of select trees remaining[a]
				Original	Retained		
A. mangium							
1990	Lannercost	PNG-N	0.8	36	25	120	6
	Lannercost	FNQ	1.9	80	36	120	9
A. mangium							
1991	Lannercost	QCR	1.4	98	65	120	ns[b]
	Lannercost	FNQ	0.7	60	40	120	11
	Damper	PNG-SW	2.0	104	71	120	34
	Kuranda	PNG-N	1.1	70	55	136	9
	Kuranda	FNQ	1.1	60	52	180	5
	Kuranda	PNG-SE	0.8	50	41	157	16
							Total 90
A. aulacocarpa							
1991	Damper	PNG-SE	1.6	89	60	120	13
	Lannercost	PNG-SW	1.0	66	45	120	17
	Kuranda	PNG-SE	1.0	72	50	180	13
	Kuranda	PNG-SW	1.1	77	52	180	17
							Total 60[c]

[a] Total numbers of selections made were 100 for *A. mangium* and 140 of for *A. aulacocarpa*; 80 of the latter were selected and pollarded for cloning in 1994, and a further 60 were selected in 1995–1996. Two of the SSOs planted at Kuranda and 10 of the select *A. mangium* trees were destroyed by Cyclone Justin in March, 1997.
[b] No superior tree selection was undertaken.
[c] An additional 80 trees were selected and pollarded for cloning (see text); only a few of these remain alive.

The selective thinning to about 10% of original stocking has generally retained a high proportion of the families in each orchard (Table 1). The design of the SSOs (replicated, four-tree or single-tree plots in incomplete or randomised complete blocks) and the thinning methods have ensured that most of the adjacent retained trees are unrelated (i.e. from different families), thus minimising inbreeding. Furthermore, the retention of family identities of all individual trees in the SSOs allows broadly based collections of half-pedigreed seedlots representing most of the original families to be made from the orchards. As moderate heritabilities for growth and stem form were estimated from pre-thinning assessments (Harwood et al. 1993) and moderate intensities of phenotypic selection were used for thinning (around one in 10 trees retained) the SSO progenies should exhibit some genetic improvement in growth and stem form relative to the natural provenances that comprised them. These attributes of a broad genetic base and expected genetic improvement over natural provenances make seed collections from the SSOs excellent resources for a variety of purposes.

Context of the Developmental Work Undertaken since 1994

The demand for seed of *A. auriculiformis* has been only modest, and it has become difficult and expensive to maintain and protect from fire the SSOs established in the Northern Territory (NT). Broadly based seed orchards of this species now exist elsewhere e.g. Fiji, Thailand (Luangviriyasaeng and Pinyopusarerk, these Proceedings) and Vietnam (CSIRO Forestry and Forest Products 1996), and a number of collections have been made in the NT orchards. So the genetic resources of this species seem secure. In contrast, demand for *A. crassicarpa* seed has increased sharply in recent years. However, the broadly-based (170 open-pollinated families) and well-developed SSO established in the NT in 1992 has failed to produce any seed because the local environment has proved unsuitable for seed production; also, its maintenance and protection have become very expensive. Moreover, ex situ orchards of *A. crassicarpa* are now well established in other countries, for example China, Fiji, Malaysia, the Philippines and Thailand. Therefore only low-intensity management is currently planned for the established SSOs of *A. auriculiforms* and *A. crassicarpa* in the NT.

Acacia mangium is not likely to become an important plantation species in north Queensland. This species is highly susceptible to insect attack, especially by an indigenous shoot and twig borer (an undescribed species of *Cryptophlebia* — see Wylie et al., these Proceedings), and to cyclone damage. Observations made following Cyclone Justin in March 1997 showed that *A. mangium*

(PNG) was far more susceptible to wind-throw and stem breakage than *A. auriculiformis* (FNQ) in replicated trials at Lannercost in the coastal lowlands of north Queensland.

Most of the eight remaining *A. mangium* SSOs have borne large seed crops and should continue to do so (Table 2); the others are expected to yield heavily soon. Furthermore, there is a strong international demand for seed, so ongoing maintenance of these *A. mangium* orchards and seed collections and the establishment of genetic gain trials are warranted. Another factor influencing the work being undertaken with *Acacia* species in north Queensland is the now-demonstrated great promise of F_1 hybrids of *A. mangium* and *A. auriculiformis* (Le Dinh Kha 1996). It is anticipated, therefore, that future work with the *A. mangium* SSOs in north Queensland will involve maintenance and seed collection in accordance with demand, and management of a breeding population for use in hybrid development.

Acacia aulacocarpa may be used to a significant extent in commercial and other tree planting schemes in north Queensland in the future. Therefore the initial genetic base established (some 230 natural-stand families across four SSOs) warrants development and extension. Such work would provide improved varieties for local use and sources of broadly-based genetic material and varieties for direct use or further development elsewhere. This further genetic development of *A. aulacocarpa* is described below.

Seed yields

Table 2 presents estimates of the amount of seed produced by each SSO between 1994 and 1996. Collections in individual SSOs commenced once heavy flowering of at least 50% of the retained trees was observed. Therefore most, but not all, of this seed has been collected. Significant amounts of seed have been collected from many seed parents in SSOs of four provenance regions of *A. mangium* but only small amounts have been obtained so far from only two of the *A. aulacocarpa* SSOs.

The year of onset of general flowering and the seed yields varied considerably between species and between orchards within species. Most *A. mangium* orchards yielded good seed crops from age 3–5 years onwards, some 2–3 years before *A. aulacocarpa* commenced production. Clearly the Damper (near Cardwell) *A. mangium* SSO has been precocious and prolific, whereas its cohort *A. aulacocarpa* orchard, located on a similar site only a few hundred metres away, has been slow to flower and yield seed (Table 2). There appears to be a strong species × environment effect on seed production.

For both *A. aulacocarpa* and *A. mangium*, provenance regions within species have commenced

Table 2. Seed production[a] in *Acacia* seedling seed orchards in north Queensland.

Species and planting year	Location	Provenance region(s)	Area (ha)	Cumulative seed production (kg) 1994–1996 inclusive	
				per orchard	per hectare
A. mangium					
1990	Lannercost	PNG-N	0.8	5	6.3
	Lannercost	FNQ	1.9	5	2.6
	Kuranda	PNG-SE & SW	1.5	minimal	minimal
	Kuranda	FNQ	1.9	minimal	minimal
A. mangium					
1991	Lannercost	QCR	1.4	30	21
	Lannercost	FNQ	0.7	5	7.1
	Damper	PNG-SW	2.0	430	215
	Kuranda	PNG-N	1.1	100	91
	Kuranda	FNQ	1.1	96	87
	Kuranda	PNG-SE	0.8	80	100
A. aulacocarpa					
1991	Damper	PNG-SE	1.6	minimal	minimal
	Lannercost	PNG-SW	1.0	15	15
	Kuranda	PNG-SE	1.0	5	5
	Kuranda	PNG-SW	1.1	20	20

[a] Seed production includes seed yields actually collected and our estimates of other seed available for harvest but not collected.

general flowering at a similar age, and have displayed similar seasonal flowering phenology. SSOs of different provenance regions of the one species established at the same locations, for example *A. mangium* (FNQ, PNG-N and PNG-SE), and *A. aulacocarpa* (PNG-SE and PNG-SW) established in 1991 at Kuranda, have performed similarly.

Among localities sampled for SSO establishment those best for *A. mangium* seed production appear to be Damper (coastal lowland at 18°S, 2100 mm mean annual rainfall, 24°S mean annual temperature) and, for *A. aulacocarpa*, Kuranda (plateau at about 400 m altitude and 17°S, 1740 mm, 23°C). Both localities experience pronounced dry seasons from August to November.

The yields of the Damper *A. mangium* SSO (which is some 2 ha in area) have grown year by year: 33 kg in 1994, 136 kg in 1995, and 261 kg (i.e. approximately 130 kg per ha) in 1996. In 1996 the PNG-N (Kuranda), PNG-SE (Kuranda) and FNQ (Kuranda) orchards each provided yields equivalent to approximately 90 kg per ha. Yields forecast for 1997 are similar to those of 1996, so it appears that annual harvests may plateau at about 90–130 kg per ha (depending on orchard location) — equivalent to an average of about 1 kg per tree, at around 6 years of age. These harvests are somewhat higher than those recorded in an 8-year study of an *A. mangium* seed orchard in Sabah, Malaysia. There, per-tree annual harvests fluctuated from 0.13 to 0.53 kg (Chia and Kabi 1994). More synchronised flowering, confined to the months March to June, in the strongly seasonal climate of north Queensland (latitude 17–18°S), compared to the more-or-less continuous flowering and fruiting commonly observed in equatorial latitudes, may explain greater seed production and/or easier harvesting of more synchronous seed crops in north Queensland, leading to higher harvests of collected seed. *Acacia. aulacocarpa* yields per tree have been much lower than those of *A. mangium*.

Acacia mangium, at least, is capable of responding rapidly to annual trimming for pod collection. New growth, which takes place following trimmings (to branch diameter of around 1.5 cm) in October, is able to subtend flowering shoots in the following March–June.

Selection and use of superior trees

Scientists identified 3-year-old trees with outstanding stem form and above average vigour in the four *A. aulacocarpa* SSOs. Twenty trees were selected per orchard — the best tree in each replicate in each orchard was selected on a purely phenotypic basis. The selection rates in the four orchards ranged from one in 66 to one in 89 trees. The selections were well distributed among families, with from 15 to 19 families being represented in each set of 20 select trees (Harwood et al. 1996). These empirical findings suggested that a first round of careful phenotypic selection in unpedigreed *Acacia* provenance resource stands (PRSs — Nikles and Newton 1983) of appropriate genetic composition would yield a suitable, broadly-based breeding population of good genetic merit, not dominated by one or a few families. Hence, Harwood et al. (1996) proposed this as an alternative, low-cost means of assembling an initial breeding population, in contrast to the commonly used alternative of selecting an initial breeding population from pedigreed family trials testing many natural provenance families.

In 1996, a further 60 superior trees of *A. aulacocarpa* were selected phenotypically, distributed among orchards as shown in Table 1. Intensive phenotypic selection of superior trees was also undertaken in the *A. mangium* orchards. Selections were made in 1994 and 1995 and resulted in the marking of some 100 trees; the 90 remaining after Cyclone Justin are distributed among orchards as shown in Table 1. Open-pollinated seed is being collected from these selections of both species, once mass flowering and seed set occurs in the relevant SSOs.

Bulk seed collections from the SSO seedlot can be used for commercial forestry plantation establishment. Individual orchard bulks offer the opportunity to preserve the identity of provenance regions in the resulting plantations, and to establish breeding sublines or multiple breeding populations. This provides a means for large-scale conservation of provenance–region populations, at least during the period of a rotation. The second-generation stands established from the SSO seedlot bulks also provide opportunity for local development of seed production areas (SPAs) and for selection of superior trees for breeding and/or propagation populations.

Seedlots from the individual superior trees selected in the SSOs in Queensland also have a number of possible uses. They can be used as an initial base population in new breeding programs, or as an infusion into established programs. Also, seedlots could be used to establish second-cycle seedling seed orchards (with family identities retained), or bulked to establish single- or multi-region SPAs of high genetic merit. As well, seedlings from the best families could be used to establish hedges for initiation of clonal testing.

As part of a long-term plan to ensure the conservation of the genetic resources of each provenance region, it is desirable to arrange for the long-term storage of seed and the occasional growing out of the material for future cycles of seed collections and storage. This can probably be best undertaken in collaboration with commercial growers who maintain strict records of seed source identity in plantations and who are growing the species on a scale such that collections maintaining provenance region purity can be assured. This is not likely to be feasible in Queensland because neither *A. mangium* nor *A. aulacocarpa* are commercial forestry species there at present.

Ongoing genetic resource development of pure species

A. mangium

In recent years large amounts of seed of the main provenance regions have been dispatched to a number of plantation ventures in Asia, either directly from natural-stand collections or from the SSOs in north Queensland. There are advanced breeding programs with this species in several countries including Indonesia (Hardiyanto 1996), Malaysia (Sim Boon Liang, pers. comm. 1996), the Philippines and Vietnam (CSIRO Forestry and Forest Products 1996). New commercial plantation schemes in Asia require only starter samples of early-generation selected material for follow-up selection and breeding locally. Thus adequate genetic resources of the species are conserved in ex situ plantations as trials and PRSs. Therefore it is planned to merely maintain the eight surviving *A. mangium* SSOs in north Queensland for a further few years, during which time it is anticipated that a demand for seed from them will continue. Also, a small broadly based sample of seed from each orchard will be retained in storage.

A second-generation *A. mangium* SSO was planted in June 1996 on an irrigated site at Southedge near Mareeba, north Queensland (elevation 500 metres, latitude 17°S, mean annual rainfall 1000 mm, mean annual temperature 22°C, grey coarse granitic sand overlying metamorphic substrate (Tenosol, Isbell 1996). It comprised second-generation families from 32 select trees in the Queensland SSOs, appropriate natural provenance controls and unrelated infusions from superior provenance regions. After selective thinning, this trial will function as a second-generation SSO and provide information on the utility of irrigation to augment seed production in a seasonally dry environment.

A preliminary study of variation among first- and second-generation populations of *A. mangium* and *A. auriculiformis* is in progress with material established in 1996 in a species-hybridising orchard at Meunga near Cardwell. Details of the design and early results are given in a later section on hybrid development.

A. aulacocarpa

This species is potentially of much greater interest than *A. mangium* for plantation establishment in north Queensland, because it has more valuable wood and is less susceptible to wind damage. Further, it has good potential on some sites in Asia, e.g. in the program of Sabah Forest Industries in southeast Sabah, Malaysia where *A. mangium, A. aulacocarpa, A. crassicarpa* and eucalypt species plantings are matched to particular site types (Sim Boon Liang, pers. comm. 1996). With the exception of Thailand and Sabah, breeding programs for *A. aulacocarpa* are not advanced in countries outside Australia. Therefore joint action has been taken by CSIRO and QFRI in north Queensland to develop superior clones from the 80 phenotypic selections made from the four SSOs in 1994, and to extend the genetic base of the species as elaborated below. The 80 3-year-old trees selected were pollarded at a height of about 1 m, and cuttings struck from the resulting coppice shoots. All selections were brought into clonal propagation in this way but only about half of the clones had a cutting strike rate in excess of 50%. Cuttings produced from two cycles of propagation were used to establish a clonal seed orchard (CSO), a hedge garden and three clone trials.

Two of the clone trials have not yielded useful rankings — the first because of damage by Cyclone Justin on a poorly-drained site, and the second through inadequate weed control (due to lack of access to the trial site for some time after Cyclone Justin). Results of the third clone trial and CSO are summarised in Table 3. The clone trial was established on a red podsolic or red earth soil (Kandosol, Isbell 1996) at Silkwood, a coastal site 60 km north of Cardwell receiving around 3000 mm annual rainfall with a mean annual temperature of 24°C. The trial tested a total of 205 ramets from 35 clones (between one and nine ramets per clone) and 155 seedlings from nine control seedlots from the same *A. aulacocarpa* provenance regions, in a randomised design with nine blocks. Initial spacing was 5 × 2 m. The CSO, incorporating 63 clones, was planted in September 1995 at Southedge, near Mareeba, on a grey Tenosol adjacent to the second generation *A. mangium* SSO described above. Five blocks of single-tree plots were established, giving a total of 300 ramets at a spacing of 5 × 4 m. Sprinkler irrigation is provided during dry periods. The Silkwood trial was assessed at age 26 months for tree height, diameter at breast height (dbh) and stem form, and the Southedge CSO orchard was assessed for the same traits at age 22 months. Stem form was assessed using a 6-point scale (1 worst–6 best).

Table 3. Assessments of *Acacia aulacocarpa* clonal trial at Silkwood and clonal seed orchard at Southedge.

Trial and items considered	Height (cm)	Dbh (cm)	Stem form score
Silkwood (age 26 months)			
Mean of *A. aulacocarpa* clones	616	7.7	3.44
Best *A. aulacocarpa* clone (no. 14)	753	8.1	4.62
A. crassicarpa clone[a]	872	11.9	4.05
Mean of *A. aulacocarpa* seedlings	596	8.1	3.11
Significance of differences			
between *A. aulacocarpa* clones and seedlings	***	***	***
between *A. aulacocarpa* and *A. crassicarpa*	***	***	***
between different *A. aulacocarpa* clones	***	***	*
Standard error of difference of means			
between *A. aulacocarpa* clones and seedlings	11	0.14	0.12
between different *A. aulacocarpa* clones (mean)	55	0.72	0.74
Southedge (age 22 months)			
Mean of *A. aulacocarpa* clones	439	6.0	3.23
Best *A. aulacocarpa* clone (no. 4)	476	7.8	4.49
A. crassicarpa clone	586	8.4	3.25
Significance of differences			
between *A. aulacocarpa* and *A. crassicarpa*	***	***	***
between different *A. aulacocarpa* clones	*	**	***
Standard error of difference of means			
between different *A. aulacocarpa* clones (mean)	83	1.33	0.82

* 0.05 < P < 0.01
** 0.01 < P < 0.001
*** P < 0.001
a Included inadvertently in SSO from which cuttings/species for clone trials and clonal seed orchards were collected.

One of the clones tested at both sites proved to be *A. crassicarpa*, two families of which had been inadvertently included in the original *A. aulacocarpa* SSOs. The two trials were analysed using the FIT and REML procedure in Genstat 5.3 (Williams and Matheson 1994) with blocks and clones as fixed effects. Differences between *A. aulacocarpa* clones were significant for all three traits assessed at both sites (Table 3). *A. aulacocarpa* clones at Silkwood displayed similar growth (slightly greater height and slightly lower dbh, on average) compared with the seedling controls planted there. This indicated that the vegetative propagation procedures had not resulted in serious loss of vigour. The mean stem form score for clones (3.44) was significantly better (P < 0.001) than for seedlings (3.11) demonstrating a positive effect of ortet selection.

During the first few months after establishment, most plants at the Southedge CSO were heavily attacked by two longicorn beetle species *Platyomopsis* nr. *albocincta* Guerin and *Penthea pardalis* Newm. (M. Debaar, pers. comm. 1997) whose larvae girdle young stems. Despite these attacks, most plants recovered well and many clones had re-established excellent stem form and apical dominance by age 22 months. The *A. crassicarpa* clone grew much faster than all *A. aulacocarpa* clones at both Silkwood and Southedge, indicating the potential for superior early vigour of this species relative to *A. aulacocarpa*.

For each site, best linear unbiased predictor (BLUP) values for each clone were calculated by REML, using models in which replicates were fixed and clones were random effects. Twenty-nine of the *A. aulacocarpa* clones were represented by two or more ramets at both trial sites. For each variate, the correlations between the clone BLUPs of these 29 clones at the two sites were calculated to give estimates of clonal performance repetition across sites. These correlations were all strongly positive: 0.62 for height, 0.71 for dbh and 0.54 for stem form. This good correlation of clone performance across two widely differing environments suggests there may be no need to maintain different *A. aulacocarpa* breeding populations for upland and coastal environments in north Queensland.

As well as enabling identification of first stage, superior clones for use in local plantings, the clonal orchard and clonal test will serve to produce genetically improved seed after culling to the best clones. The clonal orchard and clonal trial together contain a total of 64 clones. The best 20–25 of these clones, retained in the clonal seed orchard after roguing, will also serve as a breeding subline. Seed from the culled orchard will be used to establish hedges and to test the second-generation clones.

Second-stage base population of A. aulacocarpa

In mid 1997 a second-stage base population was planted near Cardwell in north Queensland. The main components of the population are: 18 second-generation families from the initial SSOs/SPAs; 65 second-generation families from an SSO in Thailand, based on 169 first-generation families; 11 provenance bulks which sampled seedlots from collections involving 184 parents in natural stands; and one bulked seedlot from a first-generation SSO in Fiji. This planting will serve a number of purposes including:

- a genetic gain trial
- an infusion to the initial breeding population
- development of a second subline in north Queensland
- ranking of the 11 'new' provenances
- a seed source.

Procurement, testing and development of interspecific *Acacia* hybrids

Hybrids between *A. auriculiformis* and *A. mangium* have now been observed in several countries, including Australia, China, Indonesia, Malaysia, Thailand and Vietnam. Among spontaneous hybrids, individuals displaying great phenotypic superiority of vigour and other desirable features including good branching, bole circularity, single stem and excellent wood properties for pulp production have been noted (Le Dinh Kha 1996). In two well-designed clonal trials in Vietnam, evaluated respectively at 30 and 32 months of age, rooted cuttings from respectively 30 and 19 selected F_1 hybrid trees greatly exceeded in growth similar rooted cuttings from seedlings of fast-growing natural provenances of each parental species.

Knowledge of this hybrid superiority stimulated the authors to establish a hybridising orchard, and to procure and test three of the best clones from Vietnam, along with clones from putative hybrids obtained locally from proximal trees in adjacent plots of a good Queensland *A. auriculiformis* provenance (Morehead River) and a good Papua New Guinea *A. mangium* provenance (Boite). Replicated field trials of these hybrids and appropriate controls were planted at two locations in north Queensland in mid 1997 for identification of superior clones locally.

Hybridising orchard — design and early performance of sources within species

The hybridising orchard, comprising alternate rows of seedlings of the two species, incorporated *A. auriculiformis* progeny from four different SSOs of Queensland, PNG or mixed provenance origins, and nine different sources of *A. mangium.* The orchard was planted on a red Kandosol at Meunga, near Cardwell in coastal north Queensland in June 1996 as four replicates of four paired rows (one row of *A. auriculiformis* and one of *A. mangium* in each pair) each row having 54 seedlings. There was one row of *A. auriculiformis* seedlings from each of the four sources in each replicate. The *A. mangium* seedlots were set out in single-tree plots, completely randomised across the four replicates. The rows in each two-species row pair were 3 m apart and the row pairs were separated from one another by 6 m. An initial spacing of 1.5 m was used between plants along the rows.

At age 10 months height was measured and plants were assessed as having single stem (scored as stem class 1) or multiple stems (scored as stem class 2). At age 13 months height was remeasured and axis (i.e. main stem) persistence was assessed. Axis persistence was scored in four classes: 1) single main stem loses persistence in lowest quarter of tree height, 2) stem persists to second quarter, 3) stem persists to third quarter and 4) stem persists to fourth quarter. Results are given in Table 4.

Acacia mangium seed sources did not differ significantly in height, but there were significant differences ($P < 0.05$) in multiple-stemming and axis persistence. At age 10 months the form differences equated to a lower proportion, 9%, of multiple-stemmed plants for 15 selected PNG-SW SSO families compared to 21% of multiple stemmed plants for the PNG-SW natural provenance control (a mix of equal proportions of 20 families selected at random from the 104 families that made up the original planting stock for the PNG-SW SSO). However, by age 13 months there was no difference in mean axis persistence between the 15 selected PNG-SW families (score of 2.41) and the control PNG-SW seedlot (score of 2.44). This change between ages 10 and 13 months was attributed to severe attack by the shoot-boring moth *Cryptophlebia* sp., which halted growth of the main leaders of virtually all *A. mangium* plants at around age 10 months, so that side-shoots took over dominance on many trees, leading to multiple-stemming. The minimal height growth of *A. mangium* between months 10 and 13 (Table 4) supports this interpretation, which was developed from frequent field inspections. The Sabah SPA and Lake Murray seed sources showed significantly ($P < 0.05$) poorer axis persistence at age 13 months than did the other seed sources. A separate, replicated trial of 16 select SSO open-pollinated families planted near Cardwell in mid 1996 and scored for axis persistence at 13 months showed highly significant differences between

Table 4. Results of 10 and 13 month assessments of hybridising orchard of *Acacia auriculiformis* and *A. mangium at* Meunga.

Species and seed source	No. of entries	No. of plants tested	Height 10 month (cm)	Height 13 month (cm)	Form[a] 10 month score	Axis pers[b] 13 month score
Acacia mangium						
SPA Sabah	1	40	251	259	1.15	1.83
Lake Murray PNG nat. prov.	1	40	249	254	1.12	1.95
Fiji SSO	1	82	288	298	1.11	2.38
Claudie R Qld nat. prov	1	40	263	275	1.18	2.32
PNG-SW nat. prov	1	40	274	282	1.21	2.44
Selected SSO families in Qld						
PNG-N	2 families	40	279	291	1.10	2.42
FNQ	7 families	140	284	291	1.05	2.62
PNG-SE	7 families	140	285	295	1.04	2.73
PNG-SW	15 families	302	280	288	1.09	2.41
(Total no. of seed sources)	36					
Standard error of diff. of seed source means			17	22	0.05	0.39
Significance of diff. between seed sources			n.s.	n.s.	*	*
A. auriculiformis						
Fiji SSO ex PNG		216	226	257	1.24	2.08
Fiji SSO ex Qld		216	223	250	1.05	2.44
Sakaerat (Thailand) SSO		216	214	240	1.24	1.73
Melville Island SSO ex PNG		216	234	264	1.25	1.75
Standard error of difference of means			5.2	6.3	0.037	0.087
Significance of diff. between seed sources			**	**	***	***

[a] Form scored as 1 = multiple stem, 2 = single stem
[b] Axis persistence scored as 1 = main stem persists to lowest quarter of stem height, 2 = persists to second, 3 = to third and 4 = to fourth quarter.
n.s. not significant
* 0.05 < P < 0.01
** 0.01 < P < 0.001
*** P < 0.001

families (data not presented) with some outstanding families and individuals, despite experiencing very severe attack by *Cryptophlebia* sp. from age 6 months onwards.

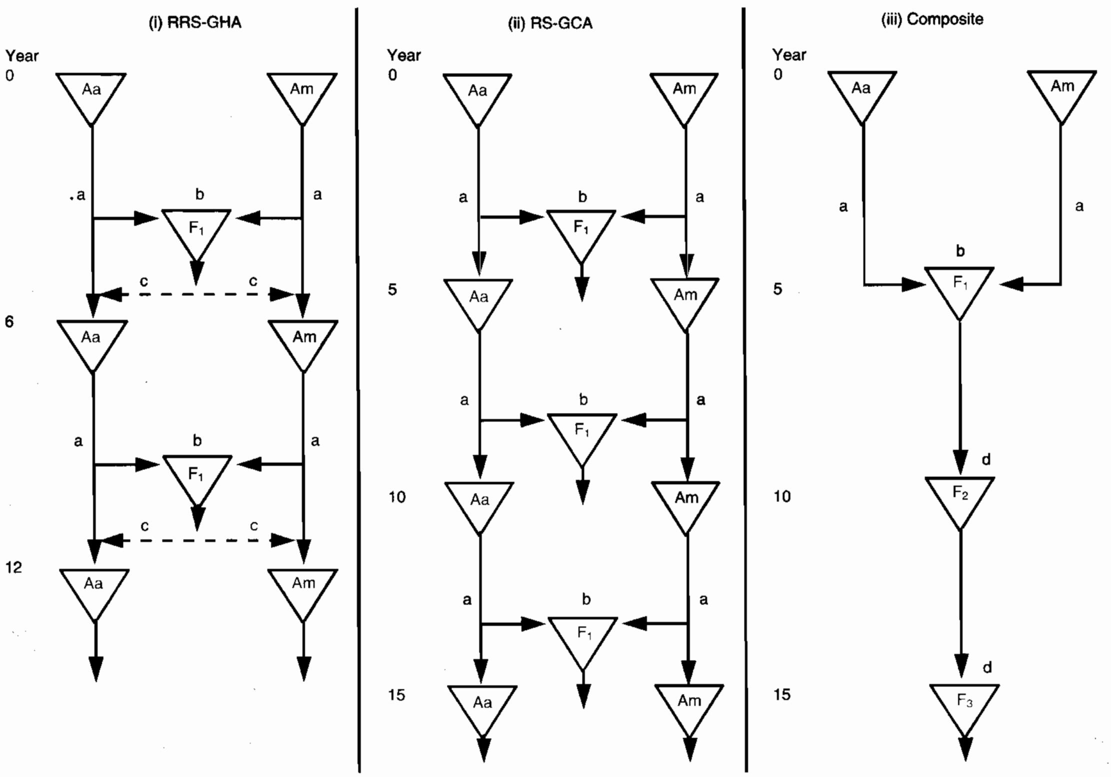
The clearly superior (P < 0.001) 10-month stem form and 13-month axis persistence of progeny of the Fiji SSO of Queensland-provenance origin of *A. auriculiformis* (scores of 1.05 and 2.44 respectively) relative to the other three sources of this species (with scores ranging from 1.24 to 1.25 for 10-month stem form and 1.73 to 2.08 for 13-month axis persistence) are also evident from Table 4. This is in accord with the expectation from many provenance trials of this species, which have consistently identified Queensland-provenance region as having better stem form than PNG or NT. The Thai (Sakaerat) multi-region SSO, which incorporates many selections from the inferior Thai land race and NT provenances (Pinyopusarerk et al. 1998) was inferior for height growth, stem form and axis persistence. These results augur well for reducing by selection the incidence of multi-stemming in both *A. mangium* and *A. auriculiformis*.

Planned orchard and progeny management

The initial espacement used in our hybridising orchard permits successive cullings based on population and individual performance. It is planned to cull the hybridising orchard progressively to a stocking of about 160 sph or about 10% of initial stocking. This would retain about 85 superior trees of each species. It is hoped there will be sufficient synchrony of flowering to obtain hybrid seedlings from at least 60 trees of each species. The hybrid progeny (identified on morphological criteria before planting) are to be established in multisite trials designed to estimate average reciprocal effects, variation between and within F_1 families and the general hybridising abilities (GHAs) of each of the parents. It is anticipated that the very best individuals of the hybrid progeny will be used for clonal testing and identification of superior clones, while their parents will be used for further pure species and hybrid development.

Alternative breeding methods for production of improved hybrids

It has been demonstrated for the *Pinus elliottii* × *P. caribaea* hybrid in Queensland that pure-species breeding in a hybrid program should be based on parents with high GHAs (Dieters and Nikles 1998). Figure 2(i) shows our proposed breeding strategy for the production of improved hybrids. The strategy involves **reciprocal recurrent selection for general hybridising ability** (RRS-GHA — see Nikles 1993) in open-pollinated hybridising orchards, relying on the performance of open-pollinated hybrid progeny to obtain GHA rankings for use in selecting the individuals of both parent species for the next breeding generation. Advancement of the two parent-species breeding populations and hybrid production could all be implemented in the one open-pollinated stand, by planting out open-pollinated progeny of the 40 (or thereabouts) individuals of both species with the highest GHAs, in a second-generation hybridising orchard of similar design to that described above (F_1 hybrid individuals would be culled from this second orchard). Some build-up of inbreeding in the parent species can be tolerated as the F_1 hybrids in each generation are fully outcrossed. A disadvantage of the scheme is that differences in fecundity, and limited pollen movement within the orchards, will result in



Aa: *Acacia auriculiformis*, Am: *A. mangium*, F_1: F_1 interspecific hybrid
a: assess breeding population and carry out first selective thinning prior to production of F_1 hybrids
b: open-pollination between *A. auriculiformis* and *A. mangium* produces F_1 hybrids
c: information from field trials of hybrid progeny used to identify individual *A. auriculiformis* and *A. mangium* parents with best general hybridising abilities, other individuals are removed from pure-species breeding populations before next generation is produced by open pollination
d: open pollination among many hybrid individuals produces the next generation of the composite hybrid breeding population

Figure 2. Alternative breeding methods for production of genetically improved *Acacia* hybrids in open-pollinated hybridising orchards. (i) RRS-GHA = reciprocal recurrent selection for general hybridising ability, (ii) RS-GCA = recurrent selection for general combining ability, (iii) Composite = composite advanced-generation hybrid breeding program.

different individuals receiving different pollen mixes, so estimates and rankings of GHA values may be imprecise. Matheson and Sim (1993) have proposed a somewhat similar scheme for hybrid breeding of *Acacia* species in Sabah.

At least two other long-term breeding methods could be considered for production of genetically improved hybrids. The first alternative would involve advancement of the two species by **recurrent selection for general combining ability** (RS-GCA — Nikles 1993). This uses the performance of the open-pollinated pure-species progeny as the basis for selection, with production of F_1 hybrids from interspecific crossing in each generation (Figure 2(ii)). RS-GCA has the disadvantage that GCA may be poorly correlated with GHA, resulting in lower genetic gain per generation in hybrid breeding. Assessing 10-year-old progeny trials, Dieters and Nikles (unpubl.) found there was no significant correlation between GCA and GHA for 95 *Pinus elliottii* parents used in the production of pure-species families and interspecific hybrid families with *P. caribaea* in Queensland. Turnover of generations of *Acacia* would be quicker than with RRS-GHA as there is no requirement to wait for information from the hybrid progeny tests to select the trees whose progeny will comprise the next generation's pure-species breeding populations. This scheme could also be carried out using a single, open-pollinated breeding facility.

The third alternative is **development of a composite hybrid population** by breeding a large set of superior unrelated F_1 hybrids through to an advanced, say, F_4 generation, when the hybrid breed should have become stabilised (Figure 2(iii)). Broadly, this is a procedure used to develop hybrid animals (Bourdon 1997) and 'synthetic varieties' of plants. A stabilised advanced-generation hybrid population, maintained with minimal inbreeding, would have three advantages: it would be expected to retain a large proportion of the hybrid vigour of the F_1, it would require management of only one breeding population, and mass propagation using open-pollinated seed could be used in situations where mass clonal propagation is difficult. It would be important to have a broadly based initial F_1 breeding population comprising many (preferably at least about 100) unrelated, superior F_1 individuals to avoid rapid buildup of deleterious inbreeding in later generations. Loss of some genetic diversity (a consequence of high selection intensities over several generations) might be tolerated in the interests of increasing the genetic merit and phenotypic uniformity of the hybrid population. To test the merit of outcrossed F_2 hybrids, a small breeding orchard of F_1 hybrid individuals was established near Cardwell in June 1997. The orchard will be selectively thinned, retaining unrelated, superior F_1 genotypes, so as to produce non-inbred F_2 progeny for testing. It may be that superior open-pollinated families of the F_2 population are of sufficiently high merit and uniformity to be used to establish operational plantations. This is the case with tropical pine hybrids in Queensland where thousands of hectares have been planted successfully with outcrossed F_2 orchard bulks (Nikles 1996).

For all three of the above breeding methods, breeders have the options of setting up multiple breeding populations and elite nucleus breeding populations using marcots of outstanding trees, and of carrying out controlled pollinations among the very best trees (Jiwarawat et al. 1996).

Discussion

Conservation function of the SSOs

Conservation of genetic diversity of the four tropical *Acacia* species discussed here might be accomplished effectively via the recycling of large commercial plantations provided (a) very large samples are transferred from most of the range of each species, and (b) broad genetic bases are maintained in the new areas to which the species are introduced. The first criterion seems very likely to have been satisfied already for these species, with the possible exception of *A. aulacocarpa*. Certainly for the other three species, seeds from many hundreds of trees from throughout their main occurrences have been collected and used to establish vast commercial plantations, numerous provenance trials, many progeny trials and large numbers of seed orchards/SSOs. Records of seed collections and dispatches held by the ATSC, one of the main suppliers of seed of these species, demonstrate this clearly. In the case of *A. aulacocarpa* the numbers of seed parents sampled in Papua New Guinea and north Queensland would exceed 500, but the areas of plantations, trials and orchards established are far less than those for the other species. Yet it is considered that the ex situ plantings made already, the seed orchards established in several places, and the seed in store will guarantee adequacy of initial conservation of diversity ex situ.

The second criterion mentioned above will also be satisfied in the short term during which all cycled plantations are established with broad bases from SPAs and seed orchards. However, if deployment via clonal plantations using relatively small numbers of clones becomes more wide spread, there will be a danger of loss of genetic diversity in some areas. The maintenance of the north Queensland SSOs and the occasional replenishment of seed stocks via collections from large numbers of trees per SSO can assist, but there should also be a conscious effort by major growers or concerned organisations to maintain small broadly-based plantations across cycles of crop harvesting and replacement. This approach has been adopted with *Pinus radiata* in New Zealand (Burdon 1995) and *P. elliottii* in Queensland (Toon et al. 1996). It is suggested that the community of tropical acacia growers and breeders should give consideration to this simple means for conservation of genetic diversity.

Genetic development function of the SSOs

Just over 90 phenotypically superior trees remain of some 100 selected across all the *A. mangium* SSOs and other *A. mangium* plantings in north Queensland. These trees represent many provenances across four superior provenance regions, and their seed is ideal for establishment of second-generation SPAs and/or pedigreed SSOs in 'green-field' plantation projects. Culling of the second-generation SPAs and SSOs would enable retention of individual trees that are well adapted in the new environment. These could provide seed well suited for both commercial plantings and, along with infusions from elsewhere, good breeding bases. For example, 68 open-pollinated progenies of *A. mangium* selections from the Queensland SSOs were provided to the Royal Forest Department, Thailand to contribute to pedigreed breeding populations planted in that country in 1997. Selected seedlots from the *A. mangium* SSOs have also been incorporated in SPAs and SSOs established over the period 1995–1997 in Vietnam, the Philippines, Indonesia and India to support improvement activities carried out via FAO's FORTIP program (CSIRO Forestry and Forest Products 1996).

Economic considerations

The rapid development of our Australian SSOs and similar ones in Southeast Asian countries has occurred while large plantations continue to be established using seed from poor land races and inferior local seed sources of *A. mangium* in Indonesia and Malaysia (Otsamo et al. 1996), and of *A. auriculiformis* in India (Bulgannawar and Math 1991), Thailand (until recently — Luangviriyasaeng and Pinyopusarerk 1998) and other tropical countries. There is a compelling economic argument that operational plantings of seed from these poor land races should be discontinued immediately in favour of seed derived from SSOs developed from the best provenance regions (or, if not available, seed collected from these best natural provenance regions). While local, genetically inferior seed sources might be available cheaply at around $US100 per kg or less, our experience is that a well managed SSO program can deliver seed at a cost below $US600 per kg for all the tropical *Acacia* species. A kilogram of *Acacia* seed is sufficient to establish at least 20 ha of plantations. Therefore the additional cost of using high quality seed is less than $30 per ha. Volume production can often be increased by a minimum of 50%, and even over 100% through the replacement of inferior landrace material, producing at least an additional 50–100 m^3 per ha of wood at the end of an 8–10 year rotation. The increase in value is worth over $1000 per ha, assuming a wood value of about $20 per m^3, so using improved seed is clearly very profitable. A single hectare of *A. mangium* SSO, yielding 50 kg of seed per year, will provide seed sufficient to plant over 1000 hectares of plantations annually. The corresponding ratios for *A. aulacocarpa*, *A. auriculiformis* and *A. crassicarpa* are somewhat lower, but one hectare of well-sited and well-managed SSO can provide planting material for over 100 ha of plantations per year, for all three species. Finding sufficient land for SSO establishment is therefore unlikely to be a problem for any agency charged with planting large areas of *Acacia* plantations.

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References

Bourdon, R.M. 1997. Understanding Animal Breeding. Prentice Hall, NJ, USA, 523 pp.

Bulgannawar, G.N. and Math, B.B.M. 1991. The role of *Acacia auriculiformis* in afforestation in Karnataka, India. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 100–115.

Burdon, R.D. 1995. Future directions in tree breeding: some questions of what we should seek, and how to manage the genetic resource. In: Laverau, J., ed., Evolution and Tree Breeding: Advances in Quantitative and Molecular Genetics for Population Improvement.

Proceedings, 25th Meeting, Canadian Tree Improvement Association, Part 2. Canada Tree Improvement Association/Western Forest Genetics Conference, 24–39.

Chia, E. and Kabi, A. 1994. Seed production at Sabah Softwoods: a case study. In: Drysdale, R.M., John, S.E.T. and Yapa, A.C., ed., Proceedings, International Symposium on Genetic Conservation and Production of Tropical Forest Tree Seed. ASEAN–Canada Forest Tree Seed Centre, Muak-Lek, Saraburi 18180, Thailand, 194–198.

CSIRO Forestry and Forest Products 1996. Improving Tree Productivity in Southeast Asia through Support to FAO's Regional Project RAS/91/004. Project Completion Report to Australian Agency for International Development. CSIRO Forestry and Forest Products, Canberra.

Gunn,. B.V. and Midgley, S.J. 1991. Exploring and accessing the genetic resources of four selected tropical acacias. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35, Australian Centre for International Agricultural Research, Canberra, 57–63.

Hardiyanto, E. 1996. The status of genetic resources utilization for industrial forest plantations in Indonesia. In: Tropical Plantation Establishment — Improving Productivity through Genetic Practices. Proceedings, International Seminar 19–21 Dec. 1996. Forest Tree Improvement Research and Development Institute, Jogyakarta, II, 22–24.

Harwood, C.E., Applegate, G.B., Robson, K.J. and Williams, E.R. 1993. Early growth of provenances and progenies in *Acacia mangium* seed production areas in north Queensland, Australia. In: Awang, K. and Taylor, D., ed., Acacias for Rural, Industrial and Environmental Development. Winrock International, Bangkok, Thailand, 113–122.

Harwood, C.E., Applegate, G.B., Robson, K.J. and Haines, M.W. 1994. Establishment and management of seed production areas of tropical tree species in northern Australia. In: Drysdale, R.M., John, S.E.T. and Yapa, A.C., ed., Proceedings, International Symposium on Genetic Conservation and Production of Tropical Forest Tree Seed. ASEAN–Canada Forest Tree Seed Centre, Muak-Lek, Saraburi 18180, Thailand, 233–239.

Harwood, C.E., Nikles, D.G., Pomroy, P. and Robson, K.A. 1996. Impact of thinning via phenotypic selection on the genetic base of planted seed production areas. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings, QFRI-IUFRO Conference, Caloundra, Queensland, Australia, 27 Oct.–1 Nov. 1996, Queensland Forest Research Institute, Gympie, 148–153.

Isbell, R.F. 1996. Australian Soil and Land Survey Handbook. The Australian Soil Classification. CSIRO Publishing. Collingwood, Victoria. 143 p.

Jiwarawat, P., Luangviriyasaeng, V. and Woo, K.C. 1996. Hybrid seeds of *Acacia auriculiformis*. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings, QFRI–IUFRO Conference., Caloundra, Queensland, Australia, 27 Oct.–1 Nov. 1996, Queensland Forest Research Institute, Gympie, 234–237.

Le Dinh Kha 1996. Studies of natural hybrids of *Acacia mangium* and *A. auriculiformis* in Vietnam. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings QFRI-IUFRO Conference, Caloundra, Queensland, Australia, 27 Oct.–1 Nov. 1996. Queensland Forest Research Institute, Gympie, 328–332.

Matheson, A.C. and Sim Boon Liang 1993. Breeding Acacias in Sabah. Consultancy Report to ACIAR Project 8630. ACIAR, Canberra.

Nikles, D.G. 1993. Breeding methods for production of interspecific hybrids in clonal selection and mass propagation programmes in the tropics and subtropics. In: Davidson, J., ed., Proceedings of the regional symposium on recent advances in mass clonal multiplication of forest trees for plantation programmes, 1–8 December 1992, Cisarua, Bogor, Indonesia. FAO, Los Baños, Philippines, 218–261.

Nikles, D.G. 1996. The first 50 years of the evolution of forest tree improvement in Queensland. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings, QFRI-IUFRO Conference, Caloundra, Queensland, Australia, 27 Oct.–1 Nov. 1996, Queensland Forest Research Institute, Gympie, 51–64.

Nikles, D.G. and Newton, R.S. 1983. Inventory and uses of provenance resource stands of *Pinus caribaea* Mor. var. *hondurensis* Barr. and Golf. in Queensland. Silvicultura (Brazil), 29, 122–125.

Otsamo, A., Nikles, D.G. and Vuokko, R.H.O. 1996. Species and provenance variation of candidate acacias for afforestation of *Imperata cylindrica* grasslands in South Kalimantan, Indonesia. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings, QFRI-IUFRO Conference, Caloundra, Queensland, Australia, 27 October–1 Nov. 1996, Queensland Forest Research Institute, Gympie, 46–50.

Soil Survey Staff 1975. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. US Dept. Agriculture handbook No. 436. Govt. Printer, Washington.

Toon, P.G., Dieters, M.J. and Nikles, D.G. 1996. Components of a slash pine (*Pinus elliottii* var. *elliottii*) breeding strategy for the continued improvement of its hybrids. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings, QFRI-IUFRO Conference, Caloundra, Queensland, Australia, 27 Oct.–1 Nov. 1996, Queensland Forest Research Institute, Gympie, 388–389.

Williams, E.R. and Matheson, A.C. 1994. Experimental Design and Analysis for Use in Tree Improvement. CSIRO, Melbourne and ACIAR, Canberra, 174 p.

Evaluation of Clonal Strategies for Tropical Acacias

S.M. Walker and R.J. Haines[1]

Abstract

This paper undertakes a simple marginal benefit/cost analysis for an acacia clonal forestry strategy and examines the sensitivity of key performance measures to variation in parameters such as: size of plantation estate; rotation length; stumpage price; productivity gains; total clonal program cost, and plant propagation cost. This analysis indicates that at likely stumpage prices and realistic costs of producing cuttings, investment in a clonal program is highly profitable where such a program is properly conducted to ensure delivery of a significant productivity gain.

A clonal program is very attractive for a plantation estate of 100 000 hectares or greater, yielding a high IRR, marginal wood costs which are well below market price, marginal plant costs that are likely to be acceptable, and large additional volumes of wood to meet mill demand. The outcome is not influenced greatly by rotation length within the range 6 to 9 years, and is very favourable for stumpage prices of US$8 or greater. The outcomes of the analysis are quite sensitive to the size of the planting program, with investment in a well designed and conducted clonal program unlikely to be justified for small plantation programs.

Similarly, exceptionally high plant production costs would render investment in a clonal program unattractive unless gains achieved are much higher than those which can presently be predicted with confidence over a large plantation estate.

THE Asia-Pacific region will play a major role in meeting the increasing worldwide demands for wood and wood products. The establishment of acacia plantations for pulp production will be of major importance in these expanding programs. By early next century there is likely to be an acacia plantation estate of over 2 million hectares in Indonesia and Malaysia.

In South America, South Africa and the Congo, tested clones of *Eucalyptus grandis*, *E. tereticornis* and the *E. grandis* × *urophylla* hybrid are being mass propagated successfully by cuttings (Eldridge et al. 1994). The Queensland Forestry Research Institute has an advanced clonal forestry program with tropical pines in Queensland (Walker et al. 1996) and has a major involvement in a large acacia clonal forestry program in Indonesia.

The clonal forestry techniques and strategies now being employed with acacias in Indonesia were initially developed in an ACIAR project in Malaysia (Haines and Griffin 1992; Haines et al. 1992; Wong and Haines 1992). Since then, work has progressed to provide a range of technologies and strategies for maximising wood production from plantations.

Technological advances, for example molecular approaches and novel propagation techniques, have led to high expectations in relation to benefits from their deployment. However, such high technology strategies must not be isolated from consideration of the full economic and logistical implications of their use.

In 1992, Haines and Griffin demonstrated that clonal strategies with acacias could realise productivity gains of up to 40%, and concluded that net financial returns are influenced by both the genetic quality of planting stock and the cost of selection and multiplication procedures. A detailed analysis of the economics and market prospects of *Acacia mangium* plantations by Othman and Tang Get Seng (1993) demonstrated that even small increases in site productivity can significantly increase financial returns.

This paper undertakes a simple marginal benefit/cost analysis for an acacia clonal forestry strategy and examines the sensitivity of key performance measures to variation in parameters such as: size of plantation estate; rotation length; stumpage price; productivity gain; total clonal program cost; and plant propagation cost.

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Methods

Assumptions for base scenario

1. The analysis relates to a plantation estate required to feed a large pulp mill in Indonesia with a projected operational life of 22 years.
2. The mill, which has just become operational, will depend largely on plantation timber within the next 5 years, and will rely on plantation timber until the end of its projected life.
3. The mill requires an annual log input of 3 million m^3 and maximisation of supply is essential.
4. An acacia plantation program commenced 3 years ago, and currently uses seedlings derived from bulked provenance collections (base population).
5. There is a total plantable estate of 100 000 hectares.
6. The rotation length is 8 years, giving an annual planting program of 12 500 hectares.
7. Plantations are established at 1111 stems per hectare with 10% additional stock production to allow for refilling (blanking).
8. The Mean Annual Increment (MAI) for unimproved plantations established using seed from natural stands is 25 m^3/ha/year.
9. The clonal strategy adopted is based on parallel clonal testing and multiplication of initially juvenile material, with the deployment of clones after a test period of 3 years.
10. The first operational planting of clones (Series 1) would commence at Year 5, with full implementation by Year 7 (Figure 1). The clones used in these plantings would be derived from selections made in an unimproved seedling (base) population, realising a 30% productivity gain or an MAI of 32.5 m^3/ha/year.
11. The planting of a second series of clones (Series 2), selected in an improved population derived from a cycle of breeding, would commence in Year 10 with full implementation by Year 12 (Fig. 1). These clones would provide an additional 10% gain over the base population, resulting in a total productivity gain of 40% or an MAI of 35 m^3/ha/year.
12. Future potential disease/insect threats in monoclonal plantings would be managed by the deployment of 10–15 clones in any one year, with replacement of clones every 5 years.
13. The clonal program, including breeding, clonal testing, multiplication and associated R&D, would cost US$500 000 per annum with a 2-year scale-up time at commencement and a 3-year scale-down time prior to the last plantings.
14. There is a US$0.06 per plant out-the-gate propagation cost for the production of containerised cuttings. This unit cost includes: nursery construction and replacement costs; the purchase and replacement of containers and supporting frames; and all other materials, labour and overheads associated with both plant propagation and hedge management.
15. The stumpage price is US$10/$m^3$.

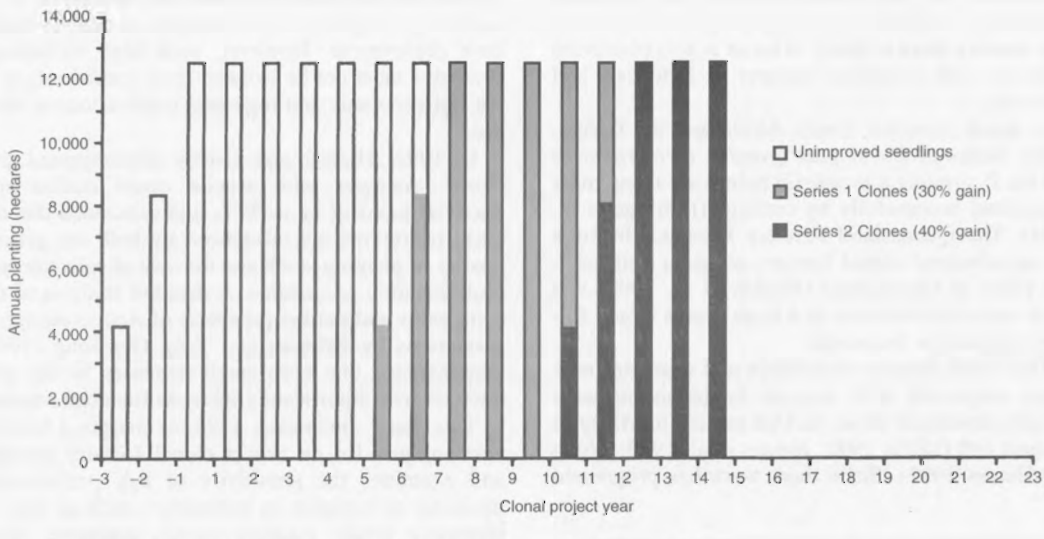

Figure 1. Staged introduction of clones into the plantation estate (base scenario).

Analysis

The analysis aims to evaluate the financial wisdom of immediately embarking on a clonal forestry program aimed at rapid increases in the productivity of new plantations. The clonal forestry program life was assumed to be 22 years with the annual costs and benefits occurring over this period being discounted back to current values. A real discount rate of 12% is used to reflect the opportunity cost of capital over the life of the project.

Performance measures used in the analysis include:

- *Internal Rate of Return (IRR)* This is the rate at which the discounted benefits equal the discounted costs.
- *Marginal Wood Cost (MWC)* This term describes the discounted cost stream divided by the discounted volume of additional wood produced over the project life (US$/$m^3$).
- *Marginal Plant Cost (MPC)* This term describes the discounted production cost (including total clonal program and plant propagation cost) divided by the discounted quantity of cuttings produced over the project life (US$/$m^3$).
- *Marginal Wood Yield (MWY)* This term describes the total additional yield of wood resulting from the clonal program (m^3).

The analysis examines the sensitivity of these performance measures to variation in the following key parameters:

- Size of plantation estate
- Rotation length
- Stumpage price
- Productivity gains resulting from the clonal program
- Total clonal program cost
- Plant propagation cost

When conducting the sensitivity tests only the parameter in question was varied; all other parameters were held constant as per the base scenario.

Results

Base scenario

For a plantation estate of 100 000 hectares, rotation length of 8 years and a stumpage price of US$10/$m^3$, investment of US$500 000 per annum in a clonal forestry program yielding average productivity gains of 30% (Series 1 clones) and 40% (Series 2 clones), with cuttings costing US$0.06 each to produce, results in an IRR of 18.6%.

The total marginal wood yield is 7.75 million m^3, produced at a marginal wood cost of US$5.96/$m^3$ (well below the price at which such requirements could be purchased, assuming stumpage of US$10/$m^3$), equating to a marginal plant cost of US$0.13 per plant.

Effect of size of plantation estate

The outcomes are quite sensitive to the size of the plantation estate (Table 1). The clonal program is marginally affordable for a plantation estate of 50 000 hectares — with IRR and the marginal cost of wood close to the standards. At this level, sourcing wood from external markets would be an alternative to a clonal program for meeting mill requirements. The clonal program would not be financially viable for a smaller plantation estate.

The clonal program is very attractive for a plantation estate of 100 000 hectares or greater, yielding a high IRR, marginal wood costs which are well below market price, marginal plant costs which are likely to be acceptable, and large additional volumes of wood to meet mill demand.

Effect of rotation length

The outcomes are less sensitive to rotation length (Table 1), although shorter rotations are more favourable in all respects because of earlier returns and the greater proportion of plantings established with improved Series 2 clonal material. Such advantages may be outweighed, however, by wood quality and other establishment cost considerations.

Effect of stumpage price

IRR is very sensitive to stumpage price (Table 1) being well over the 12% standard for prices of US$8 (or higher) per m^3.

Effect of productivity gains

The outcomes are also very sensitive to the level of productivity gains achieved through a clonal program. An initial (Series 1) productivity gain of 20% still results in an IRR above the 12% standard. A Series-1 productivity gain of 30% is perhaps slightly conservative, but it is a realistic estimate of what might be achieved as an average over a plantation estate of this size.

Table 1 demonstrates that this level of productivity yields an excellent IRR (18.6%), and is highly favourable in terms of the other parameters. Series-1 productivity gains of 40 and 50% yield IRRs in excess of 20%, but gains of this size are less likely to be achieved over the whole plantation estate.

Table 1. Sensitivity of performance measures with respect to key analysis parameters.

Simulations	IRR (%)	MWC (US$/m³)	MPC (US$/plant)	MWY ('000 m³)
Plantation size (ha)				
25 000	8.7	14.66	0.32	1 938
50 000	13.9	8.86	0.19	3 875
100 000	**18.6**	**5.96**	**0.13**	**7 750**
150 000	21.1	4.99	0.11	11 625
200 000	22.6	4.51	0.10	15 500
Rotation length (years)				
6	22.0	5.39	0.11	9 750
7	20.2	5.60	0.12	8 750
8	**18.6**	**5.96**	**0.13**	**7 750**
9	17.1	6.45	0.14	6 750
Stumpage price (US$/m³)				
6	12.9	5.96	0.13	7 750
8	16.1	5.96	0.13	7 750
10	**18.6**	**5.96**	**0.13**	**7 750**
12	20.7	5.96	0.13	7 750
14	22.5	5.96	0.13	7 750
Productivity gain - Series 1 (% over base population)				
10	8.6	14.95	0.13	3 250
20	14.6	8.52	0.13	5 500
30	**18.6**	**5.96**	**0.13**	**7 750**
40	21.7	4.58	0.13	10 000
50	24.2	3.72	0.13	12 250
Productivity gain — Series 2 (% over base population)				
30	17.6	6.60	0.13	6 750
35	18.1	6.26	0.13	7 250
40	**18.6**	**5.96**	**0.13**	**7 750**
45	19.1	5.68	0.13	8 250
50	19.5	5.43	0.13	8 750
Clonal program ($US/annum)				
250 000	22.6	4.51	0.10	7 750
500 000	**18.6**	**5.96**	**0.13**	**7 750**
750 000	15.9	7.41	0.16	7 750
1 000 000	13.9	8.86	0.20	7 750
Propagation cost ($US/plant)				
0.04	20.4	4.94	0.11	7 750
0.06	**18.6**	**5.96**	**0.13**	**7 750**
0.08	17.0	6.98	0.15	7 750
0.10	15.6	8.00	0.18	7 750
0.12	14.2	9.02	0.20	7 750

IRR = Internal rate of return
MPC = Marginal plant cost
MWC = Marginal wood cost
MWY = Marginal wood yield
(base scenario shown in bold)

The outcomes are less sensitive to the level of productivity gain achieved in the breeding cycle leading to the selection and deployment of Series-2 clones. This is because the additional wood yield is available only in the last 5 years of the project life (Fig. 2). The additional volume of wood, however, may be significant in relation to security of mill supply

Effect of cost of the clonal program

The outcomes are somewhat sensitive to cost of the clonal program. An annual cost of US$500 000 is considered a realistic estimate for a properly designed and conducted, low-risk clonal program in Indonesia. At this cost, financial outcomes are highly favourable (Table 1).

Even at an unrealistically high cost of US$1 000 000 per annum, IRR is still above the 12% standard. If the program could be conducted at a cost lower than US$500 000 per annum, financial outcomes would be even more attractive. It is considered unlikely that such a program could properly address important parameters such as genotype-by-environment interaction, and could test and identify sufficient outstanding clones. A low budget program such as this would be conducted at much higher risk of not achieving the productivity gains.

Effect of propagation cost

Financial outcomes are sensitive to the propagation cost per plant, with IRR very high at likely plant propagation costs, and still above 12% within the realistic range presented in Table 1. The influence on IRR of a broader range of plant production costs (including discounted costs of clonal program and plant propagation) is graphically demonstrated in Figure 3 for a broad range of productivity gains. This illustrates the crippling financial impact of very high plant production costs. Plant production costs of US$0.50–0.70 per plant, for example, will yield an IRR above the 12% standard only when very high productivity gains (80–100%) are achieved. Predictions of productivity gains of these proportions are unrealistic during the 22-year project life considered here.

Conclusions

This analysis indicates that at likely stumpage prices and at realistic costs of producing cuttings, investment in a clonal program is highly profitable where such a program is properly conducted to ensure delivery of a good productivity gain.

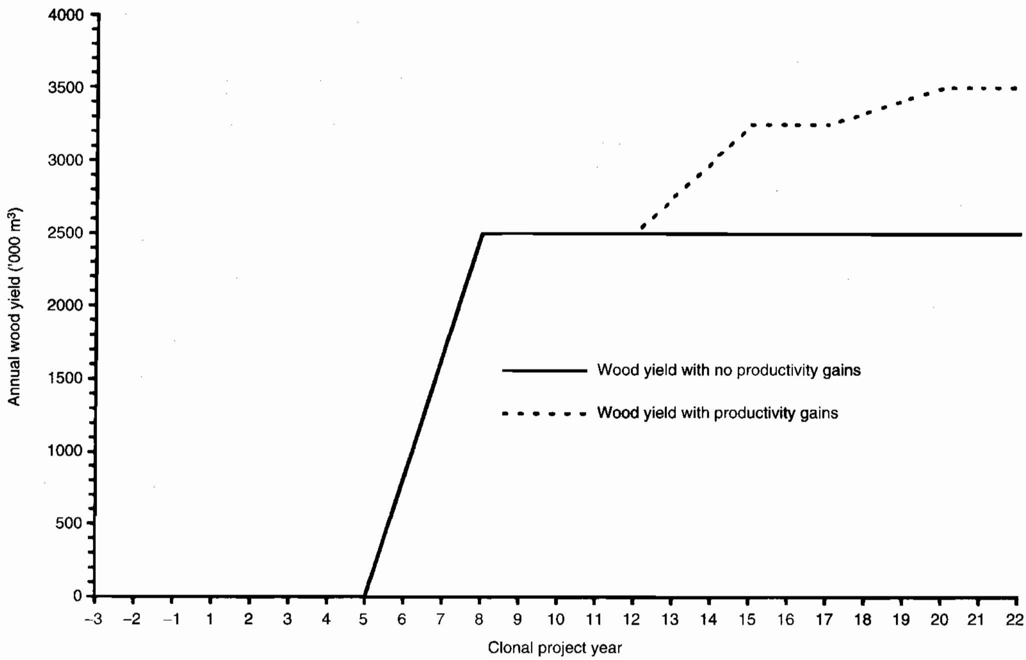

Figure 2. Annual wood yield resulting from productivity gains (base scenario).

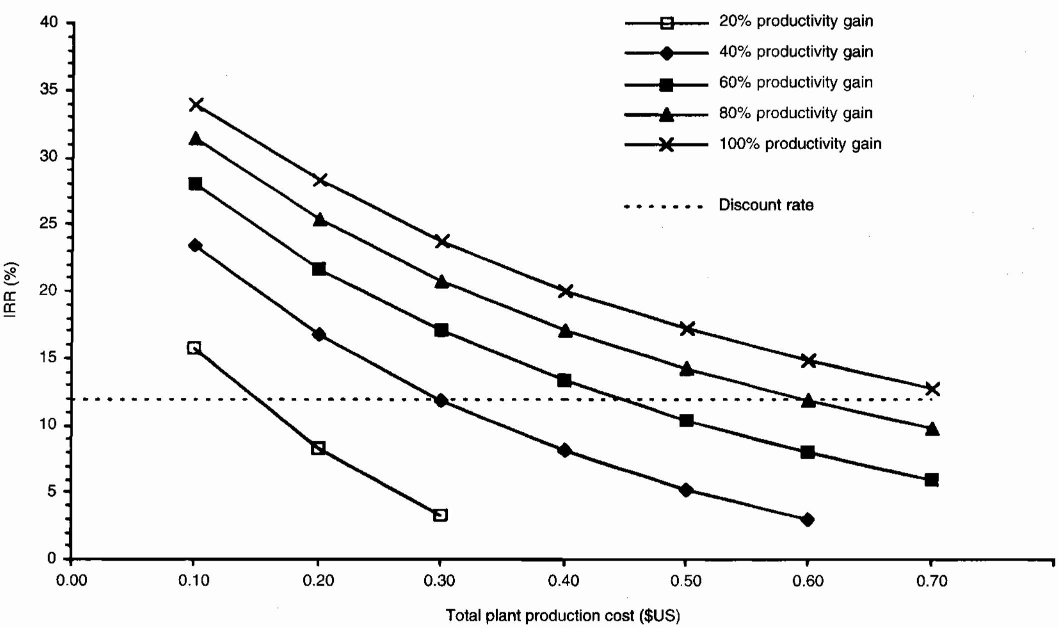

Figure 3. Effects of productivity gains and total plant production costs (clonal program and plant propagation) on projected financial returns, assuming 100 000 hectare plantation estate, 8 year rotation and US$10/m^3 stumpage price.

The program is very attractive for a plantation estate of 100 000 ha or greater, yielding a high IRR, marginal wood costs well below market price, marginal plant costs that are likely to be acceptable, and large additional volumes of wood to meet mill demand. The additional wood provided would be equivalent to that available by increasing the plantation estate by approximately one-third.

The outcomes are not influenced greatly by rotation length within the range 6–9 years. They are quite sensitive, however, to the size of the planting program, with investment in a well designed and conducted clonal program unlikely to be justified for small plantation programs.

Although influenced little by unit plant propagation costs within the range US$0.04–0.12 that might be expected for a cutting, exceptionally high plant production costs (e.g. US$0.50–0.70) render investment in a clonal program unattractive unless gains achieved are much higher (say 80–100%) than those which can currently be predicted with confidence over a large plantation estate. Potentially, application of molecular techniques and novel propagation approaches may ultimately deliver larger gains. However, there are high risks associated with this, and any application of such technologies is unlikely to impact on wood harvested during the 20-year project life considered here. Additionally, a major investment in technology development would be required.

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References

Eldridge, K., Davidson, J., Harwood, C. and Van Wyk, G. 1994. Eucalypt domestication and breeding. Oxford Science Publications, Oxford, UK.

Haines, R.J. and Griffin, A.R. 1992. Propagation options for *Acacia mangium, Acacia auriculiformis* and their hybrid. In: Carron, L.T. and Aken, K.M., ed., Breeding Technologies for Tropical Acacias. Proceedings of a Workshop held in Tawau, Sabah, Malaysia, 1–4 July 1991. ACIAR Proceedings No. 37, Australian Centre for International Agricultural Research, Canberra, 122–127.

Haines, R.J., Wong, C.Y. and Chia, E. 1992. Prospects for the mass propagation of superior selection-age phenotypes of *Acacia mangium* and *Acacia auriculiformis*. In: Carron, L.T. and Aken, K.M., ed., Breeding Technologies for Tropical Acacias. Proceedings of a Workshop held in Tawau, Sabah, Malaysia, 1–4 July 1991. ACIAR Proceedings No.37, Australian Centre for International Agricultural Research, Canberra, 115–118.

Othman, M. and Tang Get Seng, R. 1993. Economics and market prospects. In: Awang, K. and Taylor, D., ed., *Acacia mangium* Growing and Utilisation. MPTS Monograph Series No. 3. Bangkok, Thailand: Winrock International and FAO, 243–258.

Walker, S.M., Haines, R.J. and Dieters, M.J. 1996. Beyond 2000: clonal forestry in Queensland. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI-IUFRO Conference held in Caloundra, Queensland, Australia, 27 October–1 November 1996, 351–354.

Wong, C.Y. and Haines, R.J. 1992. Multiplication of families of *Acacia mangium* and *Acacia auriculiformis* by cuttings from young seedlings. In: Carron, L.T. and Aken, K.M., ed., Breeding Technologies for Tropical Acacias. Proceedings of a Workshop held in Tawau, Sabah, Malaysia, 1–4 July 1991. ACIAR Proceedings No. 37, Australian Centre for International Agricultural Research, Canberra, 112–114.

Clonal Tests and Propagation Options for Natural Hybrids between *Acacia mangium* and *A. auriculiformis*

Le Dinh Kha, Nguyen Dinh Hai and Ho Quang Vinh[1]

Abstract

Cuttings from selected clones of F_1 natural hybrids between *Acacia mangium* (Daintree provenance, Queensland) and *A. auriculiformis* (Darwin provenance, Northern Territory) together with seedlings of the F_2 hybrid generation were included in a set of four trials planted at Ba Vi, northern Vietnam. At age 4 years a marked heterosis effect was observed for cuttings of F_1 hybrids. Their growth was significantly higher than seedlings and cuttings of parental species and this tendency could be maintained for the next several years. Growth of F_2 hybrid seedlings after 2 years was intermediate between that of their parental species and segregation in their morphology was obvious. From the clonal tests, some promising F_1 hybrid clones that are fast growing, good in stem form and relatively high in wood density have been identified.

NATURAL hybrids between *Acacia mangium* and *A. auriculiformis* (hereafter referred to as acacia hybrids) have been studied by the Research Centre for Forest Tree Improvement (RCFTI) since 1993. Morphology and wood density of F_1 acacia hybrid trees was intermediate between *A. auriculifomis* and *A. mangium*, and obvious heterosis in growth rate was observed (Le Dinh Kha et al. 1993). Pulp productivity as well as tearing and folding strength of paper made from the wood of the acacia hybrid were significantly higher than for their parents (Le Dinh Kha and Le Quang Phuc 1995).

Because of these advantages, the Ministry for Agriculture and Rural Development of Vietnam decided to establish pilot plantations of superior hybrid clones in different ecological zones of Vietnam. Up to now, more than 100 hectares of acacia hybrid plantations have been established, and the planted areas of acacia hybrids are expected to increase rapidly in the next few years.

However, it should be noted that the natural hybrids used so far have been produced at random between trees of unknown phenotypes. Their parents were not selected, so the acacia hybrids are not homogeneous in growth rate. Clonal tests in Vietnam showed that if plus trees among natural F_1 acacia hybrids are properly selected, the growth of cutting-propagated ramets of these selected ortets, measured at the age of 3 years, is much greater than that of cuttings and seedlings from both parent species (Le Dinh Kha et al. 1995; Le Dinh Kha 1996). However, if acacia hybrid ortets are not selected and tested properly, growth rates of some of the hybrid clones are lower than those of their parent species (Pham Van Tuan et al. 1995). Selection of plus trees among natural hybrids that are fast growing and good in stem form, conducting cutting propagation and setting up clonal tests to identify the best clones among selected hybrid plus trees are therefore very important.

Another problem is that due to a lack of genetic knowledge, seeds collected from F_1 hybrid trees are still used for plantation establishment in some places. Therefore, further research on clonal testing, and selection of suitable propagation methods for the acacia hybrids is necessary to develop acacia hybrid materials for use in large-scale forest plantings in Vietnam.

Materials and Methods

The materials used for the studies reported here were selected clones of natural hybrids between *A. mangium* (Daintree provenance, Queensland) and

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A. auriculiformis (Darwin provenance, Northern Territory). These two seed sources were growing adjacent to one another in northern Vietnam. The selected hybrids were identified in plantations of the *A. mangium* seed source, and brought into clonal propagation (Le Dinh Kha 1996). Parental species used as control treatments are *A. mangium* (cuttings from unselected seedlings of Pongaki and Gubam Village natural provenances from Papua New Guinea (PNG), and seedlings from Dong Nai and Ba Vi seed sources from Vietnam) and *A. auriculiformis* (cuttings from unselected seedlings of Coen River and Morehead River natural provenances from Queensland and seedlings from Dong Nai seed source, Vietnam). The Pongaki and Gubam Village provenances of *A. mangium* and the Coen River provenance of *A. auriculiformis* were the most promising within provenance trials at age 6 years (Nguyen Hoang Nghia and Le Dinh Kha 1996). F_2 acacia hybrids were obtained by collecting open-pollinated seeds from an isolated stand of 12 superior F_1 hybrid trees, of seedling origin, in the south of Vietnam. No individuals of *A. mangium* or *A. auriculiformis* were within 500 m of this stand, so the seed collected for the study was either the result of outcrossing between different F_1 trees or selfing within the crowns of the individual trees.

Four trials were established at Ba Vi, northern Vietnam (21°08′N, 105°28′E, altitude 50 m). Annual rainfall at the trial sites is 1650 mm, and the soil is a shallow rocky infertile ferallitic clay loam derived from schist parent material. All trials used randomised complete block designs, and spacing between trees was 2 × 3 m. Trials 1–3 were planted in September–October 1993, and Trial 4 in August 1995.

Trial 1 tested four trial entries using 30-tree plots with three replicates. Trial entries were:

- acacia F_1 hybrid — mix of cuttings from 30 selected clones
- *A. mangium* seedlings (Ba Vi seed source)
- *A. mangium* cuttings (Pongaki and Gubam Village provenances)
- *A. auriculiformis* cuttings (Morehead River provenance)

Trial 2 tested six entries using 10-tree row plots with four replicates. Trial entries were:

- acacia F_1 hybrid — mix of cuttings from 19 selected clones
- *A. mangium* seedlings (Ba Vi seed source)
- *A. mangium* cuttings (Pongaki and Gubam Village provenances)
- *A. auriculiformis* cuttings (Coen River and Morehead River provenances)
- *A. auriculiformis* seedlings (Dong Nai seed source)

Trial 3 tested 21 entries using 10-tree row plots with three replicates. Trial entries were:

- acacia F_1 hybrid — 19 selected clones, tested as separate entries
- *A. mangium* cuttings (Pongaki provenance)
- *A. auriculiformis* cuttings (Coen River provenance)

Trial 4 tested nine entries using 20-tree plots with four replicates. The F_2-hybrid seedlings used in Trial 4 were classified before out-planting according to their phyllode morphology into four classes: bulk (unsorted) seedlings, and three sorted classes — *A. mangium*-like, *A. auriculiformis*-like and hybrid-like seedlings. Trial entries were:

- acacia F_1 hybrid — mix of cuttings from 19 selected clones
- acacia F_2 hybrid seedlings (unselected)
- acacia F_2 hybrid seedlings with morphology of F_1 hybrid
- acacia F_2 hybrid seedlings with morphology of *A. mangium*
- acacia F_2 hybrid seedlings with morphology of *A. auriculiformis*
- *A. mangium* seedlings (Ba Vi seed source)
- *A. mangium* cuttings (Pongaki provenance)
- *A. auriculiformis* cuttings (Coen River provenance)
- *A. auriculiformis* seedlings (Dong Nai seed source)

Prior to establishment, the trial sites were completely ploughed (Trials 1–3) or the planting lines ploughed (Trial 4) and each planting hole was fertilised with 2 kg of cow manure and 100 g of superphosphate. Additional pilot plantings of seedling cuttings of *A. auriculiformis* (Coen and Morehead Rivers) and *A. mangium* (Pongaki), of around 0.2 ha per seed source, were established adjacent to Trial 1.

Stem volume (V) was calculated according to the following formula:

$$V = \pi dbh^2/4 * h * f$$

where dbh = diameter at breast height, h = tree height and f = stem form index.

Stem form index f was calculated according to the following formula:

$$f = \frac{\text{Measured tree volume}}{\text{Cylinder volume based on tree height and dbh}}$$

Three medium-sized trees of acacia hybrids and *A. mangium* and six trees of *A. auriculiformis* from Trial 1 were felled and measured to determine tree volumes. The measured tree volume was calculated as the sum of volumes of all stem sections of length of 2 m and the top section. Volumes of individual sections were calculated from section length (2 m) and top and bottom end diameters, using the formula for the frustrum of a cone. The stem form indices (mean of the sampled trees, for each taxon) were as follows:

hybrid	f = 0.497
A. mangium (seedlings and cuttings)	f = 0.536
A. auriculiformis (seedlings and cuttings, Coen and Morehead River provenances)	f = 0.510

For all trees in Trial 3, the following quality characters of the tree stem were determined: straightness (St), branch size (Br), and crown development (Cr). These three traits were each scored subjectively using a six-point scale from 0 (poorest) to 5 (very straight stem, small branches or pyramidal crown). Quality index (I) was determined as I = St * Br * Cr.

Wood density (D) was determined for three ramets of each of the 19 hybrid clones, and for six trees of *A. auriculiformis* and three trees of *A. mangium*, sampled from Trial 3. Disk sections 10 cm in length were collected from the base, mid-point and top of the stem of each sampled tree. Bark was removed and samples were dried in the oven for 48 h at a temperature of 105°C. Oven-dry weight of each disk was then measured, and the disk dry volume calculated from the length of the disk (mean of four measurements) and the circumference mid-way along the disk. Density of each tree was calculated as follows:

$$D = \frac{W1 + W2 + W3}{V1 + V2 + V3}$$

where W1, W2 and W3 are the weights and V1, V2 and V3 the volumes of the base, middle and top wood samples. The mean wood density for each hybrid clone and for the two parent species was then calculated as the mean of the densities of the individual trees measured for each taxon.

Collected data were analysed using the programs DATACHAIN and GENSTAT (Williams and Matheson 1994).

Results and Discussion

Trials of bulk cuttings of hybrid clones

Data collected from Trial 1 and the pilot plantings (Table 1) and Trial 2 (Table 2) showed that at age 44 and 45 months, respectively, growth of selected acacia hybrids planted in rows and in block plots was

Table 1. Growth of selected acacia hybrid clones and controls in Trial 1 and pilot planting areas at Ba Vi (October 1993–June 1997).

Treatment	Dbh (cm)		Height (m)		Volume dm³/tree
	D	V%*	H	V%	
1. Trial planting area					
— Cuttings of acacia hybrids	12.7	18.0	13.0	10.0	81.8
— Cuttings of *A. mangium* (Pongaki)	10.0	11.3	8.7	13.3	37.4
— Cuttings of *A. aur.* (Morehead River)	8.0	17.7	7.5	12.9	19.2
2. Pilot planting area					
— Cuttings of *A. mangium* (Pongaki)	9.3	18.9	8.0	14.4	29.1
— Cuttings of *A. aur.* (Coen River)	8.5	15.5	9.2	10.5	26.6
— Cuttings of *A. aur.* (Morehead River)	8.0	19.2	7.8	15.3	20.0

*V% = coefficient of variation

Table 2. Growth of selected acacia hybrid clones and controls in Trial 2 at Ba Vi (September 1993–June 1997).

Treatment	Dbh (cm)		Height (m)		Volume dm³/tree
	D	V%*	H	V%	
— Cuttings of acacia hybrids	11.9	10.9	12.5	5.9	69.9
— Cuttings of *A. mangium* (Pongaki)	9.8	19.5	10.5	11.9	42.4
— Seedlings of *A. mangium* (BaVi)	10.1	11.6	9.9	5.1	42.2
— Cuttings of *A. mangium* (Gubam village)	9.5	16.7	10.0	11.9	38.1
— Seedlings of *A. mangium* (Dong Nai)	9.0	21.9	9.9	11.7	33.3
— Seedlings of *A. auric.* (Coen River)	7.8	22.0	8.8	14.4	21.6
— Cuttings of *A. auric.* (Morehead R.)	7.2	21.6	8.1	16.3	16.8
— Seedlings of *A. auric.* (Dong Nai)	6.2	20.8	7.5	14.4	11.7

*V% = coefficient of variation

significantly higher than that of both seedlings and cuttings of the most promising provenances of *A. mangium* and *A. auriculiformis*. Mean stem volume of hybrid trees was 81.8 dm³/tree in Trial 1 and 69.9 dm³/tree in Trial 2. That of *A. mangium* was only 37.4 dm³/tree (Trial 1), 29.1 (pilot planting) and 33.3–42.4 dm³/tree (Trial 2), and that of *A. auriculiformis* was 19.9–26.6 dm³/tree (Trial 1 and pilot planting) and 11.7–21.6 dm³/tree (Trial 2). Thus, stem volume of selected hybrids at around 4 years was 60–100% higher than *A. mangium* and 200–400% higher than *A. auriculiformis*.

This showed that the heterosis observed in the original, selected, seed-derived F_1 hybrid individuals (ortets) in plantations was maintained in the cutting-propagated ramets obtained from these individuals.

Growth trends in tree height and diameter of the acacia hybrids and the parent species in Trials 1 and 2 are presented in Figure 1.

It can be seen that the growth advantage of the hybrids is being maintained through to age 44-45 months and shows no sign of diminishing. Therefore, the acacia hybrids are very promising for use in plantations.

Clonal test of acacia hybrid clones

Data collected from Trial 3 at age 44 months (Table 3) showed that differentiation in growth rate between hybrid clones was obvious. While stem volumes of the fastest growing clones were 85–87 dm³/tree, those of slow-growing clones were only 47–55 dm³/tree. Therefore, growth of poorly selected hybrid clones could be lower than that of parent species as was found in the clonal test at Trang Bom, Dong Nai province (Pham Van Tuan et al. 1995). Moreover, the stem quality index values of the fastest growing clones (clones 5, 10, 16, 23, 29 and 32) were best (27.8–50.5) and those of the slow growing clones were much lower (17.0–26.0). The correlation between wood density and stem volume was low (r = 0.0585) and not statistically significant.

Hybrid clones that were fast growing, of high stem quality and also had relatively high wood density were clones 5, 32 and 33; lower wood density was observed for clones 10, 16 and 29. The highest value in wood density (0.63) was observed for clone 28, which had a higher density than that of *A. auriculiformis*.

Table 3. Tree growth, stem quality index and wood density of hybrid clones and controls in Trial 3 at Ba Vi (planted October 1993, measured June 1997).

Clone number	Dbh (cm)		Height (m)		Volume dm³/tree	Quality index	Wood density
	D	V%*	H	V%			
HB 5	12.9a[1]	7.4	13.5	4.4	87.75	43.9	0.561
HB 16	12.9a	7.6	13.6	3.8	87.78	37.9	0.481
HB 33	12.8a	4.7	13.1	3.2	84.05	32.7	0.537
HB 10	12.6a	10.6	13.7	4.3	85.19	45.3	0.511
HB 29	12.5ab	13.5	13.4	7.5	81.34	27.8	0.524
HB 32	12.4ab	7.9	13.4	2.5	81.19	30.6	0.558
HB 23	12.2ab	12.3	13.2	6.8	77.43	50.5	0.527
HB 12	12.0ab	10.5	12.8	5.9	71.07	21.1	0.582
HB 17	11.9ab	4.0	12.0	2.6	74.79	21.9	0.547
HB 13	11.8ab	9.6	12.6	6.4	68.71	23.5	0.543
HB 19	11.7ab	4.6	12.4	1.5	66.25	21.4	0.537
HB 20	11.7ab	8.7	12.5	6.9	66.38	26.0	0.582
HB 28	11.3ab	13.3	12.3	7.5	61.21	17.3	0.629
HB 11	11.2ab	9.6	12.4	4.2	60.13	23.4	0.480
HB 15	11.1ab	7.3	11.8	9.9	57.10	18.2	0.547
HB 27	11.1ab	13.6	12.6	6.2	60.91	28.8	0.537
HB 30	11.1abc	6.5	12.0	4.0	59.70	20.0	0.537
HB 14	10.8abc	7.0	12.2	6.5	55.24	18.0	0.574
HB 22	10.3 bc	13.3	11.4	8.9	47.35	17.0	0.537
A. man. Pongaki	8.8 c	14.3	9.5	6.4	31.01	23.5	0.430
A. auri. Coen.	5.1 d	24.7	6.3	19.4	6.55	19.6	0.593
S.e.d.	1.14		0.98				
F prob.[2]	< 0.001		< 0.001				

[1] Treatments with the same letter not significantly different at the 5% probability level
[2] F probability for significance of differences between treatments, including *A. mangium* and *A. auriculiformis* controls
*V% = coefficient of variation

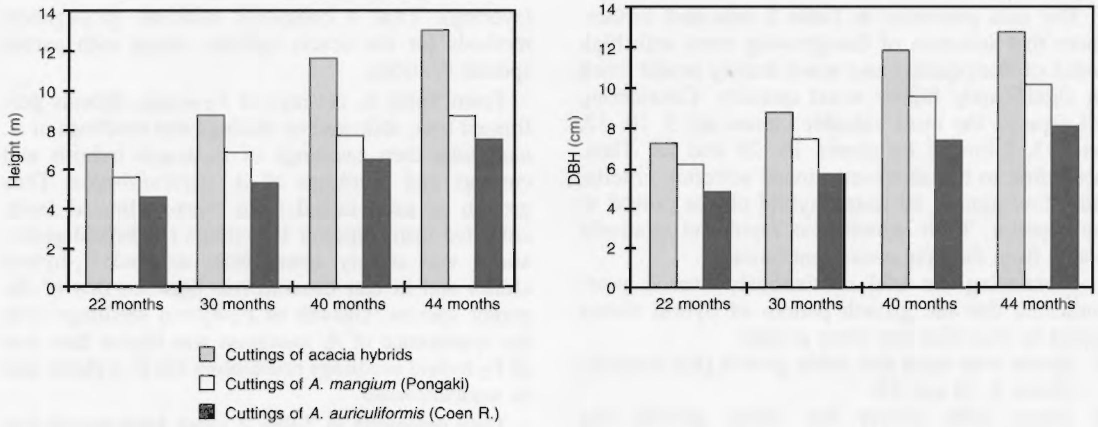

Figure 1a. Growth of acacia hybrids and parent species in Trial 1.

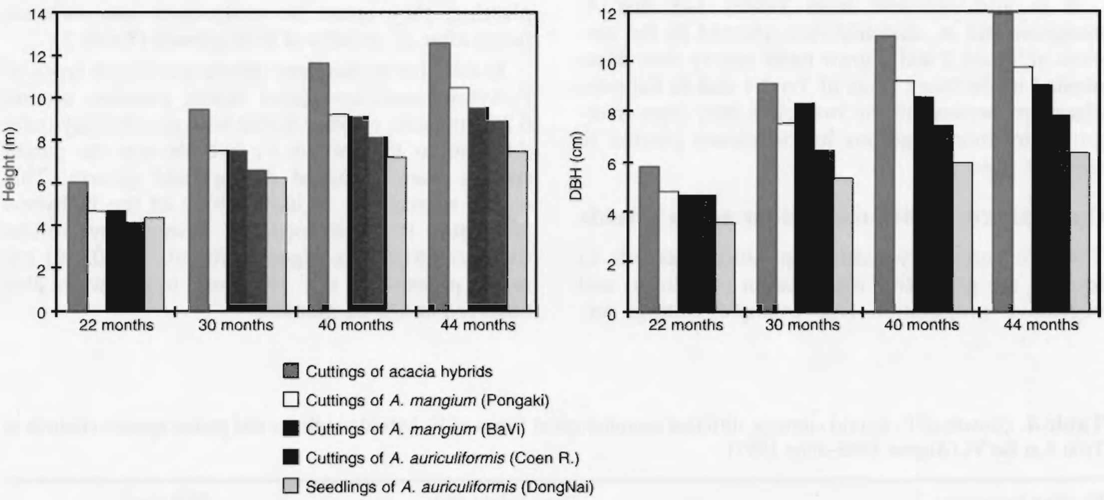

Figure 1b. Growth of acacia hybrids and parent species in Trial 2.

The data presented in Table 3 indicated furthermore that selection of fast-growing trees with high index of stem quality and wood density would result in significantly higher wood quantity. Considering all aspects, the most valuable clones are 5, 10, 32, and 33, followed by clones 16, 29 and 23. Thus, according to the above-mentioned selection criteria, only four among 19 tested hybrid clones proved to be superior. Their growth was rapid and relatively stable from the first assessment onwards.

Monitoring the trial continuously over 4 years indicated that the growth pattern of hybrid clones could be classified into three groups:

1. clones with rapid and stable growth (for example, clones 5, 10 and 33)
2. clones with slower but stable growth (for example, clones 11, 14, 22)
3. clones with varying growth rhythm (for example, clone 27)

This indicated that a sufficient time interval is needed for exact assessment of a clonal test. A 4-year assessment period is considered suitable for selection of superior acacia hybrid clones for pulpwood production.

It is also apparent from Tables 1–3 that *A. mangium* and *A. auriculiformis* planted in the row plots of Trials 2 and 3 grew more slowly than those planted in the block plots of Trial 1 and in the pilot plantings, because in the row plots they were overgrown by more vigorous hybrid clones planted in adjacent rows.

Optional propagation methods for acacia hybrids

The two commonly used propagation methods in forestry are generative regeneration (seedlings) and vegetative propagation (for example cutting, air-layering). Trial 4 compared different propagation methods for the acacia hybrids, along with parent species controls.

From Table 4, cuttings of F_1-acacia hybrids performed best, followed by cuttings and seedlings of *A. mangium*, then seedlings of F_2-acacia hybrids and cuttings and seedlings of *A. auriculiformis*. Thus growth of trees raised from open-pollinated seeds collected from superior F_1 hybrids (F_2-hybrid generation) was clearly lower than selected F_1-hybrid clones and in fact intermediate between that of the parent species. Growth of F_2-hybrid seedlings with the appearance of *A. mangium* was higher than that of F_2-hybrid seedlings resembling the F_1 hybrids and *A. auriculiformis*.

Data presented in Table 4 show furthermore that the coefficient of variation in growth of different forms of F_2-hybrid seedlings, particularly that of bulk (unsorted) seedlings, is significantly higher than a mix of cuttings from 19 F_1-hybrid clones, and the parent species. This indicates that growth rate of F_2-hybrid trees is strongly differentiated. Although the F_2-hybrid seedlings were sorted into different groups according to their phyllode morphology before planting, they could be reclassified into different forms after 22 months of field growth (Table 5).

In addition to the three above-mentioned types of F_2-hybrid seedlings sorted before planting, around 6.2% (overall) of other forms with morphology quite different to that of the F_1 hybrids and the parent species were observed during field growth. This means segregation in morphology of the F_2-hybrid generation is an obvious fact. Overall, hybrid-like trees comprised the highest proportion (50.2%) but many parent-like and abnormal forms were also observed at age 22 months.

Table 4. Growth of F_1-hybrid cuttings, different morphological forms of F_2-hybrid seedlings and parent species controls in Trial 4 at Ba Vi (August 1995–June 1997).

Planting treatments	Tree height (m)		Dbh (cm)	
	H	V%*	D	V%
Cuttings of F_1-hybrids in bulk	5.8	14.1	6.1	19.8
Cuttings of *A. mangium* (Pongaki)	4.4	15.0	4.9	20.3
Seedlings of *A. mangium* (Ba Vi)	4.3	15.3	4.9	22.0
Seedlings of F_2-hybrids in bulk	4.1	23.2	4.2	33.3
Seedlings of F_2-hybrids like *A. mangium*	4.1	20.4	4.5	25.6
Seedling of F_2-hybrids like F_1-hybrid.	4.0	19.5	4.0	27.9
Seedlings of F_2-hybrids like *A. auriculiformis*	3.8	22.6	3.7	31.0
Cuttings of *A. auriculiformis* (Coen River)	3.5	14.9	3.4	19.0
Seedlings of *A. auriculiformis* (Ba Vi)	3.4	18.7	3.2	23.7

*V% = coefficient of variation

Table 5. Segregation in phyllode morphology of 22-month-old F_2 hybrids at Ba Vi.

Seedling group of F_2 hybrids (sorted before planting)	Total no. of trees	Seedling groups (sorted at the age of 22 months)							
		A. mangium like seedlings		F_1 hybrid like seedlings		*A. auric.* like seedlings		Abnormal forms	
		n	%	n	%	n	%	n	%
Seedlings (unsorted)	93	9	9.7	46	49.5	30	32.3	8	8.6
Seedlings like F_1 hybrids	95	11	11.6	65	68.4	13	13.7	6	7.5
Seedlings like *A. mangium*	70	28	40.0	39	55.7	1	1.4	2	2.9
Seedlings like *A. auriculiformis*	83	8	9.6	21	25.3	49	59.0	5	6.0
Grand total	**341**	**56**	**16.4**	**171**	**50.2**	**93**	**27.3**	**21**	**6.2**

The higher variability among F_2 seedlings is because F_2 seeds collected from F_1-hybrids result from randomised genetic recombination in gametes. The gametes then combine with each other at random to form new combinations. As a result of this process, F_2 hybrids are greatly diversified in many of their traits. Therefore segregation in F_2-generation cannot be avoided and seeds collected from F_1-hybrid generation should not be used for plantation establishment, as the resulting plantation would have far too much phenotypic variation and overall poor vigour.

Rooted F_1-hybrid cuttings (ramets) retain the exact genetic constitution of the original selected F_1-hybrid ortet. Cutting propagation is an adaptable propagation method for maintaining heterosis as well as other superior characteristics of the F_1-hybrid generation. This enables preservation of desired genotypes and capture of maximum genetic gains when used for mass propagation in operational planting programs (Zobel and Talbert 1984; Haines and Griffin 1991).

Therefore the genetic improvement strategy for forest species must take into account the mastery of vegetative propagation by cuttings, the influence of which will vary according to the degree of improvement in the technique (Chaperon 1984). As vegetative methods are improved, hybrids will become widely used (Zobel and Talbert 1984).

Recently, a technical procedure for cutting propagation of acacia hybrids has been prepared by RCFTI. It is simple but effective for mass production of hybrid cuttings for large-scale planting. Even farmers could apply this simple technical procedure for producing hybrid cuttings.

Conclusion

1. Stem volume of F_1-hybrid acacia cuttings at around four years is 1.6–2 times higher than that of *A. mangium* and 2–3 times higher than *A. auriculiformis*.
2. The rapid growth of F_1-hybrid acacia cuttings in comparison with cuttings and seedlings of the most promising provenances of their parent species is still maintained at age 4 years.
3. There are significant differences in growth rate, stem quality and wood density between the acacia hybrid clones tested. From the clonal tests, some hybrid clones with highest stem volume, good stem form and high wood density have been selected.
4. Growth of F_2 generation of acacia hybrids is significantly lower than that of F_1-hybrids and segregation in morphology and growth rate are observed for the F_2-generation of hybrid. In addition to trees having morphology like that of F_1 hybrids and the parent species, abnormal forms in the F_2-hybrid generation were also observed. The coefficient of variation for growth traits within each form is high.
5. Seeds collected from F_1-hybrid trees should not be used for establishment of new plantations because they yield highly variable offspring with poor vigour. Cutting propagation is the most suitable method for maintaining heterosis and other superior characteristics of F_1-hybrid acacias.

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References

Chaperon, H. 1984. Influence of propagation by cutting on the breeding strategy of forest trees. Provenance and Genetic Improvement Strategies in Tropical Forest Trees. Mutare, Zimbabwe, 9–14 April, IUFRO working parties, 135–148.

Haines R.J. and Griffin A.R. 1991. Propagation options for *Acacia mangium*, *A. auriculiformis* and their hybrid. In: Carron., L. and Aken, K., ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37. Australian Centre for International Agricultural Research, Canberra, 122–127.

Le Dinh Kha, Nguyen Dinh Hai and Pham Van Tuan 1993. Natural hybrid between *A. mangium* and *A. auriculiformis*. Vietnam Forestry Review (1993) No. 7, 18–19.

Le Dinh Kha and Le Quang Phuc 1995. Pulp potential of natural hybrid between *A. mangium* and *A. auriculiformis*. Vietnam Forestry Review (1995) No. 3, 6–7.

Le Dinh Kha, Nguyen Dinh Hai and Tran Cu 1995. Selection and clonal test of hybrid acacias at Ba Vi. Information of Forest Science, Technology and Economics (Ministry of Forestry, Hanoi, Vietnam) No. 2, 23–26.

Le Dinh Kha 1996. Studies on natural hybrids of *Acacia mangium* and *A. auriculiformis* in Vietnam. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of the QFRI-IUFRO Conference, Caloundra, Queensland, Australia, 27 Oct–1 Nov 1996. Queensland Forest Research Institute, Gympie, 328–332.

Nguyen Hoang Nghia and Le Dinh Kha 1996. *Acacia* species and provenance selection for large-scale planting in Vietnam. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of the QFRI-IUFRO Conference, Caloundra, Queensland, Australia, 27 Oct–1 Nov 1996. Queensland Forest Research Institute, Gympie, 443–448.

Pham Van Tuan, Nguyen Van Chien and Luu Ba Thinh 1995. Plus tree selection, propagation and clonal test of *Eucalyptus* spp. and acacia hybrid in south-eastern zone of Vietnam. Information of Forest Science, Technology and Economics No. 2, 26–28.

Williams E.R. and Matheson A.C. 1994. Experimental Design and Analysis for Use in Tree Improvement. CSIRO, Melbourne and ACIAR, Canberra, 174 p.

Zobel B. and Talbert J. 1984. Applied Forest Tree Improvement. John Wiley and Sons, New York, 505 p.

Use of Molecular Markers in Domestication and Breeding Programs for Acacias

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Abstract

The development of DNA markers for acacias has provided the tools to more efficiently resolve genetic questions related to breeding. The higher variability of DNA markers compared with allozymes has provided insights into some deficiencies in existing breeding programs and opportunities for their improvement. In *Acacia mangium*, a species with low levels of allozyme variation, restriction fragment length polymorphism (RFLP) markers were used to assess the proportion of variation in natural populations present in seed production stands. Only 56% of genetic variation detected in the natural populations was represented in the seed production area at Subanjeriji, Indonesia. The majority of trees originated from a region characterised by low levels of diversity, indicating that the breeding program could be improved by expanding the genetic base.

The higher variability of molecular markers also increases the power to genetically discriminate between individuals, allowing improved quality control in breeding programs and seed orchard management. In *A. mangium*, full-sib pedigrees have been screened using RFLP markers to remove progeny derived from foreign pollen or selfing. The effect of different pollination techniques has also been investigated with these markers. A genetic linkage map is also being developed in *A. mangium* using RFLPs and microsatellites. Markers in chromosomal regions linked to quantitative traits such as pulp yield and disease resistance can then be used to select progeny at the nursery stage, thereby improving the efficiency of breeding programs.

DOMESTICATION and breeding programs for forest trees have, until recently, relied on estimates of genetic diversity and inbreeding from population surveys using isozymes. Isozymes continue to provide a relatively simple and inexpensive method of obtaining genetic information, however their application is limited by the number of enzyme loci and the fact that they only reveal variation in protein-coding genes. With the potentially unlimited number of DNA markers and their ability to detect variation in both coding and non-coding regions of the DNA molecule, some of the limitations of allozyme markers can be overcome.

Restriction fragment length polymorphisms (RFLPs) and microsatellites are two types of DNA marker currently used in domestication and breeding programs for acacias. RFLPs are simple Mendelian genetic markers that result from various types of mutation and rearrangements of the DNA (insertions and deletions or point mutation). They are detected as differences in the lengths of homologous restriction fragments following hybridisation of genomic DNA to a labelled probe. Microsatellites or simple sequence repeats (SSRs) are short tandem repeats of two, three or four bases. They can be assayed using primers designed from the unique sequence flanking the tandem repeat and the polymerase chain reaction (PCR), requiring less DNA than RFLP analysis. Microsatellites are particularly useful for fingerprinting, as the number of repeats is highly variable, giving a higher number of alleles per locus than isozymes or RFLPs.

The main areas where DNA markers can be applied in domestication programs for acacias include the estimation of genetic variation in natural and domesticated populations, germplasm identification and, in advanced breeding programs, the construction of genetic linkage maps leading to marker-assisted selection. Breeding strategies can be developed based on the ability to determine the paternal contribution of superior progeny from small open-pollinated

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breeding populations using DNA markers. There is also potential to improve the efficiency of selection and mating as knowledge of the number of controlling genes and alleles and modes of gene action increases.

Monitoring Seed Orchards: a Case Study from *A. mangium*

Genetic diversity

In *Acacia mangium* low levels of allozyme variation precluded detailed investigation of gene flow between populations or studies of the breeding system (Moran et al. 1989). Higher levels of variation have been detected with RFLP markers that enabled comparison of levels of genetic diversity in natural populations with those in seed orchards. Provenance trials had shown that progeny from seed production areas established at Subanjeriji in southern Sumatra to supply planting stock for Indonesian plantations produced volumes 70–80% less at 30 months of age than seed from a New Guinea provenance (Turvey 1995). Using RFLP markers it was shown that only 56% of the variation in natural populations was represented in the Subanjeriji seed production stands (Butcher et al. 1996). The breeding program could therefore be improved by broadening the genetic base of seed production stands.

Seed orchard origins

Molecular markers can be used to determine the source of seed orchard trees if alleles restricted to a single population or geographic region are found. Records from the Subanjeriji seed production area indicated that the trees screened using RFLP markers originated from Julatten, Mossman and Cassowary in Queensland, Australia, Sidei in Irian Jaya, Indonesia and second generation seed produced from open-pollination of these trees at Subanjeriji. In the survey of RFLP diversity in the natural populations of *A. mangium* one allele identified occurred in all individuals sampled in the Sidei population and not in any other population. Of the 100 trees tested from Subanjeriji, three trees had this allele, considerably less than the eight trees indicated by seed orchard records. Only three of the 33 alleles confined to New Guinea populations were detected in Subanjeriji, which was consistent with records that indicated this region was not represented in the breeding population. This was further investigated using RFLPs from the chloroplast genome, which had revealed mutations that were population- or region-specific (Perkins unpubl.). Mutations confined to the New Guinea provenances were not detected in any of the Subanjeriji trees.

Data from both the chloroplast and nuclear genomes indicated that, with the exception of trees from Sidei, the breeding population was derived from the Daintree–Townsville region. This region was characterised by lower levels of genetic diversity and higher levels of inbreeding than populations in the Cape York region of northern Queensland and New Guinea (Butcher et al. 1996). The progeny from these populations generally perform poorly in progeny trials (Harwood and Williams 1992) suggesting that the poor performance of Subanjeriji material in plantations (Turvey 1995) may simply reflect its geographic origins.

Inbreeding

The introduction of *A. mangium* to Sabah is often cited to illustrate the decline in performance that results when local populations develop from narrowly based introductions (Simons 1992). Plantations established in Sabah in the 1970s and 1980s were descended from a single open-pollinated progeny from Mission Beach, Queensland. There was a progressive decline in yield in successive generations (Sim 1984). The decline in performance has often been attributed to inbreeding depression, however, this has not previously been tested in *A. mangium*. Inbreeding coefficients calculated from the RFLP data indicated a significant level of inbreeding in populations in the south of the species' geographic range but not those in New Guinea. There was also evidence of significant inbreeding in the Subanjeriji seed production stand that may reflect substructuring in the source populations or may have resulted from establishment of the seed stand from a narrow genetic base. Accurate estimates of inbreeding are essential to avoid bias in estimates of genetic variance from open-pollinated progeny arrays. If inbreeding is not taken into account, heritability and potential genetic gain will be overestimated.

Applications for Molecular Markers in Advanced Breeding Programs

Monitoring and certifying breeding material

Seed orchard management

DNA markers can be used in seed orchard management for estimating pollen contamination and inbreeding and determining mating patterns. These all rely on determining male parentage of seed produced in the orchard, as the female genotype can be determined directly from the tree from which seed was collected. The power of genetic discrimination among males is a function of the number of markers, the amount of allelic variability at individual loci, the frequencies of alleles in the population, and the number of males in the population.

The development of microsatellite markers in acacias has greatly increased the power to discriminate between individuals. Testing of five microsatellites on full-sib pedigrees of *A. mangium* has shown them to be inherited in Mendelian fashion. These microsatellites were also tested across 20 unrelated individuals from five populations of *A. mangium*. The level of variability detected was five times higher than RFLPs tested on the same individuals and 40 times higher than detected in previous population surveys using allozymes (Table 1). Microsatellites will therefore be particularly useful for genetic fingerprinting.

Table 1. Comparison of levels of genetic diversity detected in natural populations of *A. mangium* with different markers.

	Number of loci	Allelic diversity	Polymorphic loci (%)	Expected heterozygosity
Microsatellites	5	6.6	100	0.704
RFLPs	57	1.6	40.2	0.140
Isozymes[a]	30	1.1	12.7	0.017

[a] A rangewide study but not the same individuals as for other markers

Identification and certification of clones

Germplasm identification is an important component of advanced breeding programs that rely on controlled crosses or the correct identification of breeding clones and of mass propagation programs. DNA markers provide a means of testing the validity of controlled crosses and fingerprinting clones. In *A. mangium* RFLPs have been used to determine the level of contamination in controlled crosses made to construct a genetic linkage map. The effects of different pollination techniques, including emasculation and bagging of flowers prior to pollination, were also examined. The level of contamination from foreign pollen was extremely low, with only one contaminant in over 300 progeny. This came from a pod where the flower was not emasculated prior to pollination.

Bagging prior to pollination had no effect. Only one self-fertilised seed was detected among seedlings produced from flowers that had been emasculated, however 29% of pods produced from flowers that were not emasculated contained selfs (Table 2). This suggests that the extra time and effort required for emasculating flowers prior to cross-pollination is warranted. Alternatively, all progeny must be screened to remove selfs from the progeny arrays. Where pods produced from flowers without emasculation contained a self, all other progeny tested within the pod were also selfs. Based on these data and evidence from previous paternity analyses in acacia showing a high probability of a single pollen source for each pod (Muona et al. 1991), the error rate from screening a single individual from each pod to determine paternity would be low.

Table 2. Numbers of selfs detected in pods produced from controlled pollinations of *A. mangium.*

	Emasculated flowers	Selfs	Flowers not emasculated	Selfs
Pods	112	1	24	7
Progeny	314	1	39	9

In other species with more advanced breeding programs, considerably higher error levels have been detected in mapping pedigrees. Controlled crosses of two pedigrees of *Pinus radiata* were established at three sites in southeastern Australia. Two per cent of progeny were incorrect in one pedigree, while 20% of progeny were incorrect in the second pedigree (Moran unpubl.). The majority of these errors occurred in a single trial, suggesting that errors occurred at the stage of trial establishment rather than with the controlled crosses.

In *Eucalyptus nitens* pedigrees the time that flowers were bagged following pollination had a significant effect on contamination from foreign pollen. The error rate increased from zero in a pedigree where bags were left in place for two weeks following pollination to 20% in a second pedigree where bags were removed one week after pollination (Byrne and Moran unpubl.). These studies illustrate that DNA markers are not only useful in determining error levels in breeding pedigrees but can also help identify the source of errors. With the availability of suitable markers in acacia, similar error rates can be avoided by screening plants prior to trial establishment.

Development breeding strategies without controlled crosses

The difficulty and low success rate of controlled pollination in acacias (Sedgely et al. 1992) can be avoided in a novel approach to breeding which utilises the discriminating power of microsatellites. If a small number of superior trees are planted in a breeding population and allowed to cross-pollinate, progeny established in family/progeny trials and selections made, the male parentage of selections can be determined using microsatellites. In addition to improving the accuracy of estimates of quantitative parameters, this would ensure second generation selections included a number of different males.

Mapping and characterisation of QTLs

The development of highly variable molecular markers in acacias has provided the tools for genome mapping. Genetic linkage maps provide a framework in which genes of economic or practical importance can be located, as well as providing a means of comparing chromosome organisation in other species. Molecular markers in chromosomal regions showing strong associations with a particular trait can be used for early selection. The potential benefits of marker-aided selection (MAS) are greatest for species with long generation intervals, for traits that are difficult or expensive to phenotype and for traits that appear only under certain conditions such as resistance to a particular pest, pathogen or abiotic factor such as salinity.

Until recently the development of maps in acacias was limited by the lack of multigeneration pedigrees. Parents and at least one generation of full-sib progenies are required for linkage analyses. A genetic linkage map is currently being developed in *A. mangium* using interprovenance crosses from New Guinea. The map, based on RFLP and microsatellite markers, will be used to locate quantitative trait loci (QTLs) for wood quality traits such as pulp yield and wood density. These markers can also be used to develop maps in pedigrees that segregate for rust resistance, allowing selection at the nursery stage. There is evidence that rust diseases are emerging as a major problem, affecting the productivity of *A. mangium* plantations in Southeast Asia (Old et al. 1996).

Utility of Molecular Markers across the Genus

To determine the utility of microsatellite and RFLP markers across the genus *Acacia* five microsatellites and 22 RFLPs developed in *A. mangium* were tested on three individuals from each of 15 acacia species and the closely related genera *Archidendron* and *Pararchidendron* (Family Mimosaceae). Preliminary results indicated that four out of five primer pairs designed for microsatellites in *A. mangium* amplify loci in closely related species in the *Acacia* Section Juliflorae. However, they do not appear to be highly conserved across other sections in the genus (Table 3). RFLP markers have been tested on a wider range of species, including the tropical acacias *A. auriculiformis, A. crassicarpa* and *A. aulacocarpa,* which have greatest potential for timber and pulp production. In contrast to microsatellites, the majority of RFLP markers can be used across the genus providing opportunities for synteny mapping of other acacias with commercial potential.

Table 3. Comparison of the utility of microsatellite and RFLP markers in the genus *Acacia*.

Species	Section	Microsatellite loci	RFLP loci
A. mangium	Juliflorae	5	22
A. neurocarpa	Juliflorae	4	22
A. holosericea	Juliflorae	4	22
A. aneura	Juliflorae	2	20
A. flavescens	Plurinerves	1	21
A. melanoxylon	Plurinerves	2	21
A. dealbata	Botrycephalae	0	20
A. mearnsii	Botrycephalae	0	20
A. falciformis	Phyllodineae	0	20
A. victoriae	Phyllodineae	0	18
A. alata	Alatae	0	20
A. lycopodifoliae	Lycopodifoliae	0	19
A. bidwillii	Acacia	0	18
A. boliviana	Acacia	0	17
A. nilotica	Acacia	0	16
Archidendron lucji	Archidendron	0	19
Archidendron ramiflorum	Archidendron	0	19
Pararchidendron pruinosum	Pararchidendron	0	20

Conclusions

DNA markers provide a powerful tool for addressing genetic questions related to breeding and domestication programs. In species such as *A. mangium* with low levels of allozyme diversity, DNA markers can be used to gain more information on the level and distribution of variation and the breeding system. This is particularly important for non-industrial breeding programs that aim to conserve high levels of diversity and ensure long-term stability rather than maximising production in the short term.

In advanced breeding programs, the increased variability of RFLP and microsatellite markers compared with allozymes improves the ability to discriminate among individuals. Parentage can be determined in progeny from seed orchards and controlled crosses can be verified. DNA markers have proved particularly useful, not only in determining error levels in controlled crossing programs but also in identifying the source of errors. The development of genetic linkage maps for acacias has the potential to further improve the efficiency of breeding programs. The characterisation of markers linked to traits of commercial interest—in particular, wood quality and disease resistance—will allow selection of progeny at the nursery stage.

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References

Butcher, P.A., Moran, G.F. and Perkins, H. 1996. Genetic resources and domestication of *Acacia mangium*. Proceedings QFRI–IUFRO Conference 'Tree Improvement for Sustainable Tropical Forestry' Vol. 2, Caloundra, 27 Oct.–1 Nov. 1996, 467–471.

Harwood, C.E. and Williams, E.R. 1992. A review of provenance variation in growth of *Acacia mangium*. In: Carron, L.T. and Aken, K.M. ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37. Australian Centre for International Agricultural Research, Canberra, 22–30.

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.

Muona, O., Moran, G.F. and Bell, J.C. 1991. Hierarchical patterns of correlated mating in *Acacia melanoxylon*. Genetics, 127, 619–626.

Old, K.M., Lee Su See and Sharma, J.K. 1996. Diseases of Tropical Acacias. CIFOR Special Publication, Center for International Forestry Research, Indonesia.

Sedgley, M., Harbard, R.M., Smith, M., Wickneswari R. and Griffin, A.R. 1992. Reproductive biology and intraspecific hybridisation of *Acacia mangium* and *Acacia auriculiformis* A. Cunn. Ex Benth. (Leguminosae: Mimosoideae). Australian Journal of Botany, 40, 37–48.

Simons, A.J. 1992. Genetic improvement of non-industrial trees. Agroforestry Systems, 18, 197–212.

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

Turvey, N.D. 1995. Afforestation of *Imperata* Grasslands in Indonesia. ACIAR Technical Report 33. Australian Centre for International Agricultural Research, Canberra, 43 p.

Isoenzyme Analysis of a Breeding Population of *Acacia auriculiformis*

Suchitra Changtragoon[1]

Abstract

The genotypes of ten plus trees and their corresponding ramets in a breeding population of *Acacia auriculiformis* in Nakornrathchasima province, Thailand were identified and confirmed by isoenzyme analysis. Eleven isoenzyme systems were used in the investigation. Twelve putative isoenzyme gene loci were identified. The results showed that four loci namely. PGM-A, PGM-B, IDH-A and DIA-A were putatively polymorphic.

The identity of the genotype of each plus tree and its ramets was confirmed for all plus trees, except one ramet that differed in its genotype from the corresponding plus tree and other remaining ramets. This disparate ramet was found 0.63% from this breeding population.

The multilocus genotype at the PGM-A, PGM-B and IDH-A loci could be used to identify the selfed (versus outcrossed) progenies obtained in most of the controlled crosses. These crosses can be pollinated without emasculation and the selfed progenies identified at a later stage by isoenzyme analysis. Hence the polymorphism described at these loci could simplify controlled pollination for 90% of the parental combinations in this breeding population of *A. auriculiformis* in Thailand.

PLUS tree selection is one of the first and most important steps in forest tree breeding programs. In most cases, large numbers of clones and ramets, produced by marcotting, grafting and budding are used in clone banks, seed orchards and breeding populations. However, mistakes (due to mislabelling and/ or discordance from rootstock genotype) may occur in the large-scale production of such clones. Failure to rectify these errors could be detrimental to productivity and quality, therefore the supplement of isoenzyme analysis to distinguish genotypes of the clones in the breeding program is useful.

The identification of clones in forest trees by isoenzyme analysis has been applied in many species such as *Tectona grandis* (Kumaravelu 1979), *Populus* spp. (Bergmann 1981), aspen (Cheliak and Pitel 1984; Bergmann 1987), loblolly pine (Ryu and Na 1987), chestnut (Fineshi 1988), *Pinus korianensis* (Yoo et al. 1988), Norway spruce (Rothe 1990) and *Azadirachta indica* var. *siamensis* (Changtragoon et al. 1993).

In the breeding program of *Acacia auriculiformis* in Thailand the identification of clones is an important step that should be done before conducting controlled pollination, since large numbers of the ramets per clone of this species have been produced by marcotting. Therefore, all of the clones and ramets of this breeding population should be identified.

The controlled hybridisation of plus trees of different provenances of *A. auriculiformis* and related species is difficult because of asynchronous flowering cycles and the difficulty of emasculating the tiny flowers in the spike. This partly explains why controlled pollination has not been used widely for the production of acacia hybrid seeds for field planting. These problems can be ameliorated by using stored pollen for crosses between asynchronous trees and using isoenzyme gene markers (prior to pollination) to identify which parental combinations could be pollinated without emasculation. Subsequent isoenzyme analysis of the F_1 hybrids produced will help to distinguish selfed from outcrossed progenies.

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Materials and Methods

The genotypes of 10 plus trees of *A. auriculiformis* and their ramets from a breeding population in Nakornrathchasima province, Thailand (Table 1) were identified by using isoenzyme analysis. Eleven isoenzyme systems (Table 2) were investigated by means of horizontal starch gel electrophoresis, using the methods of Feret and Bergmann (1976), Conkle et al. (1982), Changtragoon et al. (1993) and Changtragoon and Finkeldey (1995).

Table 1. List of plus trees and number of ramets per clone of *Acacia auriculiformis* breeding population, Nakornrathchasima, Thailand. (Provenances are NT = Northern Territory; (Qld = Queensland; PNG = Papua New Guinea)

List of plus trees	CSIRO seedlot number	Number of ramets per plus tree
1) NT 1	16160/513	18
2) NT 2	16160/513	20
3) NT 3	16149/374	15
4) PNG 1	16106/1018	20
5) PNG 2	16106/1052	18
6) PNG 3	16106/979	10
7) Qld 1	16485/13299	11
8) Qld 2	16141/1482	14
9) Qld 3	16142/1486	15
10) Qld 4	16145/1549	18

Table 2. Investigated isoenzyme systems.

Isoenzyme systems	Abb.	EC code
Leucine aminopeptidase	LAP	3.4.11.1
Glutamate-oxaloacetate-transaminase	GOT	2.6.1.1
Glutamine-dehydrogenase	GDH	1.4.1.3
Isocitrate-dehydrogenase	IDH	1.1.1.42
6-Phosphogluconate-dehydrogenase	6-PGDH	1.1.1.44
Phosphoglucose-mutase	PGM	2.7.5.1
Malate-dehydrogenase	MDH	1.1.1.37
Glucose-6-phosphate-dehydrogenase	G-6PDH	1.1.1.49
Diaphorase	DIA	1.1.4.3
Formiate-dehydrogenase	FDH	1.6.99.3
Shikimate-dehydrogenase	SKDH	1.1.1.25

Results and Discussion

The results showed that apart from eight putatively monomorphic gene loci, four loci were polymorphic, namely PGM-A, PGM-B, IDH-A and DIA-A. PGM-A and PGM-B loci had four and three putative alleles respectively, while only two putative alleles were found for IDH-A and DIA-A (Table 3).

The identity of the genotype of each plus tree and its ramets was proved for all plus trees except one ramet (ramet No.18), which differed in its genotype from the corresponding plus tree (PNG 2) and other remaining ramets at PGM-B and DIA-A loci as shown in Table 3, Figure 1 and Figure 2. Table 4

Table 3. Isoenzyme genotypes from plus trees and their ramets in *Acacia auriculiformis* breeding population, Nakornrathchasima, Thailand.

Plus tree no.	Isoenzyme genotypes																							
	GOT-A		LAP-A		GDH-A		PGM-A		PGM-B		MDH-A		SKDH-A		IDH-A		6-PGDH-A		FDH-A		DIA-A		G-6-PDH-A	
	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	T	P	T
NT 1	11	11	11	11	11	11	33	33	22	22	11	11	11	11	11	11	11	11	11	11	11	11	11	11
NT 2	11	11	11	11	11	11	33	33	23	23	11	11	11	11	11	11	11	11	11	11	11	11	11	11
NT 3	11	11	11	11	11	11	11	11	22	22	11	11	11	11	11	11	11	11	11	11	11	11	11	11
PNG 1	11	11	11	11	11	11	33	33	22	22	11	11	11	11	11	11	11	11	11	11	11	11	11	11
PNG 2	11	11	11	11	11	11	33	33	22	22(11)*	11	11	11	11	12	12	11	11	11	11	11	11(12)*	11	11
PNG 3	11	11	11	11	11	11	33	33	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Qld 1	11	11	11	11	11	11	14	14	22	22	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Qld 2	11	11	11	11	11	11	33	33	22	22	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Qld 3	11	11	11	11	11	11	33	33	22	22	11	11	11	11	12	12	11	11	11	11	11	11	11	11
Qld 4	11	11	11	11	11	11	24	24	22	22	11	11	11	11	11	11	11	11	11	11	11	11	11	11

Remarks : *The genotype of false ramet (No. 18) of plus tree No. PNG 2
P : Plus trees R : Ramets

Table 4. Percentage of incorrected ramets found in a breeding population of *Acacia auriculiformis*, Nakornaratchasima, Thailand.

Species	Number of investigated clones	Number of ramets per clone	Number of investigated ramets	Number of incorrected ramets	Percentage of incorrected ramets
Acacia auriculiformis	10	10–20	159	1	0.63

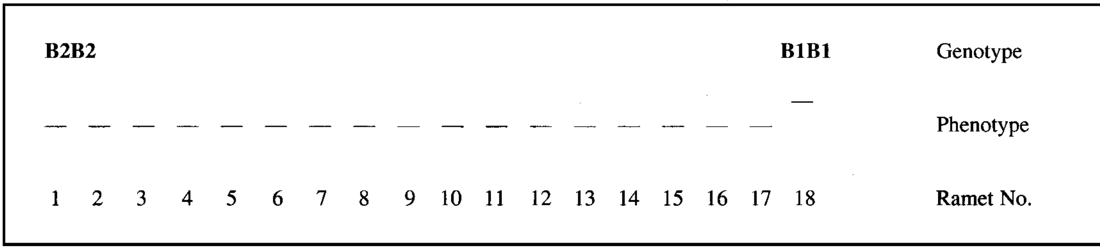

Figure 1. Schematic illustration of PGM phenotypes and genotypes found in PNG-2 clone of *Acacia auriculiformis* plus trees. One ramet (ramet No. 18) has different phenotype and genotype from the other ramets at PGM-B gene locus.

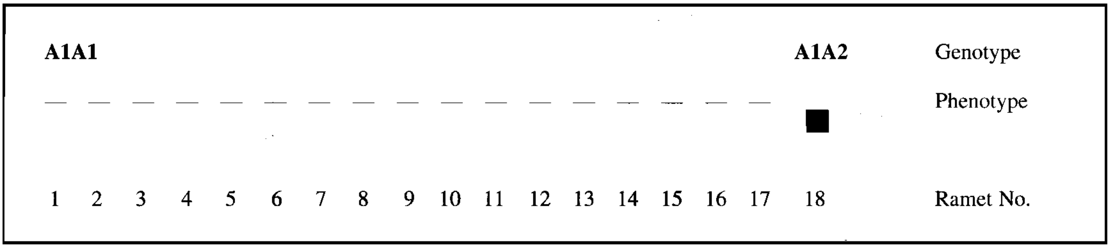

Figure 2. Schematic illustration of DIA phenotypes and genotypes found in PNG-2 clone of *Acacia auriculiformis* plus trees. One ramet (ramet No. 18) has different phenotype and genotype from the other ramets at DIA-A gene locus.

shows that the disparate ramet was found 0.63% from this breeding population. This ramet was presumably taken from the wrong plus tree and mislabelled during marcotting and transplanting. It should be removed from the population and should not be used as a parent in the crosses.

Table 5 and Figure 3 show that if these 10 parents were mated in a half dialleled, of the 45 potential crosses, the genotype of selfed and outcrossed progenies could be distinguished in 22 crosses at the PGM-A locus (1 × 3; 1 × 7; 1 × 10; 2 × 3; 2 × 7; 2 × 10; 3 × 4; 3 × 5; 3 × 6; 3 × 8; 3 × 9; 3 × 10; 4 × 7; 4 × 10; 5 × 7; 5 × 10; 6 × 7; 6 × 10; 7 × 8; 7 × 9; 8 × 10; 9 × 10) and nine crosses at the PGM-B locus (1 × 6; 2 × 6; 3 × 6; 4 × 6; 5 × 6; 6 × 7; 6 × 8; 6 × 9; 6 × 10). However, the distinction can be made additionally with crossed progenies containing different alleles from each of their corresponding parents at the IDH-A locus and some crosses at PGM-A and PGM-B loci. Hence crossed progenies can be distinguished from selfed progenies in 16, 2 and 8 (out of 45) crosses at the IDH-A (1 × 5; 2 × 5; 3 × 5; 4 × 5; 6 × 5; 7 × 5; 8 × 5; 10 × 5; 1 × 9; 2 × 9; 3 × 9; 4 × 9; 6 × 9; 7 × 9; 8 × 9; 10 × 9), PGM-A (3 × 7; 7 × 10) and PGM-B (1 × 2; 3 × 2; 4 × 2; 5 × 2; 7 × 2; 8 × 2; 9 × 2; 10 × 2) loci respectively.

Table 5. Isoenzyme genotypes from different plus trees of *Acacia auriculiformis* breeding population, Nakornrathchasima, Thailand

Putative isoenzyme gene loci	Isoenzyme genotypes									
	(1) NT 1	(2) NT 2	(3) NT 3	(4) PNG 1	(5) PNG 2	(6) PNG 3	(7) QLD 1	(8) QLD 2	(9) QLD 3	(10) QLD 4
GOT-A	11	11	11	11	11	11	11	11	11	11
LAP-A	11	11	11	11	11	11	11	11	11	11
GDH-A	11	11	11	11	11	11	11	11	11	11
PGM-A	33	33	11	33	33	33	14	33	33	24
PGM-B	22	23	22	22	22	11	22	22	22	22
MDH-A	11	11	11	11	11	11	11	11	11	11
SKDH-A	11	11	11	11	11	11	11	11	11	11
IDH-A	11	11	11	11	12	11	11	11	12	11
6-PGDH-A	11	11	11	11	11	11	11	11	11	11
FDH-A	11	11	11	11	11	11	11	11	11	11
DIA-A	11	11	11	11	11	11	11	11	11	11
G-6-PDH-A	11	11	11	11	11	11	11	11	11	11

	NT1	NT2	NT3	PNG1	PNG2	PNG3	QLD1	QLD2	QLD3	QLD4
	1	2	3	4	5	6	7	8	9	10
1		1 × 2	1 × 3	1 × 4	1 × 5	1 × 6	1 × 7	1 × 8	1 × 9	1 × 10
2			2 × 3	2 × 4	2 × 5	2 × 6	2 × 7	2 × 8	2 × 9	2 × 10
3				3 × 4	3 × 5	3 × 6	3 × 7	3 × 8	3 × 9	3 × 10
4					4 × 5	4 × 6	4 × 7	4 × 8	4 × 9	4 × 10
5						5 × 6	5 × 7	5 × 8	5 × 9	5 × 10
6							6 × 7	6 × 8	6 × 9	6 × 10
7								7 × 8	7 × 9	7 × 10
8									8 × 9	8 × 10
9										9 × 10

Figure 3. Forty-one combination crosses (except 1 × 4, 1 × 8, 4 × 8 and 5 × 9) could be identified from their outcrossed and selfed progenies by using isoenzyme gene loci at PGM-A, PGM-B and IDH-A.

Pollination of the above crosses which represent 90% (41 crosses) of the total parental combinations (45 crosses) could be carried out without any need for emasculation since the selfed and crossed progenies can be identified at a later stage by isoenzyme analysis. Hence the above polymorphism of multilocus genotypes at PGM-A, PGM-B and IDH-A loci could greatly facilitate the production of hybrid progenies in the breeding of *A. auriculiformis* in Thailand.

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References

Bergmann, F. 1981. Unterscheidung von Pappelklonen mit Hilfe von Isoenzym-Muster. Holzzucht, 35, 24–27.

— 1987. Characterization of mullticlonal aspen cultivars using isozyme electrophoresis. Forest Ecology and Management, 22, 167–172.

Changtragoon, S., Boontawee. B and Szmidt, A.E. 1993. Application of isoenzyme gene markers for clone identification of plus trees in *Azadirachta indica* var. *siamensis* (Valuton) grafted clone bank. In: Proceedings of the Forestry Conference. Royal Forest Department (RFD), Marauy Garden Hotel, 20-24 December 1993, Thailand, P: 20–30. (English Abstract).

Changtragoon, S. and Finkeldey, R. 1995. Inheritance of Isoenzyme phenotype of *Pinus merkusii*. Journal of Tropical Forest Sciences, 8(2), 167–177.

Cheliak, W.M. and Pitel, J.A. 1984. Electrophoretic identification of clones in trembling aspen. Canadian Journal of Forest Research, 14:5, 740–743.

Conkle, M.T., Hodskiss, P.D., Nunally, L.B. and Hunter, S.C. 1982. Starch Gel Electrophoresis of Conifer Seed: A Laboratory Manual. General Technical Report PSW-64. Pacific Southwest Forest and Range Experement Station, Berkeley, California, 18 p.

Feret, P.P. and Bergmann, F. 1976. Gel electrophoresis of proteins and enzymes. In: Miksche, J.P., ed., Modern Methods in Forest Genetics. Springer, Berlin, Heidelberg, 49–77.

Fineshi, S. 1988. Short Note: Genetics of chestnut (*Castanea sativa* Mill) II: Uniformity of isozyme phenotypes in grafted orchards. Silvae Genetica, 37:2, 82.

Kumaravelu, G. 1979. Clonal identification of *Tectona grandis* by isoenzyme studies. Indian Forester, 105:10, 716–719.

Rothe, G.M. 1990. Identification of Norway spruce clones by isoenzyme analyses of needles. Allgemeine Forst und Jagszeitung, 161:5, 103–107.

Ryu, J.B. and Na, C.S. 1987. Identification of loblolly pine (*Pinus taeda* L.) clones through isozyme analysis. Journal of Korean Forestry Society, 76:4, 330–337.

Yoo, S.K, Kwon, Y.L. Hwang, S.I., Cho, R.M. Kim, Y.L. and Lee, K.L. 1988. Needle characteristics and isozyme genotype identification of 21 *Pinus korianensis* clones. Research Report of the Institute of Forest Genetics. No. 24, 114–120.

Tree Improvement of Acacias: What about the People?

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Abstract

In this paper we describe a participatory approach to tree improvement programs for acacias in Vietnam. Farmers and communities would be involved in the evaluation of provenance tests, the establishment, management and evaluation of on-farm progeny tests, and the management of some kinds of production population. Tree breeders would act mainly as facilitators who combine sets of knowledge and expertise to work within the constraints of farmers, and would be responsible for drawing up breeding strategies and managing breeding populations. This approach would empower farmers by enabling them to choose the trees that make up breeding populations. Technology transfer would also be easier, since farmers involved in selection and testing would understand the advantages of tree improvement.

TOO often, foresters and scientists make the assumption that their professional input will benefit rural communities and that tree planting will offer socio-economic advantages (Turnbull 1987). In reality, trees may not always be what farmers perceive as their priorities (Cromwell et al. 1995), and characters selected in tree breeding programs may not always be the preferred ones. Farmers may well be interested in a variety of non-timber produce (e.g. fodder) and compatibility with other species grown in their production systems (i.e. ecological combining ability), rather than in timber for construction or pulp.

Increasingly, farmers have had the opportunity to express their needs and objectives for tree breeding (Raintree et al. 1992; Midgley et al. in press). In this paper we look at a new approach to tree breeding which would take farmers' management practices and opportunity into account and transform the role of the tree breeder. Our ideas arose from discussions about the next stage of a research project, being carried out at the University of Wales, on the genetic variation in salt tolerance of African *Acacia* species.

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Genetic Variation in Salt Tolerance of Acacias

Genetic variation in salt tolerance has been reported in a number of tree species (Bell et al. 1994), including some of the acacias (Craig et al. 1990; N. Marcar, pers. comm.). If provenance[1] variation in salt tolerance is present in an *Acacia* species that is to be grown in saline soils, seed should only be collected from salt-tolerant populations. If the species is uniformly salt-tolerant, seed can be collected from any population that satisfies other selection criteria, with probable savings in cost. In most *Acacia* species the potential for increasing salt tolerance by breeding is unknown; progeny tests are needed to identify individuals with high breeding values and to estimate the heritability of salt tolerance. Once this information is available, genetic gains from different tree improvement strategies can be calculated.

The African species *Acacia karoo*, *A. nilotica*, *A. tortilis* and *A. albida* (syn. *Faidherbia albida*) occur on a wide range of soil types, including some that are saline. The authors have grown provenances, families and clones in controlled environment chambers, using a hydroponic system to provide a range of salt concentrations.

1. Provenance: the place where seed is collected. The term is applied both to the seed and the trees grown from the seed.

In all four species we have found significant genetic variation in salt tolerance between provenances. The practical implications are clear: if the species are to be planted on salt-affected land, planting stock should be grown from seed collected from salt-tolerant populations.

We have also found within-provenance variation that could be exploited in tree breeding programs. We have been able to identify tolerant and intolerant individuals of *A. nilotica* and *A. tortilis*, and have propagated them from cuttings. A clonal test of the cutting material and a progeny test of individual trees from a single, salt-tolerant provenance of *A. tortilis* are in progress. When these are completed we will be able to estimate the potential genetic gain from breeding for salt tolerance.

At this point, we had always intended to establish field trials to confirm (or otherwise) the salt tolerance of our selections and to test a wider range of material. We had assumed that tests would be carried out by a research institution on a small number of sites which are either uniformly saline or which have a uniform gradient of salinity. Randomised complete block or incomplete block designs would be used and trees would be assessed for biomass production and chemical composition of the leaves. Index selection would be used to identify genotypes for inclusion in breeding and production populations.

During recent discussions we have realised that this 'conventional' approach to tree improvement, in which all decisions would be made by research scientists and tree breeders, is probably not appropriate for acacias which are grown by small farmers. These species often have important sociocultural functions which must be taken into account if tree improvement strategies are to succeed. The example of *A. albida* in West Africa is discussed by Bonkoungou (1992), who considers that research on this species (which includes provenance and progeny testing) has not taken sufficient account of socioeconomic factors. It is common belief that small-scale tree breeding programs are not economically viable but this assumption is now challenged by some research in Costa Rica (Hamilton et al. in press).

Is the 'Conventional' Approach Socially Realistic?

When looking at tree planting three major factors need consideration: tenure, gender and labour (as well as economic criteria such as market prices, availability or increase in income, and productivity).

Planting trees requires the dedication of land for the medium- or the long-term, and not all farmers have sufficient areas of land available to substitute trees for crops. Tenants have usually little or no incentive for planting trees that will eventually benefit the landlord, and often local de facto rules prohibit them from doing so. Planting trees on degraded or common land, as was often the case during social forestry programs in India (Samaj Parivartana Samudaya 1991), may also be socially damaging. Frequently poor and marginal groups who use degraded areas extensively for grazing or gathering various products are, after reforestation campaigns, prohibited from doing so and lose access to a vital resource. Few 'social' afforestation programs provide any socioeconomic benefits for the ones they are supposed to assist: in many countries, poor farmers do not buy firewood (Chambers 1997) even when made available from plantations, and pressure remains on natural resources.

Gender-focused research provides growing evidence that men and women need and use different parts of the trees. There are also noticeable differences of behaviour within genders as 'men' and 'women' are socially and culturally heterogeneous groups (Madge 1995). In the past households and communities have often been treated as homogeneous groups of people with similar interests and needs, who would benefit equally from progress in science, but generalisations tend to mislead.

Men and women carry out different tasks in the household and on the farm and for many households the shortage of labour is a major constraint to new investment on the farm (Carter 1995). Trees not only require planting, often at a time of peak labour in the fields, but also watering, weeding and protecting from thieves and livestock. In most societies, men are responsible for the planting. Women who do not own land are often prohibited from planting trees as it may give them a right over the land. On the other hand, women are usually responsible for raising the trees. This of course comes as a labour task additional to domestic and agricultural work. Exotic species may well grow faster and produce more biomass but they may require specific management practices unknown to the farmers or demand unrealistic amounts of labour. Few households, and indeed few women, can spare extra time.

Vietnam illustrates such a situation. Vietnam is a diverse country in a process of rapid social and economic diversification. The social, political and economic picture is complex. Not all households have the same access to land allocation and reforestation programs, and in the long term devising localised, flexible, appropriate approaches to solving environmental degradation in the country may be more relevant. At present there is little recognition of the gender division of labour and responsibility for forestry activities.

The approach of entrusting households with the management of allocated plots of forest land on a long-term lease basis, set out in Vietnam's new forest policy, is conducive to the development of close working relationships between farmers and tree breeders. Most rural households now have access to land on which they can grow what they see fit. Participatory approaches in land use and rural resource management are currently being tested in various development projects in Vietnam. Vietnamese farmers are responsive to new approaches and the social context seems favourable for developing and testing an innovative tree breeding approach.

A Participatory Approach to Tree Improvement Programs for Acacias in Vietnam

The first step in an improvement program would therefore be taken by a research organisation, which would establish limited-range provenance tests[2] of promising species on several sites in the country. The assessment of provenance tests would be done jointly by interested farmers and breeders on a participatory basis. Farmers would identify outstanding phenotypes using their preferred selection criteria, and breeders would explain the advantages and disadvantages of limiting the number of criteria. To some extent, communities are heterogeneous and the program would need to ensure that different voices are listened to. If it is decided that the number of selection criteria should be limited, communities would have to negotiate the list of preferred criteria within themselves.

The outcome of the joint assessment would determine the number of breeding populations and the individuals to be included in them. Because different communities may have different requirements, breeders must be prepared to design different breeding programs satisfying regional and local priorities. However, there will be practical limitations on the number of breeding populations that breeders can handle, and these must be explained to the farmers.

Breeders would be responsible for drawing up breeding strategies and managing breeding populations. Management of some types of production population (e.g. clonal seed orchards, seedling seed orchards) could be done jointly by breeders and interested farmers/communities. It should be noted that joint management is probably not appropriate for some types of production population (e.g. breeding seedling orchards).

2. Provenances for these tests should come from areas with similar climatic conditions to those found in Vietnam.

If breeding strategies include progeny testing, this would also be done on a participatory basis. Seedlings would be raised either by the research institution or by the villagers in decentralised nurseries. They would then be planted in progeny tests on farmers' land. Individual plots of allocated land could be used as replicates and in most cases would be of sufficient size to accommodate many families. Although there is little information on the progress of land allocation, some early reports suggest that the average area of forest land per household is 1–2 ha (Me et al. 1993) which should be sufficient even though farmers grow crops on these plots as well. Conventional experimental designs may be used if farmers' forest holdings are adjacent, but imaginative approaches may be needed where holdings are scattered. Farmers have the freedom to use their allocated land in the way they wish, and depending on their labour availability and financial capital they may have different management practices for growing trees. Therefore tree breeders may have to accept that different treatments will be applied to different replicates of the progeny test.

The performance of the trees would then be assessed by the farmers and the breeders. Farmers visit their forest on a regular basis for grazing, collection of various products and sometimes even live on the edge of the forested area. They are in a better position than the breeders to monitor the progress of the trial on a regular basis and note, for example, any build up of pest populations.

Although this approach is designed on the assumption that farmers are involved at each stage and fully committed, one has to expect that not all households will complete the test. Some measure of compensation or incentives for participation in the program may have to be incorporated into the approach.

In this approach to tree improvement the breeder's role is mainly that of a facilitator who combines different sets of knowledge and expertise to meet the needs of farmers.

Why Do It This Way?

The approach outlined above would of course need to be developed and tested by scientists and field workers. Nevertheless, we consider that its underlying philosophy is the way forward not only to integrating the needs and selection criteria of rural communities in tree improvement programs, but also encouraging breeders to consider the interaction between genotype and management practice. We can see many advantages, some of which are listed on the following page.

Advantages:

- evaluations are carried out by people who will grow and use the trees;
- tests are carried out on sites where the species is to be grown, using indigenous management practices;
- knowledge transfer, which should be part of the participatory approach, is crucial because it enables farmers to choose the trees that make up breeding populations, and thus empowers them;
- the involvement of farmers at the onset of the process will ensure that they understand the advantages of tree improvement. Technology transfer should therefore be easier.

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References

Bell, D.T., McComb, J.A., Van der Mozel, P.G., Bennett, J.J. and Kabay, D.E. 1994. Comparisons of selected and cloned plantlets against seedlings for rehabilitation of saline water logged discharge zones in Australian agricultural catchments. Australian Forestry, 57, 69–75.

Bonkoungou, E.G. 1992. Sociocultural and economic functions of *Acacia albida* in West Africa. In: Vandenbeldt, R.J., ed., *Faidherbia albida* in the West African Semi-Arid Tropics. ICRISAT / ICRAF, 1–6.

Carter, J. 1995. Socio-economic factors influencing alley farming adoptability. Natural Resource Perspective 3.

Chambers, R. 1997. Whose Reality Counts? Putting the First Last. IT, London.

Craig, G.F., Bell, D.T. and Atkins, C.A. 1990. Response to salt and waterlogging stress of ten taxa of *Acacia* selected from naturally saline area of Western Australia. Australian Journal of Botany, 38, 619–630.

Cromwell, E., Brodie, A. and Southern, A. 1995. Germplasm Exchange and Use of Multipurpose Trees in Small Farm Communities. Final report, ODA Forest Research Project R6054.

Hamilton, C., Chandler, L., Brodie, A. and Cornelius, J. (in press). A financial analysis of small scale *Gmelina arborea* Roxb. improvement program in Costa Rica. New Forests.

Madge, C. 1995. Ethnography and agroforestry research: a case study from the Gambia. Agroforestry Systems 32, 127–146.

Me, V.V., Van, N.T. and Warfinge, H. 1993. Land Classification and Land Allocation in Vietnam and in Tu Ne Commune of Tan Lac District, Hoa Binh Province. noi, Ministry of Forestry.

Midgley, S.J., Byron, R.N., Chandler, F.C., Thinh, H.H., Son, T.V.H. and Hanh, H.H. (in press). Do plants needs passports? A socio-economic study of the role of exotic tree and other plant species in Quang Tri Province, Vietnam, CSIRO.

Raintree, J.B and Taylor, D.A., ed., 1992. Research on Farmers Objectives for Tree Breeding. Bangkok, Winrock International.

Samaj Parivartana Samudaya 1991. Whither Common Lands? Dharwar.

Turnbull, J.W., ed., 1987. Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, Australian Centre for International Agricultural Research, Canberra, 4–7.

Diseases of Tropical Acacias

K.M. Old[1]

Abstract

Surveys of disease of four species of tropical acacias important for industrial plantations are summarised, recording occurrence and impact of the most significant diseases. The surveys, carried out in northern Australia, India, Peninsular Malaysia, Thailand and Indonesia, indicate that canker diseases (including pink disease), phyllode rust, root-rot fungi and heart-rot have the potential to reduce the productivity of acacia plantations in the tropics.

ACACIAS are of considerable social and industrial importance for tropical reforestation and it is expected that about two million hectares will be established in Southeast Asia by the year 2000. The species that have been most widely planted so far are *Acacia mangium* and *A. auriculiformis*. *Acacia crassicarpa* and *A. aulacocarpa* have been planted on a limited scale, primarily in provenance and species trials in many locations throughout the region, with a view to providing options for future hardwood plantation establishment.

Plantations of acacias in the humid tropics have been relatively free of diseases, especially when compared with eucalypts, which are commonly affected by damaging diseases. But reports from several countries in Southeast Asia and northern Australia have suggested that the future productivity of acacia plantations may be affected by fungal pathogens.

During 1995–96 surveys of diseases on the four *Acacia* species listed above were carried out in northern Australia and several countries of Southeast Asia, supported by funding from ACIAR and CIFOR. The surveys were undertaken by forest pathologists in native stands, trials, and industrial and social forestry plantations of tropical acacias in Australia, India, Indonesia, Malaysia, and Thailand. The aim was to assess the potential of fungal pathogens as factors limiting tree growth and productivity, and to assess the relative importance of individual fungal pathogens.

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The findings were published recently, providing a benchmark of the current knowledge of the pathology of acacia plantations in tropical areas (Old et al. 1997). The most significant diseases were foliar spots and necrosis, powdery mildew, rusts, stem cankers (including pink disease), root and butt rots and heart-rot.

This paper summarises the main findings of the surveys and provides information on the current and potential impacts of the pathogens on plantations.

Foliar Diseases

Phyllodes often show a range of leaf spot and tip necrosis symptoms. Associated pathogens include species of *Colletotrichum*, *Pestalotiopsis*, *Cylindrocladium*, and *Phomopsis* (Sharma and Florence 1997). In some situations a significant proportion of tree crowns can be affected, especially the foliage borne on lower branches, but the impact of these fungi on growth is largely unknown.

An outbreak of phyllode necrosis on *A. mangium* caused by a species of *Cercospora* was observed in north Queensland in the early 1990s. It was initially on seedlings, but was also seen later on trees after outplanting. The outbreak caused death of some trees and loss of form in seed orchard trees. The disease was present in several stands in the following year; but, despite annual surveys, the fungus has not been recorded since, either in plantations or in natural stands of acacias in the same region. *Cercospora* spp. have not been found to cause diseases in established acacia plantations outside Australia, although a *Cercospora* sp. was recorded on seedlings in Thailand (Pongpanich 1997).

Powdery mildew caused by a species of *Oidium* can be found on seedlings in most nurseries where tropical acacias are grown, and occasionally on phyllodes of lower branches or coppice shoots under canopies of established plantations in humid conditions. In nurseries it is simply controlled by *Benlate* or sprays containing copper and sulfur, and its impact on plantation trees appears to be negligible.

The most important and damaging phyllode disease is caused by a rust fungus identified as *Atelocauda digitata*, which occurs commonly in northern Australia; all five possible spore stages occur on a single host species. A fungus with close affinities to *A. digitata* has been found infecting nursery stock and trees of a wide range of age classes of *A. mangium* and *A. auriculiformis* in Java, central and southern Sumatra, and several locations in Kalimantan. Research is needed to confirm the identity of this pathogen and to determine its capacity to reduce plantation growth.

Damage to seedlings and trees shortly after outplanting includes major distortion and hypertrophy of growing points (Figure 1). An epidemic in 15-month-old trees in south Kalimantan induced premature phyllode shedding by all trees in the stand. In a nearby stand, foliage in the upper crowns of trees 7 m high showed widespread damage (Figures 2 and 3). There appears to be considerable variation between provenances in susceptibility to disease, indicating a potential for selection for resistant genotypes. Strategies for future selection of clones for widespread planting should include evaluation for rust resistance.

Although *A. digitata*, which principally attacks phyllodes and young shoot tips, is currently the major rust threat, *Uromycladium notabile*, which occurs on both tropical and temperate species of acacia in Australia, has a similar capacity for damage. This fungus and its close relative on bipinnate species, *U. tepperianum*, have been long recognised as major acacia pathogens. Rust galls occur on woody stems and branches, and lesions are further invaded by opportunist canker fungi and insect borers. *U. tepperianum* was a major factor in the failure of an attempt to set up a tannin industry in New Zealand based on *A. mearnsii*, and the fungus has been introduced into South Africa as a biocontrol agent for weed acacias. *U. notabile* is widely distributed in Australia, but was recorded only once in the Queensland survey. The author also found this fungus on *A. auriculiformis* in Vanuatu.

Acacia rusts were not recorded in the surveys in India, Thailand or Malaysia. However, a collection resembling *A. digitata* was made from acacia phyllodes in Hong Kong (Cannon et al. 1997), and it seems likely that this pathogen will become more widely distributed in the Southeast Asian region.

Canker Diseases

Cankers are necrotic areas of bark and outer sapwood resulting from the invasion of stems by a range of fungal pathogens. Typical avenues for invasion by canker-causing fungi are wounds, branch stubs left after pruning, incomplete occlusion of suppressed lower branches, and insect damage. Trees subjected to stress such as drought, defoliation by foliar pathogens or insects, nutrient limitation, or growth suppression are often more susceptible to canker pathogens than are vigorous trees well matched to the site.

Severe canker diseases were reported in three separate countries, India, Indonesia and Thailand (Sharma and Florence 1997; Hadi and Nuhamara 1997; Pongpanich 1997). The most damaging canker disease found at two locations at Bangalore in southern India was caused by a species of *Hendersonula* in two acacia stands, one of *A. mangium* and one of *A. auriculiformis*. These are the first records of disease of acacias caused by this pathogen.

Canker incidence was assessed in *A. auriculiformis* in three provenance trials of similar design and composition, two in Thailand (Lampao lamsai, Kanchanaburi and Sakaerat), and one in South Kalimantan (Riam Kiwa). In Thailand the cankers appeared to be induced by a species of *Botryosphaeria* that caused extremely severe damage to all provenances at Kanchanaburi, but little damage at the Sakaerat site. The latter site is more fertile with an annual rainfall of 1300 mm, compared with 900 mm at Kanchanburi which also suffered a severe drought (<600 mm) during the year of establishment. It seems likely that drought stress was a predisposing factor to the disease impact at Kanchanburi.

The trial at Riam Kiwa showed a high level of provenance variation. Of the 25 provenances in the trial, 12 from Northern Territory (Australia) showed a very high incidence of cankers (Figures 4 and 5). Several provenances from northern Queensland and Papua New Guinea had a very low incidence of cankers, and individual trees showed good growth and form.

The etiology of the cankers seen at Riam Kiwa is not clear. Rainfall is in the order of 2000 mm per annum with a marked dry season of about five months during which only 20% of the annual rainfall occurs. Also the pathogens associated with the cankers have not been identified with any certainty, although *Lasiodiplodia theobromae* and a species of *Phomopsis* have been isolated from cankered stem tissue (Hadi and Nuhamara 1997).

Figure 1. Apical shoot of *Acacia mangium* infected by *Atelocauda digitata* (phyllode rust), South Kalimantan.

Figure 2. Upper crown of *A. mangium*, heavily infected by phyllode rust, South Kalimantan.

Figure 3. Phyllodes of tree shown in Figure 2, showing extensive rust galls.

Figure 4. Stems of *Acacia auriculiformis* severely affected by canker disease, Riam Kiwa, South Kalimantan.

Figure 5. Provenance trial of *A. auriculiformis* at Riam Kiwa: the provenance to the left of the picture originated in Papua New Guinea, and is little affected by canker disease; the northern Australian provenance to the right is heavily diseased.

Figure 6. *A. mangium* affected by root rot in a provenance trial in northern Queensland: most of the trees in the plot have died.

Figure 7. Fruiting bodies formed at the base of one of the dying trees shown in Figure 6.

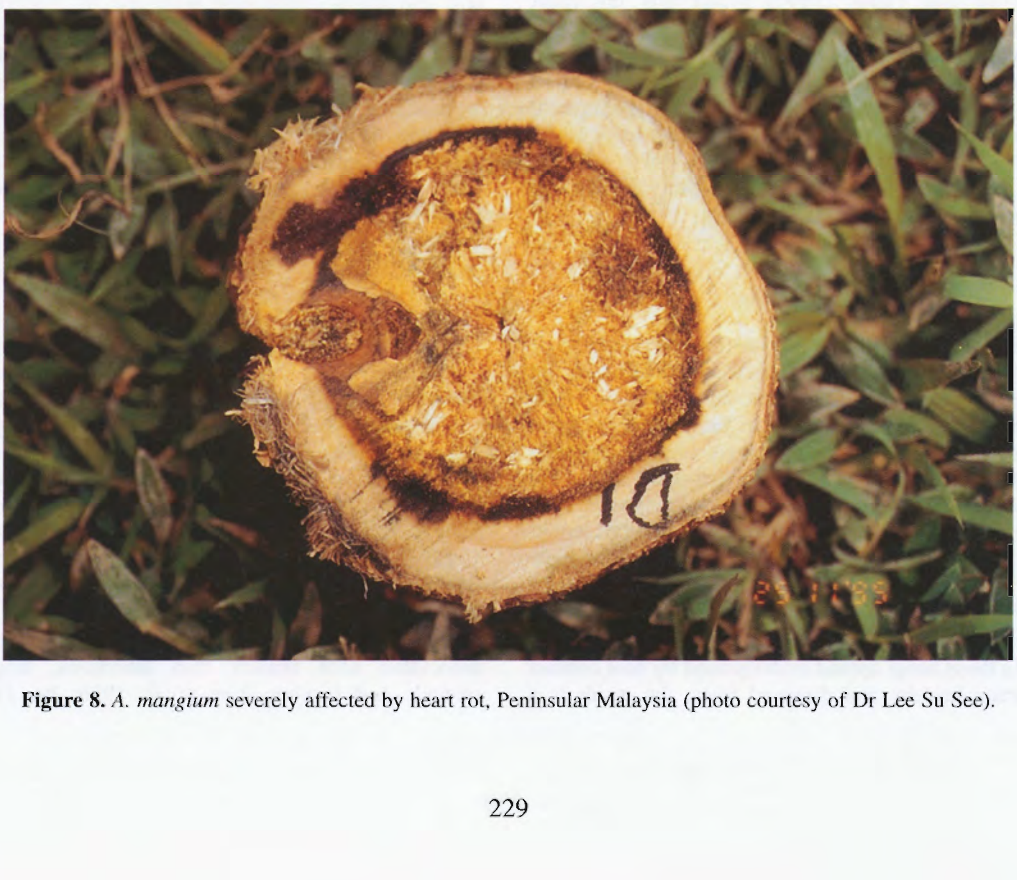

Figure 8. *A. mangium* severely affected by heart rot, Peninsular Malaysia (photo courtesy of Dr Lee Su See).

So far the best approach to management or avoidance of canker problems appears to be matching of provenance to site. The international *A. auriculiformis* provenance trial (Pinyopusarerk 1992) is providing useful information in this regard, although further detail is needed regarding the underlying basis for canker severity.

Perhaps the best known canker disease associated with tropical acacia plantations is pink disease. This disease is caused by the basidiomycete fungus, *Corticium salmonicolor*, a fungus with a very wide host range that causes damaging stem cankers on rubber (Hilton 1958), eucalypts (Sharma et al. 1984), *A. mangium* (Hadi and Nuhamara 1997; Zulfiya and Gales 1997), *A. crassicarpa* and *A. aulacocarpa* (Hadi and Nuhamara 1997), and *A. auriculiformis* (Florence and Bahsundran 1991).

The pathogen is especially active in high-rainfall areas, where a range of susceptible plantation species is grown. Access to stem tissue is through wounds and branch stubs. Infected stems show superficial mycelial growth, followed by a denser pale pink coating of fungal tissue on which the fungus fruits. Underlying bark becomes necrotic and branches may be girdled. In the field the disease comes to notice through stem breakage, often high in the crown of the tree. The disease often occurs in patches, in stands that are overstocked or stressed by other environmental factors. Zulfiyah and Gales (1997) found this the most prevalent disease in *A. mangium* in southern Sumatra; they related incidence of pink disease to stand density, with denser stands being more affected. Pink disease has been recorded on tropical acacias in Kalimantan (Hadi and Nuhumara 1997) and in India (Sharma and Florence 1997), but has not been reported as a significant disease in Thailand, Malaysia or Australia.

Root-rots

Trees in tropical rainforests are hosts to a range of root-rot and butt-rot pathogens, typically of the genera *Phellinus*, *Rigidoporus* and *Ganoderma*. In undisturbed native forests these fungi probably exist in equilibrium with their hosts, causing the death of scattered trees but rarely causing disease at a level threatening to stand survival. The fungi have a wide host range and when tropical rainforests are cleared and planted to acacias, inoculum surviving on roots and stumps of dead trees commonly invades roots of newly-planted trees, causing tree death (Figures 6 and 7).

As these fungi spread underground by root contact between healthy and diseased trees, the result is a spreading patch of dying and dead trees. Fruiting bodies form on dead and dying trees, and spores produced on these structures can disseminate the pathogen to new locations. Lee (1997) studied the incidence of root-rot in *A. mangium* stands in Peninsular Malaysia and provided details of the symptomatology and evidence for significant differences between sites and provenances in the levels of disease.

Root-rot was the most widespread disease in *A. mangium* in plantations surveyed in Peninsular Malaysia, and was observed at two locations in central Sumatra; an area of 18-year-old plantation west of Bintulu in northern Sarawak also appeared to be badly affected by root disease, according to the author's unpublished observations. In view of the projected large increase in plantation establishment in West Malaysia, this gives some cause for concern.

Root-rot has been observed less frequently in stands established on areas long cleared of forest in southern Sumatra and South Kalimantan. *A. mangium* is highly regarded in these areas where it successfully suppresses growth of alang alang (*Imperata cylindrica*). The low level of root-rot probably reflects a reduction in the level of fungal inoculum following forest clearing.

Root-rot must be regarded as a serious threat to acacia plantations established on recently cut-over forest. The planting of successive rotations of acacia will provide a continuing sequence of susceptible trees. The 'no-burn policy' imposed in Indonesia following high levels of atmospheric pollution from wildfires, may result in a build up of inoculum on the slash of cut-over forests and residues remaining after plantation harvesting. As there is no practical means to control these pathogens on a plantation-wide basis, and a range of pathogens is probably involved. Careful monitoring will be needed over the next decade to establish the scope of this problem.

Heart-rot

Heart-rot is the only disease of tropical acacias on which there has been sustained research during the last decade (Lee and Zakariah 1993; Lee et al. 1996). The condition has been reported in Peninsular Malaysia, Sabah (Mahmud et al. 1993), Sabah (Ito and Nanis 1997), Papua New Guinea (Davidson 1974), India (Mehrotra et al. 1996), and there are unpublished reports of heart-rot in both Indonesia and Thailand.

Research has shown that stem defect is closely associated with branch stub infections, singling wounds and forking (Lee et al. 1988; Ito 1991).

Although incidence of heart-rot can be very high (50–98% of stem being infected), the volume of wood affected can be quite small. This level of degrade is serious where wood is used for construction and appearance grades, but is of little significance where the crop is grown for pulp and paper or composites on rotation lengths of 7–10 years.

Heart-rots caused by basidiomycete fungi, but with the exception of *Phellinus noxious*, observed in West Kalimantan and in Peninsular Malaysia (Lee and Zakariah 1993), there is little published information as to their identity. Indeed, where stem wounds are present there are always likely to be fungi capable of invading the heartwood of young, fast growing trees that lack significant accumulation of extractives to confer durability.

The current level of heart-rot in existing plantations may in part reflect the generally poor genotypes which were planted in the first widescale establishment of tropical acacia plantations in Malaysia and Indonesia (Figure 8) and the less-than-adequate silviculture. As provenances and clones with better form are established on second-rotation sites and new plantation areas, and as silviculture improves, it can be expected that there will be fewer multi-stemmed trees requiring singling and pruning of heavy limbs. Fewer singling wounds and smaller branch stubs on trees of improved form will lead to fewer invasions by heart-rot fungi.

Wound treatment is not generally an attractive option because the evidence for the efficacy of treatment is lacking, and such measures are time-consuming and labour-intensive.

Conclusions

Managers of plantation forests based on tropical acacias will need to consider disease as a major factor in management for sustained productivity. Surveys in northern Australia and Southeast Asia have established a current benchmark of the main pathogens present, and an indication of which diseases may have a potential to impact on productivity. Table 1, which is reproduced from the proceedings of a workshop at Subanjeriji in 1996 (Old et al. 1997), summarises the available information and opinion of participants at the workshop on the diseases that appear to offer the major threats.

Experience with plantation forestry in many parts of the world has shown that diseases can be managed to reduce their impact to an acceptable level. To achieve this, forest pathologists need to contribute to many aspects of plantation management, including nursery hygiene, silviculture, site management and tree improvement, to minimise losses from disease during successive rotations.

Table 1. Summary of information on the five most significant diseases of tropical acacia plantations resulting from surveys in Australia, India, Malaysia, Thailand and Indonesia.

Disease	Causal agents	Occurrence	Management options	Notes	Gaps in knowledge
Root root	*Ganoderma* complex, especially *G.* aff. *lucidum*	All countries in survey	Surveillance. Removal of stumps and woody debris in infection foci. Trenching 0.5–0.8 m deep around infection foci. Possible use of fungicide drench (triazole compounds).	Some evidence in Sumatra that the disease is more widespread in second-rotation stands.	Identity of causal fungi. Role of woody debris after harvest as source of inoculum. Effectiveness of fire in reducing inoculum. Species, provenance, clonal difference in susceptibility.
Stem canker	Range of pathogens including *Lasiodiplodia theobromae*, *Botryosphaeria* spp., *Hendersomula* sp. (India)	All countries in survey	Remove/burn affected trees. Site, species and provenance matching to avoid stress (drought or defoliation).	Most reports for *A. auriculiformis*. Cankers often associated with borer damage.	Etiology of canker diseases. Species, provenance, clonal differences in susceptibility.
Pink disease	Corticium salmonicolor	India Indonesia (Sumatra and Kalimantan)	Remove, burn affected trees. Silviculture: diseases favoured by close spacing. Selection of species and provenances.	Broad host range on woody hosts. Most prevalent in high rainfall areas.	Incidence in different age classes. Pathogenic variation in strains of the fungus.

Table 1. (continued)

Disease	Causal agents	Occurrence	Management options	Notes	Gaps in knowledge
Heart rot	Range of wood decay fungi	All countries in survey	Silviculture especially early singling of multistemmed trees. Avoidance of wounds. Provenance selection for slender branches, single stems. Short rotation.	Problem most acute in *A. mangium*. Suggestion that plantations in regions with a seasonal drought will incur less heart rot. *A. mangium/A. auriculiformis* hybrid may be less susceptible. Stands with better form due to variation in provenance or in site quality may incur fewer singling/pruning wounds and less heart rot.	Level of heart rot in different age classes. Relative susceptibility of different provenances, families, clones and hybrids. Impact of environmental and edaphic factors on heart rot incidence. Effect of pathogen, host, environmental factors on rate and extent of stem decay. Effect of fungal invasion on pulpwood quality.
Phyllode rust	*Atelocauda digitata*	Australia Indonesia (Java, Sumatra and Kalimantan)	Destroy affected plants in nursery. Spray nursery stock to prevent further infection. Select resistant provenances, families and clones.	This disease is widely distributed in Sumatra. Reported on *A. auriculiformis*, *A. mangium* and the hybrids between these species. The potential of the pathogen to cause serious losses is unclear. Future selection of planting stock especially of clones must include determination of susceptibility to this fungus.	Etiology of the disease and role of different spore stages. Spray schedules for control in the nursery. Screening methods for selection of resistant plants. Pathogenic variability of the rust. Geographical distribution of the fungus.

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References

Cannon, P., Pascoe, I., Beilharz, V. and Yuan, Z.Q. 1997. Report on fungi from diseased acacia samples examined at Institute of Horticultural Development, Knoxfield, Victoria. In: Proceedings of an International Workshop, Subanjeriji, South Sumatra, 28 April–3 May 1996. CIFOR Special Publication, 108–113.

Davidson, J. 1974. Decayed wood in living trees of *Eucalyptus deglupta* Blume. Papua New Guinea Tropical Forestry Research Note, SR 18, 31 p.

Florence, E.J.M. and Balasundaran, M. 1991. Occurrence of pink disease of *Acacia auriculiformis* in Kerala. Indian Forester, 117, 494–496.

Hadi, S. and Nuhamara, S.T. 1997. Diseases of species and provenances of acacias in West and South Kalimantan, Indonesia. In: Proceedings of an International Workshop, Subanjeriji, South Sumatra, 28 April–3 May 1996. CIFOR Special Publication, 23–47.

Hilton, R.N. 1958. Pink disease of *Hevea* caused by *Corticium salmonicolor* Berk. et Br. Journal of the Rubber Research Institute Malaya, 15, 275–292.

Ito, S. 1991. A survey of heart rot in *Acacia mangium*. Report to SAFODA.

Ito, S. and Nanis, L.H. 1997. Survey of heart rot on *Acacia mangium* in Sabah, Malaysia. JARQ, 31, 65–71.

Lee, S.S. 1997. Diseases of some tropical plantation acacias in Peninsular Malaysia. In: Proceedings of an International Workshop, Subanjeriji, South Sumatra, 28 April–3 May 1996. CIFOR Special Publication, 53–61.

Lee, S.S., Zakaria Ibrahim, Hashim Mohd. Nor and Wan Razali Wan Mohd. 1996. Impact of heart rot in *Acacia mangium* Willd. plantations of Peninsular Malaysia. In: Nair, K.S.S. and Sharma, J.K., ed., Impact of Diseases and Insect Pests in Tropical Forests. Proceedings of IUFRO Symposium, 23–28 November, Kerala Forest Research Institute, Peechi, India, 1–10.

Lee, S.S. and Zakaria, M. 1993. Fungi associated with heart rot of *Acacia mangium* Willd. in Peninsular Malaysia. Journal of Tropical Forest Science, 5, 479–484.

Lee, S.S., Teng, S.Y., Lim, M.T. and Razali Abd. Kader. 1988. Discoloration and heart rot of *Acacia mangium* Willd. — some preliminary results. Journal of Tropical Forest Science, 6, 37–47.

Mahmud Sudin, Lee, S.S. and Ahmad Hj. Harun. 1993. A survey of heart rot in some plantations of *Acacia mangium* Willd. in Sabah. Journal of Tropical Forest Science, 6, 37–47.

Mehrotra, M.D., Pandey, P.C., Chakrabarti, K., Suresh Sharma and Hazra, K. 1996. Root and heart rots in *Acacia mangium* plantations in India. Indian Forester, 122, 155–160.

Old, K.M., Lee S.S. and Sharma, J.K. 1997. Diseases of tropical acacias. Proceedings of an International Workshop, Subanjeriji, South Sumatra, 28 April–3 May 1996. CIFOR Special Publication.

Pinyopusarerk, K. 1992. Australian collaborative research on tropical acacias. In: Awang, K. and Taylor, D.A., ed., Tropical Acacias in East Asia and the Pacific. Winrock International Institute for Agricultural Research, 8–14.

Pongpanich, K. 1997. Diseases of *Acacia* species in Thailand. In: Proceedings of an International Workshop, Subanjeriji, South Sumatra, 28 April–3 May 1996. CIFOR Special Publication, 62–69.

Sharma, J.K. and Florence, E.J.M. 1997. Fungal pathogens as a potential threat to tropical acacias: case study of India. In: Proceedings of an International Workshop, Subanjeriji, South Sumatra, 28 April–3 May 1996, CIFOR Special Publication, 70–107.

Sharma, J.K., Mohanan, C. and Maria-Florence, E.J. 1984. Outbreak of pink disease caused by *Corticium salmonicolor* in *Eucalyptus grandis* in Kerala, India. Tropical Pest Management, 30, 253–255.

Zulfiyah, A. and Gales, K. 1997. Diseases of tropical acacias in South Sumatra. In: Proceedings of an International Workshop, Subanjeriji, South Sumatra, 28 April–3 May 1996. CIFOR Special Publication, 48–52.

Insect Pests of Tropical Acacias: a New Project in Southeast Asia and Northern Australia

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Abstract

While a wide range of insect pests has been recorded in acacia plantations in Asia, there have been few major problems to date; the exception is termites. However, the pest situation may be changing rapidly with the massive expansion of plantations into new areas, and adaptation by indigenous insects to these exotic trees as hosts. There are recent indications of emerging serious problems such as mirid bugs (*Helopeltis* spp.) on *A. mangium* in Sumatra and a shoot and twig boring tortricid moth (*Cryptophlebia* sp.) on *A. mangium* in Queensland. A lack of quantitative data on pest impacts and the difficulty in obtaining up-to-date pest information are major hindrances to recognising problems. To begin addressing some of these issues, a project involving systematised surveys of current insect pest occurrence and severity in *Acacia* plantations has recently commenced in Indonesia, Malaysia, Thailand, Vietnam and tropical Australia. The information obtained should help forest managers to identify, assess and handle pest risks, and set priorities for further research. Systems developed in this initial phase may form the basis for ongoing pest assessment and information exchange in the region.

PLANTATIONS of fast-growing tree species have been established in many tropical countries to meet the needs for fuelwood and industrial wood, and to help relieve the pressure on harvesting of natural forests. The total area of such plantations is expanding rapidly. For example, in the decade 1982–92, there was an eightfold increase in the area under plantation forestry in Asia, from about 3.2 to over 25 million hectares (Day et al. 1994). This area is expected to increase by a further 30 million ha over the next five years. *Acacia* spp. are favoured in many of these plantation programs. For example, some 500 000 ha of *Acacia mangium* have been planted in Sumatra in the last several years; Australia, too, is experiencing an upsurge of interest in the establishment of tropical hardwood plantations, although the areas planned are smaller.

In an overview of insect pests of acacias, Hutacharern (1992) identified 34 *Acacia* species as pest-affected, with nine showing appreciable damage. She listed more than 40 pest species and noted that while none were yet serious, most were potentially hazardous. At that time insects on *A. mangium* appeared to have greatest significance in Malaysia, the Philippines and Thailand. In the latest review of the status of insect pests in tropical tree plantations in

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Asia, Day et al. (1994) listed only termites and the shoot-boring scolytid beetle *Xylosandrus compactus* Eichhoff as priority forest pests of acacias; the former damages young trees at establishment, the latter attacks *A. auriculiformis* seedlings in nurseries. However they mention 23 other insect species as being of occasional or potential importance on plantation acacias in the region.

The pest situation in many of these tropical plantations is, we believe, set to worsen. This is in response to a combination of factors such as:

- massive increase in planted area in recent years, much of it in monoculture;
- expansion of the plantations into new, sometimes marginal, areas; and
- adaptation by indigenous pests to the exotic tree species as hosts.

With eucalypts in southern China, for example, the principal author has noted that the recent rapid expansion in the plantation estate has been accompanied by a substantial increase in the number of indigenous insect species feeding on these new hosts, and increased damage.

Since these reviews there have been indications of problems emerging in several plantation areas in the region. In northern Sumatra, feeding by sap-sucking mosquito bugs *Helopeltis* spp. on new shoots of *A. mangium* has caused severe tip distortion and retardation of growth; such attack on young plantations has occurred regularly in recent years. Mosquito bugs are well known as serious pests of agricultural crops such as tea, cocoa and cinchona throughout the tropics, but have generally been regarded as of minor or potential importance for forest trees. There have been previous reports of localised severe damage by *Helopeltis* sp. to *A. mangium* in the Philippines (Luego 1990) and Malaysia (Hamid 1987), but the Sumatra occurrence is by far the most serious to date and is a cause for concern. In northern Queensland, *A. mangium* plantings have been badly attacked by longicorn beetles and tip-boring moths, and in the Philippines, Braza (1993) has recorded a stem-boring cossid moth *Xyleutes* sp. in *A. mangium*. Several insects in this genus are important pests of teak, *Gmelina* and other tree species in Asia (Wylie 1993) and of eucalypts in Australia (Wylie and Peters 1993).

Day et al. (1994) in their review of Asian tree pests assert that lack of quantitative data on pest impacts is a major hindrance in the recognition of problems and the identification of research priorities. Another hindrance is the difficulty in obtaining up-to-date pest information because of factors such as the rapid changes in the plantation resource, the time delay in publishing, and the fact that much of the activity in progress is not known internationally and may never be published. To begin addressing some of these issues, a collaborative, ACIAR-funded project has recently commenced, involving Australia, Indonesia, Malaysia, Thailand and Vietnam.

Project Objectives and Methodology

Project staff are conducting systematic investigations of the current status of insect pests in plantations of tropical acacias (and also eucalypts) in the participating countries, with the aims of:

- determining the key pests occurring on these species;
- reporting on their distribution and impact on plantation health and growth; and
- developing systems and networks which can form the basis for ongoing pest assessment in the region.

In each of the collaborating countries, insect pest surveys will be conducted in *Acacia* plantations across a range of species, provenances, ages, geographical locations, site conditions and times of year using standardised data collecting methods. A Forest Health Surveillance Field Form used by the Queensland Forestry Research Institute has been modified for this purpose, and an associated database developed for information storage and exchange. The range of sites sampled and the frequency of visits will be dependent on factors such as resources and time available, and this will in turn influence the degree to which extrapolation to the national level can be made. However in arriving at a country overview, the literature and information from local researchers will supplement the surveys. Taxonomic identification of collected specimens will be performed by the project scientists with the assistance of the Australian National Insect Collection and other institutions as required.

Current State of Knowledge

The Project commenced with a workshop for key participants, held at the Center for International Forestry Research (CIFOR) at Bogor in Indonesia in May 1997 to refine the methodology for the surveys and to review the latest pest information. Participants were asked to list the main pest species on *Acacia* in their countries, and to rank them in order of their importance. The results are presented in Table 1, and discussed briefly below.

Australia

The bag shelter moth or processionary caterpillar *Ochrogaster lunifer* Herrich-Schaffer is widely distributed in Australia and is one of the most common acacia defoliators. It derives its common names from

Table 1. Main pest species of tropical *Acacia* (as ranked in order of importance by participants at the project workshop in Bogor, Indonesia, May 1997.)

Pest insect	Order	Family	Main hosts	Type of damage
Australia				
1. *Ochrogaster lunifer* Herrich-Schaffer	Lepidoptera	Thaumetopoeidae	*A. mangium*, *A. crassicarpa*	Leaf feeding
2. *Penthea pardalis* (Newm.)	Coleoptera	Cerambycidae	*A. mangium*	Stem boring
3. *Platyomopsis* sp. nr *albocincta* (Guerin-Meneville)	Coleoptera	Cerambycidae	*A. aulacocarpa*	Ringbarking of stems and branches
4. *Cryptophlebia* sp. n.	Lepidoptera	Tortricidae	*A. mangium*	Shoot and twig boring
Indonesia				
1. *Coptotermes curvignathus* Holmgren	Isoptera	Rhinotermitidae	*A. mangium*	Root and stem feeding
2. *Xylosandrus* spp.	Coleoptera	Scolytidae	*A. mangium*	Stem boring
3. *Pteroma plagiophleps* Hampson	Lepidoptera	Psychidae	*A. mangium*	Leaf feeding
4. Unidentified	Lepidoptera		*A. mangium*	Leef feeding
5. *Valanga nigricornis* Burmeister	Orthoptera	Acrididae	*A. mangium*	Twig and leaf feeding
6. *Locusta* sp.	Orthoptera	Acrididae	*A. mangium*	Twig and leaf feeding
7. *Helopeltis theivora* Waterhouse	Hemiptera	Miridae	*A. mangium*	Tip sucking
Malaysia				
1. *Coptotermes curvignathus* Holmgren	Isoptera	Rhinotermitidae	*A. mangium*	Root and stem feeding
2. *Microcerotermes dubius* Haviland	Isoptera	Termitidae	*A. mangium*	Stem feeding
3. *Xylosandrus crassiuschulus* Motschulsky	Coleoptera	Scolytidae	*A. mangium*	Stem boring
4. *Nasutitermes matangensis* Haviland	Isoptera	Termitidae	*A. mangium*	Stem feeding
5. *Eurema* spp.	Lepidoptera	Pieridae	*A. mangium*	Leaf feeding in nursery
6. *Xystrocera globosa* Olivier	Coleoptera	Cerambycidae	*A. mangium*	Stem boring
7. *Platypus pseudocupulatus* Schedl	Coleoptera	Scolytidae	*A. crassicarpa*	Stem boring
Thailand				
1. *Sinoxylon* spp.	Coleoptera	Bostrychidae	*A. auriculiformis*, *A. mangium*	Stem and twig boring
2. *Indarbela* sp.	Lepidoptera	Metarelidae	*A. auriculiformis*, *A. mangium*	Bark feeding
3. *Zeuzera coffeae* Nietner	Lepidoptera	Cossidae	*A. auriculiformis*, *A. mangium*	Stem and twig boring
Vietnam				
1. *Brachytrupes portentosus* Lichtenstein	Orthoptera	Gryllidae	*A. mangium* × *A. auriculiformis*	Root collar feeding
2. *Odontotermes* spp.	Isoptera	Termitidae	*Acacia* spp.	Root and stem feeding
3. *Agrotis ipsilon* Hufnagel	Lepidoptera	Noctuidae	*Acacia* spp.	Leaf feeding and stem feeding on nursery stock
4. *Empoasca flavescens* Fabricius	Hemiptera	Jassidae	*Acacia* spp.	Sapsucking on nursery stock
5. *Eurema hecabe* Linnaeus	Lepidoptera	Pieridae	*Acacia mangium*	Leaf stock mainly on nursery stock

the habit of living gregariously in large silken bags in the canopy, or in a silken 'nest' at the base of an attacked tree, and then leaving this shelter at night in a procession to feed on foliage. It is estimated that the amount of foliage consumed by caterpillars from a single nest over the duration of their larval period is equivalent to that occurring on a 2 m high acacia (Van Schagen et al. 1992). This insect has caused occasional damage in coastal plantations of *A. mangium* in Queensland.

A recent, and increasingly important, pest in plantations is the longicorn beetle *Penthea pardalis* (Newman) which attacks *A. mangium* and *A. aulacocarpa*. The adult chews and tears the bark and outer sapwood on stems and branches with its powerful mandibles, leaving jagged scars up to 1 m long and

1–3 cm wide. The female then lays her eggs into the torn wood and the larvae tunnel in the stem. At one site in north Queensland in early 1997, 56 out of 300 *A. aulacocarpa* trees were attacked by *P. pardalis*. Another longicorn beetle, *Platyomopsis* sp. nr *albocincta* (Guerin-Meneville), ringbarks branches and sometimes the leader of *A. mangium* and *A. aulacocarpa*. Damage can be locally severe.

A shoot and twig boring moth *Cryptophlebia* sp. n. was listed as fourth in order of importance at the Bogor meeting in May 1997. Since then it has been found attacking one-year-old seed orchards of *A. mangium* at Glenbora and Meunga in northern Queensland, with 100% of trees being affected. Almost every shoot on these trees was tunnelled by the tortricid larvae resulting in dieback, loss of apical dominance and 'bushing' of the trees. At the Meunga site, *A. auriculiformis* of the same age was not attacked by the moth but its form was similarly devastated by the tip-sucking crusader bug *Mictis profana* (Fabricius). Crusader bug is a known pest of acacias in Queensland, but this is the most serious attack observed to date. Almost 100% of the trees were affected, with up to 50 bugs in all stages of development on some trees. The incidence of tip attack was 2–95% with an average of around 25%.

Indonesia

The termite *Coptotermes curvignathus* Holmgren tunnels in roots and stems and can cause tree mortality. Most damage occurs in the first year after planting, and the principal author has noted that in some young *A. mangium* plantations in central Sumatra 10–50% of trees have been affected(Wylie, unpublished data). The scolytid *Xylosandrus compactus* killed about 6000 seedlings of *A. auriculiformis* in south Kalimantan in 1981 and was listed as a priority pest by Day et al.(1994). Wong (1993) mentioned caterpillars of the moths *Spodoptera* sp. and *Euproctis* sp. as frequent defoliators of 2–12-month-old *A. mangium* stands in Indonesia, but noted that the trees recovered quickly. *Valanga nigricornis* Walker is widely distributed in East Asia, and is a pest of agricultural crops as well as forest trees (Browne 1968); species of *Locusta* have also severely damaged *A. mangium* in Malaysia (Khamis 1985). As mentioned above, severe tip distortion of young (usually 6–18-months-old) *A. mangium* caused by mosquito bugs, principally *Helopeltis theivora* Waterhouse, has occurred frequently in central Sumatra over the past several years resulting in 'bushing' and retardation of growth.

Malaysia

Like Indonesia, the most important pest on *A. mangium* in Malaysia is the termite *Coptotermes curvignathus*. In a survey by Chew (1987) of 5-year-old *A. mangium*, 17% of trees were infested, and in another by Khamis (1982) of 10-year-old *A. mangium*, 23% were infested. Two other termites, *Microcerotermes dubius* Haviland and *Nasutitermes matangensis* Haviland, both arboreal nesting, infest *A. mangium* in plantations in Sabah; the latter also attacks *Acacia* hybrid (Chey 1996). The ambrosia beetle *Xylosandrus crassiusculus* Motschulsky tunnels in the sapwood and sometimes the heartwood of living *A. mangium*, and the fungus which it introduces stains the wood black. Larvae of pierid butterflies *Eurema hecabe* Linnaeus and *E. blanda* Boisduval periodically defoliate seedlings and trees of *A. mangium* in Sabah (Khamis 1982; Chey 1987). *Platypus pseudocupulatus* Schedl. attacks *A. crassicarpa* A. Cunn. ex Benth trees in Sabah, with up to 70% of trees infested at some sites (Chey 1996). The trees are not killed, but the tunnels penetrate deep into the heartwood and there is considerable staining caused by the ambrosia fungus which the beetles carry.

Thailand

Auger beetles *Sinoxylon* spp. have caused significant damage to *A. auriculiformis* and *A. mangium*, girdling stems and branches of trees up to two years old (Hutacharern 1992). When the point of attack is at ground level, the tree dies. *Indarbela* spp. wood moths feed on bark and are recorded as pests of several tree species in Asia. In a heavy infestation the greater part of the outer bark of the stem may be destroyed. Trees are not directly killed, but the injury results in loss of vigour and exposure to infection by secondary organisms (Browne 1968). The cossid wood moth *Zeuzera coffeae* Nietner is an important pest of horticultural crops throughout Asia, and has also caused severe damage to forest tree species. For example, *Z. coffeae* rendered post-war plantations of *Eucalyptus deglupta* Blume in Malaysia useless (Edwards 1953).

Vietnam

The field cricket *Brachytrupes portentosus* Lichtenstein damages seedlings at the nursery stage or just after planting in the field by chewing the root collar. Two of the authors of this paper, Kha and Do, noted that in 1996, more than 10% of newly-planted *A. mangium* × *A. auriculiformis* were attacked by this insect and replacement planting was necessary. *Odontotermes formosanus* Shiraki and *O. hainanensis* Light damage roots and stem of *Acacia* spp. in

1–2-year-old plantations, and are most severe on sites where the forests have just been harvested. The cutworm *Agrotis ipsilon* Hufnagel is a common pest of nursery stock throughout Asia and the Pacific (Browne 1968). The larvae hide in the soil by day and feed by night, cutting young seedlings off at ground level or removing buds and leaves.

Discussion

To the present, with the exception of termites, insects have not been regarded by forest managers as significant threats to acacia plantations. One of the reasons for this may be that economic losses have not been fully quantified. There has been a tendency to underestimate the impact of pest attack which does not result in outright tree mortality (Wylie and Arentz 1993). However, studies of chronic defoliation by the chrysomelid beetle *Chrysophtharta bimaculata* (Olivier) in young eucalypt plantations in Australia have revealed a 40–50% annual reduction in growth increment (Candy et al. 1992; Elliott et al. 1992). Projections suggest that even a few defoliation episodes over a normal pulpwood rotation would make the plantation economically non-viable. Similar results have been reported from India, where it was shown that defoliation of teak plantations by larvae of the hyblaeid moth *Hyblaea puera* Cramer resulted in loss of over 40% of the potential volume increment (Nair et al. 1985). It was estimated that plantations protected from this pest could be harvested at about 26 years instead of the usual 60 years.

One of the main aims in conducting these systematic insect pest surveys in *Acacia* plantations throughout the region is to gather quantitative data wherever possible on pest impacts. In many cases this will be a basic assessment of incidence and severity, but it should allow comparisons to be made on the relative importance of different pests throughout the region. The baseline information presented in Table 1 is likely to change as the surveys proceed and data accumulate. Already, the pest rankings for Australia may need revision in the light of the severity of recent attack by *Cryptophlebia* sp. and *Mictis profana* on acacias in north Queensland.

Information obtained from the surveys should assist managers in assessing and handling risk and in setting research priorities. It is hoped that the systems developed in this initial phase will form the basis for ongoing pest assessment and will be extended to other countries in the region. The possibility of collaborative research on shared pest problems arises from this work. A further potential benefit is better forestry quarantine and early warning of pest threats.

References

Braza, R.D. 1993. Bee-hole borer is a destructive pest of *mangium*. PCARRD Monitor, 21, 6–7.

Browne, F.G. 1968. Pests and Diseases of Forest Plantation Trees. Clarendon Press, Oxford.

Candy, S.G., Elliott, H.J., Bashford, R. and Greener, A. 1992. Modelling the impact of defoliation by the leaf beetle *Chrysophtharta bimaculata* (Coleoptera: Chrysomelidae) on height growth of *Eucalyptus regnans*. Forest Ecology and Management, 54, 69–87.

Chew, T.K. 1987. Assessment of termite attack and heart rot on thinned *Acacia mangium* trees. Forestry Department, Kuala Lumpur, Unpublished Report, 2 p.

Chey, V.K. 1987. Insect defoliators of forest plantation trees in Sabah. Forest Research Centre, Sepilok, Sabah FRC, Publication No. 32.

Chey, V.K. 1996. Forest insect pests in Sabah. Sabah Forest Record No. 15. Sabah Forest Department, Sandakan.

Day, R.K., Rudgard, S.A. and Nair, K.S.S. 1994. Asian tree pests: an overview. FORSPA Publication 12.

Edwards, J.P. 1953. Report on Federal Forest Administration in the Federation of Malaya for the year 1952. Government Press, Kuala Lumpur.

Elliott, H.J., Bashford, R., Greener, A. and Candy, S.G. 1992. Integrated pest management of the Tasmanian eucalyptus leaf beetle *Chrysophtharta bimaculata* (Olivier) (Coleoptera: Chrysomelidae). Forest Ecology and Management, 53, 29–38.

Hamid, A.A. 1987. Insect pests of Acacia *mangium* Willd. in Sarawak. Forest Department Sarawak, Malaysia, Forest Research Report FE 1, 10 p.

Hutacharern, C. 1992. Insect pests of acacias: an overview. In: Awang, K. and Taylor, D.A., ed., Tropical acacias in East Asia and the Pacific. Proceedings of the First Meeting of the Consultative Group for Research and Development of Acacias (COGREDA) held in Phuket, Thailand, June 1–3, 1992, Winrock International Institute for Agricultural Research.

Khamis, S. 1982. Pests and diseases of forest plantation trees with special reference to SAFODA. Paper to 8th Malaysian Forestry Conference, Kelapan.

Khamis, S. 1985. Pests of *Acacia mangium* trees and their control. SAFODA, Kota Kinabalu.

Luego, J.N. 1990. Mirid bugs (*Helopeltis* sp.): a threat to *Acacia mangium*. Nitrogen Fixing Tree Research Reports, 8, 105-106.

Nair, K.S.S., Sudheendrakumar, V.V., Varma, R.V. and Chacko, K.C. 1985. Studies on the seasonal incidence of teak defoliators and the effect of defoliation on volume increment of teak. KFRI Research Report 30, Kerala Forest Research Institute, Peechi, India.

Van Schagen, J.J., Hobbs, R.J. and Majer, J.D. 1992. Defoliation of trees in roadside corridors and remnant vegetation in the Western Australian wheatbelt. Journal of the Royal Society of Western Australia, 75 (3), 75–81.

Wong, C.Y. 1993. Acacias for industries. Paper to Second meeting of Consultative Group for Research and Development of Acacias (COGREDA), Udorn Thani, Thailand, 15–28 February, 1993.

Wylie, F.R. 1993. Pests and diseases of fast-growing hardwoods in industrial forest plantations in the Philippines. Asian Development Bank, Manila, 47 p.

Wylie, F.R. and Arentz, F. 1993. Management of pests and diseases in tropical forestry. Centre for International Forestry Research Strategic Planning Thematic Paper No. 14. ACIAR, Canberra.

Wylie, F.R. and Peters, B.C. 1993. Insect pest problems of eucalypt plantations in Australia. 1. Queensland. Australian Forestry, 56, 358–362.

Insect Damage on *Acacia mearnsii* in China

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Abstract

Herbivore exclusion trials of *Acacia mearnsii* De Wild. were established in Fujian Province, China from 1994 to 1996. Exclusion was effected by spraying half the trees with insecticide. The incidence and damage of insect species and growth performance of the trees were assessed at fixed intervals. Surveys for insects in plantations were also conducted. Over 70 insect species were found on *A. mearnsii*, all of which were indigenous except the cottony cushion scale (*Icerya purchasi* Maskell). This study identified a number of potentially serious pests of *A. mearnsii* and presented some evidence for effective natural biological control. Although insect pest numbers were generally low in the trials, which may have been partly due to natural biological control, serious effects of herbivore damage on tree survival and productivity were detected.

BLACK WATTLE, *Acacia mearnsii* De Wild., a native of Australia, was introduced into China in the early 1950s. As a result of two projects on the silviculture and utilisation of *A. mearnsii*, funded by the Australian Centre for International Agricultural Research (ACIAR) and carried out by CSIRO Division of Forestry and the Chinese Academy of Forestry (CAF) Research Institute of Subtropical Forestry, *A. mearnsii* is now being successfully grown in large scale plantations in southern China mainly to produce tannin extractives.

Numerous insects have been recorded on *A. mearnsii* in Australia (Van den Berg 1982 a,b,c), South Africa (Hepburn 1966; Sherry 1971; Anon 1975, 1982, 1983), and China (Wang 1987a,b; Chen et al. 1990, 1994; Cai et al. 1992). In Australia the fireblight beetle, *Acacicola orphana* (Erichson), is the most serious pest and can have devastating effects on *A. mearnsii* and *A. dealbata* Link. (Elliott 1978). The African wattle bagworm (*Cryptothelea junodi* (Heylaerts)) is the most serious pest of *A. mearnsii* in South Africa (Sherry and Ossowski 1967; Hepburn 1973).

In China, damage caused by various species of termites, case moths (*Clania* spp. and others), cottony cushion scale (*Icerya purchasi* Maskell), oriental tussock moth (*Orgyia postica* (Walker)) and various noctuid caterpillars, is an important factor restricting the growth and productivity of *A. mearnsii*. Consequently, a project supported by ACIAR and carried out by CAF Research Institute of Subtropical Forestry and CSIRO Entomology was established to further study insect pests of *A. mearnsii* in Australia and China. Some preliminary results of the project are summarised in this paper.

Materials and Methods

Three herbivore exclusion trials were established at Meishan Branch of Yanxi Forest Farm, Changtai County, Fujian Province between 1994 and 1996 to measure the effect of insect feeding on *A. mearnsii* growth. Each trial was a split-plot design, with half the trees sprayed with insecticide. Insecticide treatments were carried out every two weeks from June to October each year. Trials 1 and 2 comprised 18 seedlots of *A. mearnsii* in three or four replicates, and the species trial included 8 seedlots of *Acacia* spp. in four replicates. Seeds used in the trials were provided by the Australian Tree Seed Centre.

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Monitoring of insect numbers and damage was carried out in the middle of June, August and October each year. Two observers searched each tree for 30 seconds to count the number of insects present on the tree. The level of defoliation attributed to a particular insect herbivore was visually assessed as a percentage of total foliation. When multiple observers were being used, estimates of defoliation were cross-checked at intervals on common trees.

Weekly monitoring of insect species and abundance were conducted in two ways. Firstly, weekly visual assessments were carried out in one unsprayed block in trials 1 and 2, and secondly, weekly surveys were conducted by beating buffer trees in trial 1. Three or four branches of each tree were beaten three or four times, and all insects that fell onto a white sheet beneath the tree were identified and counted. Ten trees were surveyed on each occasion.

Other plantations of *A. mearnsii* in the Zhangzhou area were visited and surveyed at irregular intervals for insect damage. A plantation at Banli, Changtai County was assessed at regular intervals following the discovery of an outbreak of *I. purchasi* and case moths (*Clania* sp.). Two marked plots, each containing 25 trees, were assessed monthly for the number of case moths and the percentage defoliation of each tree.

The height, girth and form of each tree in the three herbivore exclusion trials were assessed at least once each year, generally in winter. Tree form was scored using a scale from 0 to 5, with 0 indicating a dead tree and 5 denoting excellent form (single straight stem and light lateral branching).

A relational database was designed in Microsoft Access and included entry forms for efficient data entry. All data were entered into the database for storage, consistency checking, and manipulation. Preliminary analysis and graphical representation of the data were performed using Access and Excel.

Results

More than 70 insect species were recorded on *A. mearnsii* in the experimental trials, of which 54 were identified (Table 1). Most (83%) were herbivores, with natural enemies making up the remaining 17%. The herbivorous insects were dominated by lepidopteran leaf-feeders (60% of herbivores) and a range of hemipteran species (24%). Species of natural enemies were evenly distributed across the orders Hymenoptera, Diptera, Hemiptera, Coleoptera, Mantodea and Aranea.

The number of insects belonging to the herbivore and natural enemy functional groups varied with season and from year to year (Figure 1). More insects were found in summer than winter, and in 1995 than 1994. The most abundant herbivorous insect species included a range of lepidopteran caterpillars (*Spirama retortum* (Linn.), *Kerala* sp., *Semiothisa* spp., *Buzura suppressaria* (Guenée), *Adoxophyes orana* (Fischer von Röslerstamm), *O. postica*, various sap-sucking hemipterans (*I. purchasi*, *Anoplocnemis phasiana* Fabricius, *Erthesina fullo* (Thunberg), and several orthopterans (*Chondracris rosea* (De Geer) and *Quilta mitrata* (Stal.)).

Table 1. Insect species found on *Acacia mearnsii* in experimental trials and at monitoring sites in Fujian Province, China.

Order	Family	Insect scientific name
Araneida		To be identified
Coleoptera	Cerambycidae	To be identified
Coleoptera	Coccinellidae	To be identified
Coleoptera	Coccinellidae	*Rodolia pumila* Weise
Coleoptera	Curculionidae	*Hypomeces squamosus* Fabricius
Coleoptera	Scarabaeidae	*Holotrichia lata* Brenske
Coleoptera	Scarabaeidae	*Anomala cupripes* Hope
Coleoptera	Scarabaeidae	*Popillia mongolica* Arrous
Diptera	Tachinidae	*Exorista civilis* Rondani
Diptera	Tachinidae	*Nealsomyia rufella* Bezzi
Hemiptera	Coreidae	To be identified
Hemiptera		To be identified
Hemiptera	Coreidae	*Anoplocnemis phasiana* Fabricius
Hemiptera	Coreidae	*Riptortus pedestris* (Fabricius)
Hemiptera	Fulgoridae	*Lawana imitata* Mell.
Hemiptera	Fulgoridae	*Pyropa candelaria* (L.)
Hemiptera	Margarodidae	*Icerya purchasi* Maskell
Hemiptera	Pentatomidae	*Cantheconidea furcellata* Wolff
Hemiptera	Pentatomidae	*Dalpada smaragdina* (Walker)
Hemiptera	Pentatomidae	*Erthesina fullo* Thunberg
Hemiptera	Pentatomidae	*Nezara viridula* Linn.
Hemiptera	Reduviidae	To be identified
Hemiptera	Reduviidae	*Isyndus reticulatus* Stal.
Hemiptera		To be identified
Hemiptera	Cicadidae	*Cryptotympana atrata* (Fabricius)
Hymenoptera	Chalcididae	*Brachymeria lasus* (Walker)
Hymenoptera	Chalcididae	*Brachymeria secunadaria* (Ruschka)
Hymenoptera	Various	To be identified
Isoptera	Termitidae	*Odontotermes formosanus* (Shiraki)
Isoptera	Termitidae	*Macrotermes barneyi* Ligh.
Isoptera	Termitidae	*Capritermes nitobei* Shiraki
Lepidoptera	Arctiidae	*Amata* sp.
Lepidoptera	Cossidae	To be identified
Lepidoptera	Drepanidae	*Agnidra ataxia* Chu et Wang
Lepidoptera	Geometridae	To be identified
Lepidoptera	Geometridae	To be identified
Lepidoptera	Geometridae	To be identified
Lepidoptera	Geometridae	To be identified
Lepidoptera	Geometridae	*Buzura suppressaria* (Guenée)
Lepidoptera	Geometridae	*Comibaena quadrinotata* (Butler)
Lepidoptera	Geometridae	*Hemithea marina* (Butler)
Lepidoptera	Geometridae	*Ophthalmitis sinensium* Oberthur
Lepidoptera	Geometridae	*Phthonosema tendinosaria* (Bremer)
Lepidoptera	Geometridae	*Pingasa pseudoterpnaria* (Guenée)
Lepidoptera	Geometridae	*Semiothisa defixaria* (Walker)
Lepidoptera	Geometridae	*Semiothisa hebesata* (Walker)
Lepidoptera	Lithosiidae	*Neasura nigroanalis* Matsumura

Table 1. (continued)

Order	Family	Insect scientific name
Lepidoptera	Lymantriidae	To be identified
Lepidoptera	Lymantriidae	*Calliteara grotei* (Moore)
Lepidoptera	Lymantriidae	*Orgyia postica* (Walker)
Lepidoptera	Lymantriidae	*Porthesia scintillans* (Walker)
Lepidoptera	Noctuidae	*Hulodes caranea* (Cramer)
Lepidoptera	Noctuidae	Kerala sp.
Lepidoptera	Noctuidae	*Selepa celtis* Moore
Lepidoptera	Noctuidae	*Spirama retortum* (Linn.)
Lepidoptera	Notodontidae	*Stauropus alternus* Walker
Lepidoptera	Nymphalidae	*Polyura athamas* (Moore)
Lepidoptera	Psychidae	*Chalioides kondonis* Matsumura-Kondo
Lepidoptera	Psychidae	*Clania crameri* (Westwood)
Lepidoptera	Psychidae	*Clania variegata* (Snellen)
Lepidoptera	Psychidae	*Eumeta minuscula* (Butler)
Lepidoptera	Pyralidae	*Cryptoblabes* sp.
Lepidoptera	Pieridae	*Eurema hecabe* (Linnaeus)
Lepidoptera	Tortricidae	*Adoxophyes orana* (Fischer von Röslerstamm)
Lepidoptera	Tortricidae	*Hoshinoa longicellana* (Walsingham)
Mantodea	Mantidae	To be identified
Orthoptera	Acrididae	*Chondracris rosea* (De Geer)
Orthoptera	Acrididae	*Quilta mitrata* (Stal), etc
Orthoptera	Gryllidae	*Tarbinskiellus portentosus* Lichtenstein

Natural enemies comprised about 20% of all insects counted on *A. mearnsii* in the experimental trials. The most common species were predatory hemipterans (*Cantheconidea furcellata* Wolff, *Isyndus reticulatus* Stal.), coccinelid beetle larvae (*Rodolia pumila* Weise), an unidentified mantis, various species of spiders, and many hymenopteran parasitoids (e.g. *Brachymeria lasus* (Walker), *B. secunadaria* (Ruschka)). Some natural enemies, such as *C. furcellata*, were abundant in the first year after establishment, and then declined; other species, such as spiders, *R. pumila* and *Brachymeria* spp., increased with the age of the plantation.

The most significant insect pests in the trials were termites that attacked the root system of newly transplanted seedlings (*Odontotermes formosanus* (Shiraki), *Macrotermes barneyi* Ligh., *Capritermes nitobei* Shiraki). Termites caused the death of 38% of trees in trial 1, and 48% of the original planting of trial 2 which lead to its total replanting.

Damage caused by other herbivorous insects was low. The average defoliation of unsprayed trees in trial 1 was only about 4% with greater defoliation in summer than winter. The damage was evenly attributed to leaf-rolling caterpillars, sap-sucking bugs, grasshoppers and tip damage of an unknown

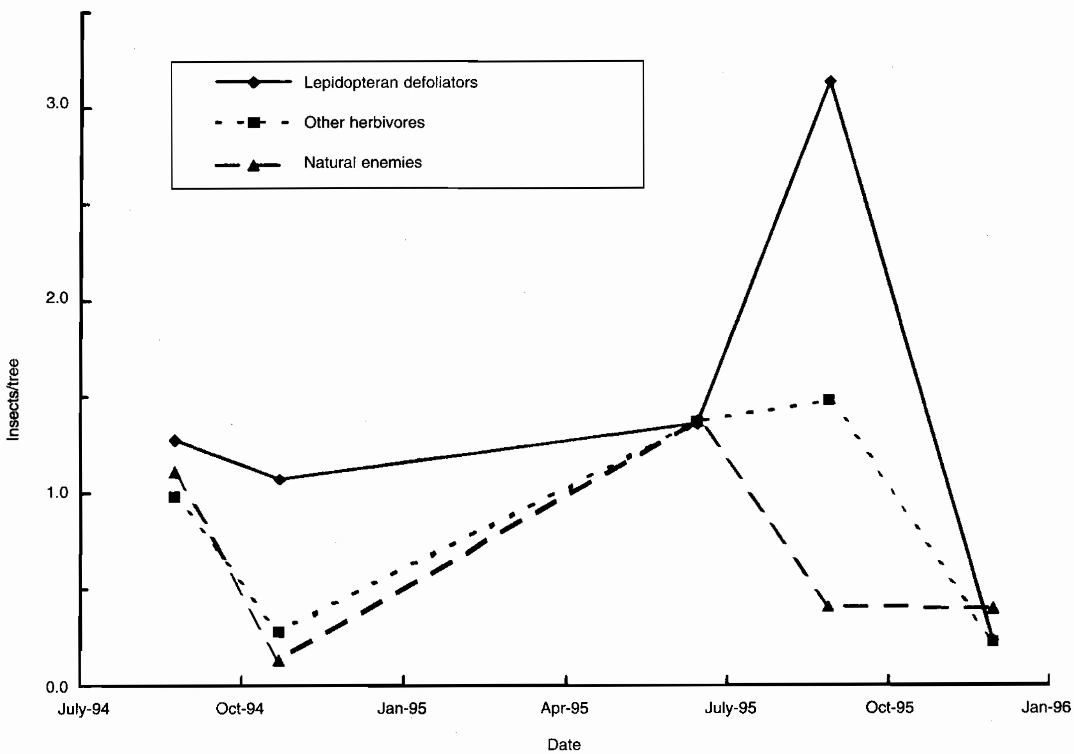

Figure 1. Mean number of insects per tree for three functional/taxonomic groupings in an experimental trial of *Acacia mearnsii* at Meishan, Fujian Province, China.

cause. The tip damage may have been caused by noctuid and geometrid caterpillars, which feed on young leaves at branch tips at night and stay on lower branches during the day. Noctuid and geometrid species accounted for about 35% of the total insect numbers.

Although insect numbers and defoliation levels were not high, trees sprayed with insecticide were taller and had a larger girth than unsprayed ones (Table 2). Preliminary analysis of the defoliation and tree growth data suggests that growth may be directly affected by the level of tip damage, presumed to be caused by lepidopteran larvae. Trees that experienced the greatest shoot tip damage (<10%) have a significantly lower average height than those with little or no shoot tip damage (Figure 2).

Table 2. Average growth and form scores for 2.7 year-old *Acacia mearnsii* when sprayed with insecticide or left unsprayed.

Treatment	Height (m)	Girth (cm)	Form
Sprayed	5.63	11.74	2.95
Unsprayed	5.33	8.30	2.68

There is a strong suggestion from the weekly monitoring of insect numbers that some of the herbivorous insects are effectively under natural biological control. It was often observed that the coccinelid *R. pumila* was a common predator of *I. purchasi*. The weekly monitoring data (Figure 3) illustrate that the *R. pumila* abundance closely tracked the abundance of *I. purchasi* with a lag of a couple of weeks. Similarly there was an outbreak of the cottony cushion scale in a plantation at Banli, Changtai which also appeared to be naturally controlled by the same predator. Weekly monitoring also showed that abundance of spiders generally followed that of lepidopteran larvae. Significant natural control and limited opportunity for invasion of pest species are considered the major reasons for low populations of pest insects in the provenance trials of *A. mearnsii*.

A plantation of *A. mearnsii* established in 1992 at Banli, Changtai County, Fujian Province was heavily attacked by both *I. purchasi* and case moths (*Clania* spp. and *Chalioides kondonis* Matsumura) in 1995. The *I. purchasi* outbreak was found in June and disappeared by September following the increase in numbers of the predacious coccinelid, *R. pumila*.

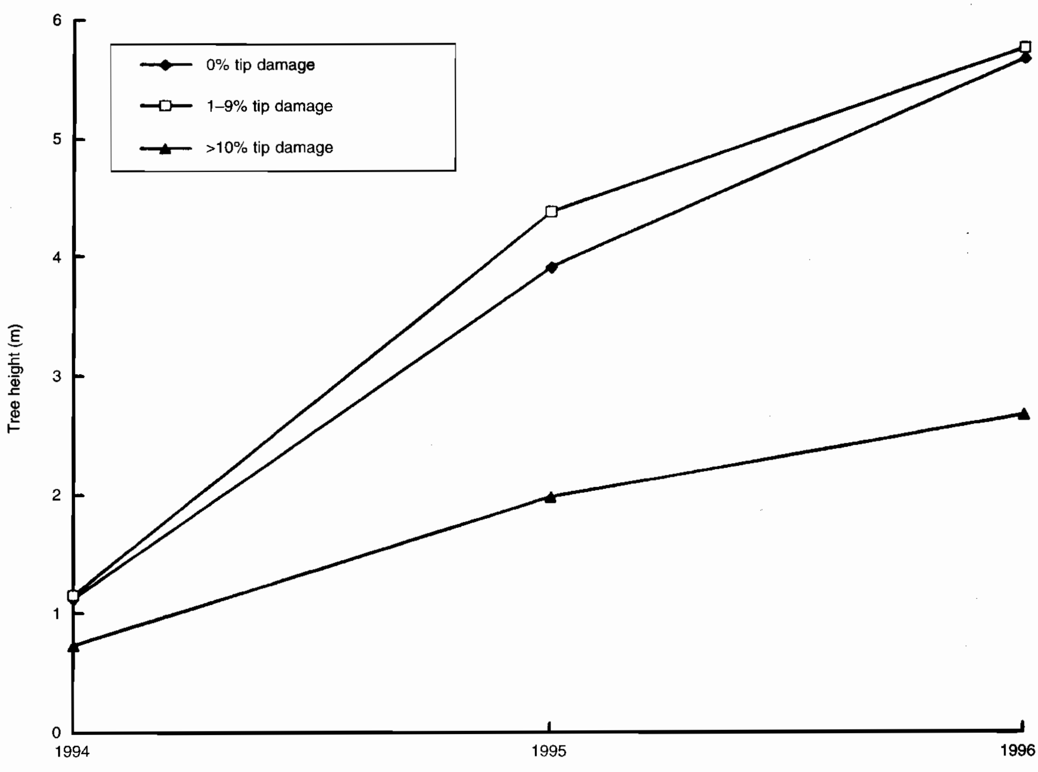

Figure 2. Mean height of *Acacia mearnsii* trees that experienced different levels of shoot tip damage in the first yearof growth.

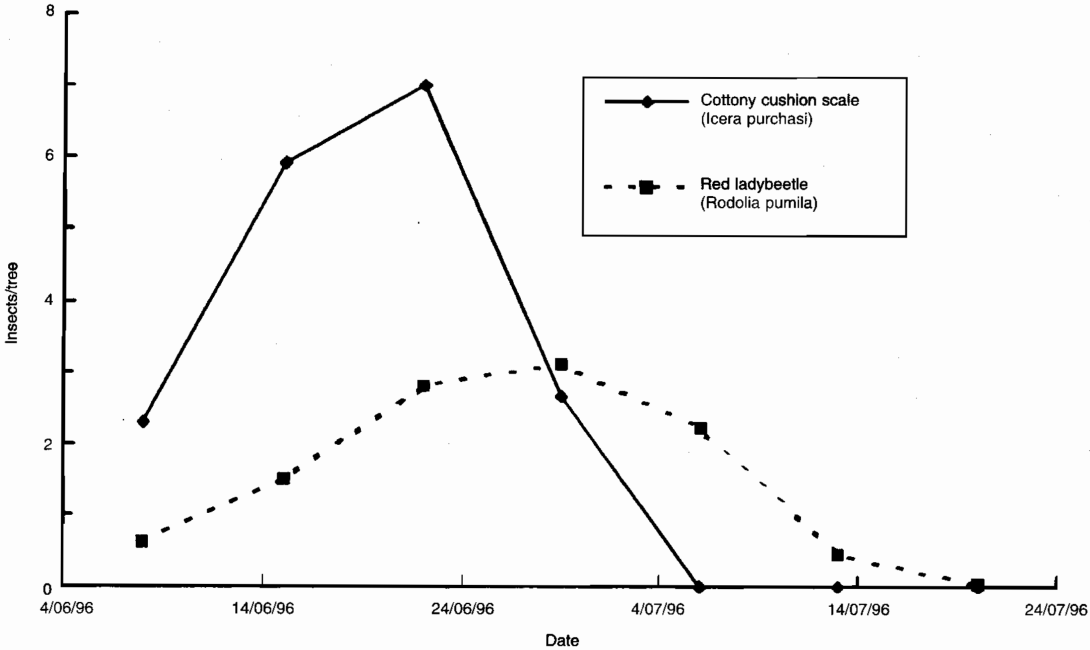

Figure 3. Mean numbers per tree of predator (*Rodolia pumila*) and prey (*Icerya purchasi*) insects suggesting effective biological control of a herbivorous pest.

High densities of case moth followed the decline of *I. purchasi*. Regular monitoring of the case moth numbers and foliage damage showed a sharp decline in numbers from 65 to 23 case moths per tree in the most severely infested plot. These trees have since recovered with foliation increasing from 40 to 90%. Both *I. purchasi* and case moths have significantly affected tree performance in the plantation, leading to some tree mortality, while most of the surviving trees showed poor vigour and appearance; they subsequently recovered with new foliage.

Discussion

This study illustrates the significant threat of herbivorous insect damage to *A. mearnsii* in plantations in China. More than 60 pest insect species have been recorded, with the most important species being a number of species of termites, case moth, cottony cushion scale, oriental tussock moth, and various noctuid and geometrid caterpillars. Although insect numbers have been very low in the trials, their damage has resulted in poor tree form and reduced growth in both height and girth. Although not reported in this paper, there are also differences in insect incidence and tree performances between seedlots of *A. mearnsii* and its allies tested in the trials.

The number of species and individuals of natural enemies in the trials was high and many examples of predation and parasitism of key insect herbivores were observed. It appears that substantial natural control of pest insects has occurred in both the project trials and other plantations. This could explain the low numbers of pest insects in the first three years of the trials. However, severe defoliation by case moths has occurred, and is continuing to occur, in plantations up to at least 15 years old.

The project study has achieved a basic understanding of insect pest problems of *A. mearnsii* in Fujian Province, China. Further studies of highly damaging species such as termites, case moths, cottony cushion scale and oriental tussock moth are required. Effective and practical control measures are urgently needed. Current results suggest that the use or encouragement of natural enemies might be an important component in an integrated pest management program for *A. mearnsii*. The roles of insect-resistant genotypes in the program and screening of provenances and progenies need to be further evaluated. Detailed studies of the ecology of insects and their interaction with natural enemies and host plants need to continue if a robust integrated pest management program for *A. mearnsii* is to be developed.

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References

Anon. 1975. The Wattle Research Institute Report for 1974–75, 35–36.

Anon. 1982. The Wattle Research Institute Report for 1981–82, 41–44, 75–78.

Anon. 1983. The Wattle Research Institute Report for 1982–83, 34–36, 65–66.

Chen, S., Chen, Q. and Li, Y. 1994. Bionomics of *Speriredonia retorta* Linnaeus and its control. Journal of Fujian College of Forestry, 14, 354–357.

Chen, S., Li, Y. and Lin, B. 1990. Studies on the bionomics of tussock moth, *Orgyia postica*, and its control. Journal of Fujian College of Forestry, 10, 130–136.

Cai, G., Lin, Q., Lin, J. and Dai, Y. 1992. Bionomics of *Ericeia fraterna* Moore and its control. Journal of Fujian College of Forestry, 12, 189–198.

Elliott, H.J. 1978. Studies on the fireblight beetle, *Pyrgoides orphana* (Erichson) (Coleoptera: Chrysomelidae) and its effect on the growth of silver wattle in Tasmania. Australian Forestry, 41, 160–166.

Hepburn, G.A. 1966. A revised list of wattle insects and spiders of South Africa. Wattle Research Institute Report for 1965–66, 67–82.

Hepburn, G.A. 1973. The wattle bagworm: A review of investigations conducted from 1899–1970. Wattle Research Institute Report for 1972–73, 75–93.

Sherry, S.P. 1971. The black wattle (*Acacia mearnsii* De Wild). University of Natal Press, Pietermaritzburg, South Africa.

Sherry, S.P. and Ossowski, L.L.J. 1967. The effect of defoliation by the wattle bagworm on growth and bark yield of wattle plantations. Wattle Research Institute Report for 1966–67, 46–52.

Van den Berg, M.A. 1982a. Lepidoptera attacking *Acacia dealbata* Link., *Acacia decurrens* Willd., *Acacia longifolia* (Andr.) Willd., *Acacia mearnsii* De Wild. and *Acacia melanoxylon* R. Br. in eastern Australia. Phytophylactia, 14, 43–46.

Van den Berg, M.A. 1982b. Hemiptera attacking *Acacia dealbata* Link., *Acacia decurrens* Willd., *Acacia longifolia* (Andr.) Willd., *Acacia mearnsii* De Wild. and *Acacia melanoxylon* R. Br. in Australia. Phytophylactia, 14, 47–50.

Van den Berg, M.A. 1982c. Coleoptera attacking *Acacia dealbata* Link., *Acacia decurrens* Willd., *Acacia longifolia* (Andr.) Willd., *Acacia mearnsii* De Wild. and *Acacia melanoxylon* R. Br. in Australia. Phytophylactia, 14, 51–55.

Wang, H. 1987a. Termite damage to black wattle and its control. Subtropical Forestry Science and Technology, 1, 67–70.

Wang, H. 1987b. Account of insects on black wattle in China. Report of Chinese Academy of Forestry, China.

Insect Feeding on *Acacia mearnsii* in Southeastern Mainland Australia

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Abstract

The geographic extent and severity of damage of outbreaks of *Acacicola orphana* (Erichson) (Coleoptera: Chrysomelidae) on *Acacia mearnsii* De Wild. in south-east mainland Australia were surveyed annually from 1994 to 1996. There was a marked increase in both area and severity. Outbreaks of *A. orphana* were found in western, central and eastern Victoria. The main insects causing damage to *A. mearnsii* in a series of experimental plantations in south-east Australia were *Maconellicoccus australiensis* (Green & Lidgett) (Hemiptera: Pseudococcidae), and several wood borers including a platypodine beetle and a root-feeding weevil. Various species of herbivorous insects, dominated by species of Coleoptera and Hemiptera, were found in beating samples from *A. mearnsii*. Beating samples also revealed a large number of spider and coccinelid predators which may be contributing to the relatively low levels of herbivory.

SINCE the late 1800s A*cacia mearnsii* De Wild. has been grown in experimental and small scale commercial plantings in Australia (Searle 1991), but has not yet been established as a major commercial forestry species. One of the reasons for this has been the significant risk in southeastern Australia of damage from outbreaks of the fireblight beetle *Acacicola orphana* (Erichson) (Coleoptera: Chrysomelidae) (*formerly Pyrgoides orphana*) which have been recorded at various times on *A. mearnsii* and *Acacia dealbata* Link. (French 1911; Froggatt 1923; McKeown 1942; Elliott 1978). Many other insects are known to feed on *A. mearnsii* (Van den Berg 1982a,b,c) but have rarely been observed to cause serious damage. However, if larger areas of *A. mearnsii* are to be planted, it is quite possible that some of these insects could become significant pests.

Consequently, with the support of the Australian Centre for International Agricultural Research, experimental trials were established in southeastern Australia and China to:

- measure the damage caused by herbivorous insects;
- monitor the abundance of herbivores and natural enemies in plantations; and
- assess a range of provenances for variation in insect resistance.

In addition to the trials, surveys of the extent and severity of *A. orphana* outbreaks in southeastern mainland Australia were conducted. This paper provides an overview of the results of some of these activities.

Materials and Methods

Surveys of fireblight beetle damage

In 1994 a survey route through the major *A. mearnsii* stands and associated agricultural areas of Victoria was established (Figure 1). At various sites along the route (hereafter called 'the beating sites'), insects on the trees were sampled by beating the foliage of the lower branches of 2–4 trees in a standard manner, and the amount of defoliation by various insect herbivores was estimated. All specimens collected where stored in alcohol and returned to the laboratory for sorting, identification and counting.

In addition to the beating sites, stands of *A. mearnsii* along the survey route with fireblight beetle

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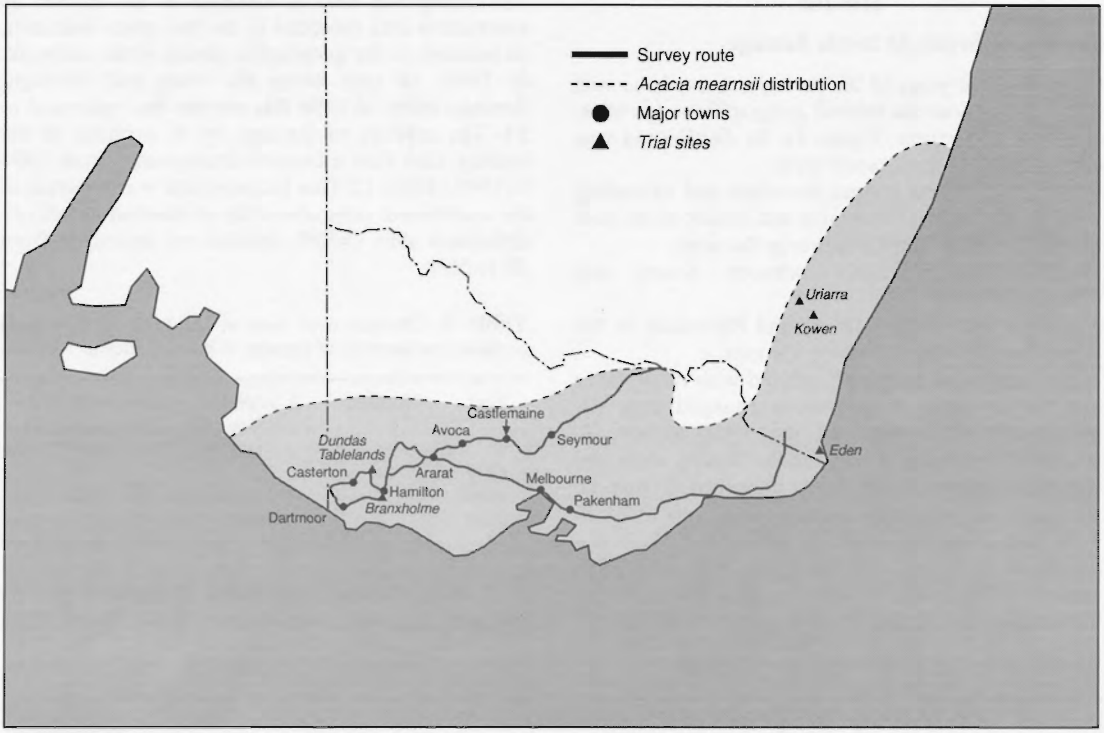

Figure 1. Route for the surveys of the intensity of damage and distribution of fireblight beetle (*Acacicola orphana*) infestations in south-east mainland Australia.

damage were also assessed (hereafter called the assessment sites). These sites were sampled in order to describe the patchiness and rate of spread of fireblight beetle infestations. For each site, the distribution and intensity of damage were estimated and recorded. Estimates of fireblight beetle damage were made at all sites by scoring foliation in intervals of 10 percentage points. Since the only sites assessed were those with significant *A. orphana* damage, averages of these results will tend to overestimate the overall severity of damage.

Insect damage in *A. mearnsii* experimental plantations

Provenance trials of *A. mearnsii* were established in 1995 at two sites in the Australian Capital Territory (ACT), two in western Victoria and one in coastal south-eastern New South Wales (NSW) (Figure 1). Tree growth (height, diameter and form) and the amount of defoliation caused by different insects and other factors were assessed for each trial in the winters of 1995, 1996 and 1997. Percentage defoliation was visually assessed in increments of 10%, with finer graduations near zero and 100%.

Beating samples at ACT trial sites

In the summer of 1996-97 the insect fauna in the buffer trees of the *A. mearnsii* trials in the ACT at Kowen and Uriarra were sampled by beating the lower branches. At each site, 36 buffer trees were chosen as permanent sampling points. Sample trees were selected to represent a wide range of provenances and to be evenly spaced throughout the site.

Trees were sampled once a month from December 1996 to April 1997. On each date all designated trees at each site were sampled using a beating tray and stick. All the lower branches of each tree were beaten a set number of times, and the resulting sample stored in alcohol and taken to the laboratory for sorting identification and counting. All specimens were identified to the lowest taxonomic level possible and assigned to one of the following functional groups: predator, parasite, herbivore, fungivore, pollen feeder or incidental.

Results

Surveys of fireblight beetle damage

Over the three years of the surveys, *A. orphana* was found throughout the natural geographic range of *A. mearnsii* in Victoria (Figure 2). Its distribution was concentrated in three broad areas:

- western, centred around Hamilton and extending to the Grampian Mountains and Ararat in the east and Dartmoor and Casterton in the west;
- central, approximately between Avoca and Seymour; and
- eastern, extending from around Pakenham in the west to the NSW border in the east.

The area of *A. mearnsii* infested with *A. orphana* and the intensity of infestation changed over the period of the surveys. In the 1994 survey, *A. orphana* was found at 38% of the beating sites and these sites tended to be widely dispersed (Figure 2). Its incidence increased dramatically from 1994 to 1995 and remained high in 1996 with incidence scores of 85% and 90% for the 1995 and 1996 surveys respectively (Table 1). In addition to the increase in the incidence of *A. orphana* at beating sites, there was also an increase in the number of assessment sites recorded in the two years indicating an increase in the geographic spread of the outbreak. In 1995, 38 sites along the route had fireblight damage, while in 1996 this number had increased to 54. The severity of damage by *A. orphana* at the beating sites also increased dramatically from 1994 to 1995 (Table 1). This increase also was apparent in the assessment sites where the proportion of heavily defoliated sites (>50% defoliation) increased from 26 to 56%.

Table 1. Changes over time in incidence of *Acacicola orphana* and severity of damage at beating sites in Victoria.

Year	Number	*A. orphana* incidence (%)	Trees with >50% defoliation (%)
1994	24	38	0
1995	26	85	15
1996	38	90	33

Greatest damage was found in central Victoria between Seymour in the east and Castlemaine in the

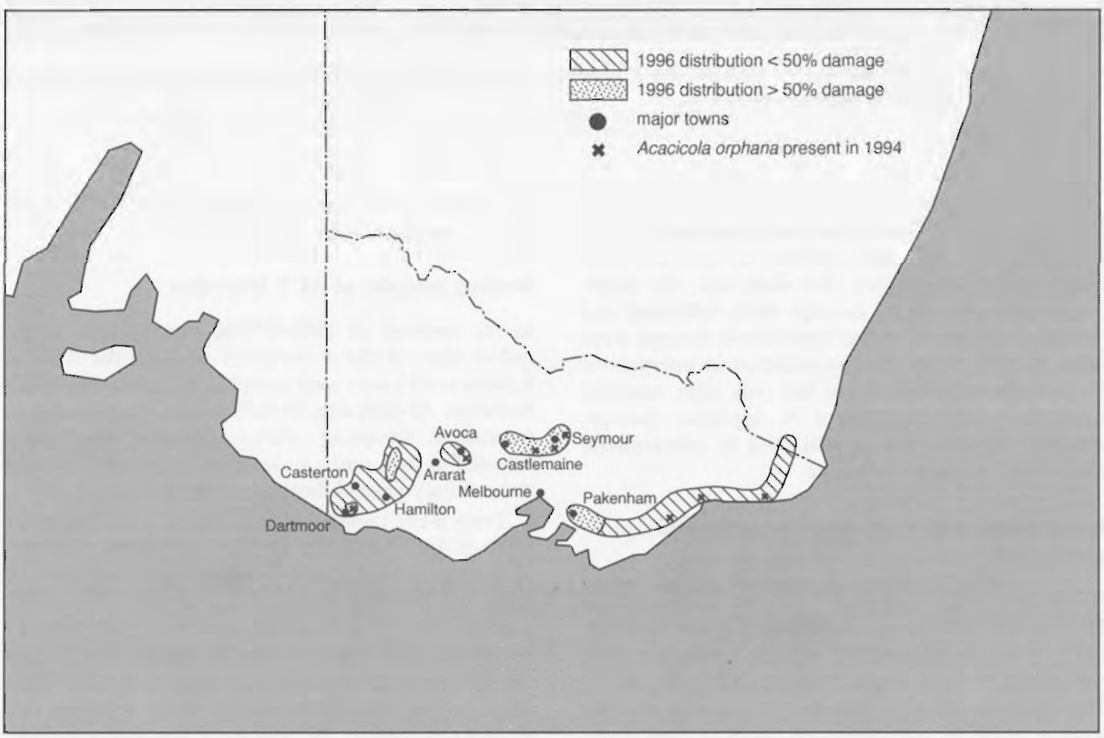

Figure 2. Distribution of fireblight beetle (*Acacicola orphana*) and severity of damage in south-east mainland Australia in 1995-96.

west, and in a pocket of *A. mearnsii* centred around Dartmoor in western Victoria. Both average damage and the geographic extent of damage in these areas increased from 1995 to 1996.

Insect damage in *A. mearnsii* experimental plantations

The amount of damage to *A. mearnsii* was low in each year, but was greatest in 1996 with average defoliation levels of up to 20% at one site. Table 2 presents the cause and amount of damage to foliage and stems for each experimental plantation in 1996.

Foliage and stem damage was not always caused by insect attack. At Branxholme, the large population of the acacia-tip psyllid *Acizzia* sp. aff. *jucunda* (Tuthill) (Hemiptera: Psyllidae) that was present in 1995 had declined in 1996; the most important cause of damage was stress, possibly as a result of waterlogging during the previous winter. Some borer damage was also observed. At Dundas Tablelands, in contrast, no trees were visibly affected by defoliators or sap-feeders; however, some trees were stressed and others had their growing shoots affected by birds. At Eden, the mealybug *Maconellicoccus australiensis* (Green & Lidgett) (Hemiptera: Pseudococcidae) caused distortion of the new growth and was the major cause of damage along with a small but significant amount of stem girdling by a species of platypodine beetle. At Kowen, 7% of trees were lost at establishment due to the effects of a root-boring weevil larva, probably the whitefringed weevil, *Graphognathus leucoloma* (Boheman) (Coleoptera: Curculionidae). Otherwise, the ACT sites remained unaffected by insects but continued to be severely damaged by an accidental boron overdose at Kowen, and black cockatoos breaking the growing shoots at Uriarra (Searle et al., these Proceedings). Only a few individual fireblight beetles have been observed in the trials in the Hamilton district, but they had not established a significant population.

Beating samples at Uriarra and Kowen

The relative abundance of the most common arthropods in the beating samples at Kowen and Uriarra is shown in Table 3. At both sites herbivores were the most abundant functional group representing about 50% of all arthropods, while predators constituted about 35% of all specimens. The main difference between the sites was more fungivores at Uriarra (10%) than Kowen (2%) due to a large number of minute mould beetles, *Cortinicara* sp. (Coleoptera: Lathridiidae) and a species of Phalacridae (Coleoptera) associated with galls caused by the fungus *Uromycetes* sp.

Within the herbivore functional group, the same main species were found at both sites, but their relative abundance varied between the sites (Table 3). For example, of the 11 most abundant herbivorous species, a species of Margarodidae was the most common at Kowen (13.8%), but only the fifth most common at Uriarra (2.7%). One of the least abundant herbivores at Kowen was a species of Anthicidae (0.5%), yet it was the fourth most abundant species at Uriarra (3.3%). At Kowen three species made up 64% of numbers of individuals found, while at Uriarra two species made up 57%. Of these most abundant species only one, a species of Miridae was abundant at both sites.

Table 2. Amount of damage caused by various agents in the *Acacia mearnsii* trials in south-east mainland Australia in winter 1996.

	Branxholme	Dundas Tablelands	Eden	Kowen	Uriarra
Foliage damage (%)					
Bird	0.0	0.4	0.0	0.0	0.0
Ringbarking borers	0.4	0.0	0.4	0.0	0.0
Boron overdose	0.0	0.0	0.0	20.0	0.0
Maconellicoccus australiensis	0.0	0.0	3.5	0.0	0.0
Stressed	15.1	1.1	1.2	0.6	0.0
Unknown defoliation	0.0	0.0	0.7	0.0	7.3
TOTAL	15.5	1.5	5.8	20.6	7.3
Stem damage (%)					
Bird	0.0	0.4	0.0	0.0	0.0
Ringbarking borers	0.0	0.0	0.9	0.0	0.0
Maconellicoccus australiensis	0.0	0.0	6.6	0.2	0.1
TOTAL	0.0	0.4	7.5	0.2	0.1

Table 3. Relative abundance of the major species in each functional group in beating samples from Kowen and Uriarra. (In each functional group, species which were rare at both sites have been lumped into the 'other species' category.)

Species	Order	Family	Abundance %	
			Kowen	Uriarra
Fungivores				
Cortinicara sp.	Coleoptera	Lathridiidae	0.0	5.1
To be determined	Coleoptera	Phalacridae	1.6	4.0
To be determined	Coleoptera	Nitidulidae	0.1	0.5
Herbivores				
Calomela sp.	Coleoptera	Chrysomelidae	2.0	1.6
Chlorocoma spp. and others	Lepidoptera	Geometridae	2.5	2.3
Cryptocephalus sp.	Coleoptera	Chrysomelidae	3.1	1.7
Elaphodes aeneolus	Coleoptera	Chrysomelidae	0.8	0.1
Melanococcus albizziae	Hemiptera	Pseudococcidae	2.3	<0.1
Monolepta sp.	Coleoptera	Chrysomelidae	0.7	1.9
To be determined	Coleoptera	Anthicidae	0.5	3.3
To be determined	Coleoptera	Chrysomelidae	4.4	9.3
To be determined	Coleoptera	Curculionidae	12.1	3.5
To be determined	Hemiptera	Margarodidae	13.8	2.7
To be determined	Hemiptera	Membracidae	2.0	0.6
To be determined	Hemiptera	Miridae	7.2	9.1
Other species	Various		5.4	4.3
Predators				
Cryptolaemus montrouzieri	Coleoptera	Coccinellidae	0.6	7.1
Spiders	Araneida	Various	29.0	25.9
To be determined	Coleoptera	Coccinellidae	1.2	1.0
Other species	Various		1.1	2.7
Others				
Incidentals	Various		9.4	8.2
Pollen feeders	Various		0.0	0.1

Spiders were the most common predatory species at both sites and in fact were the most abundant group of species in any functional group (Table 3). The only other predators to occur in any significant numbers were two species of coccinellids. One of these, a scale insect predator *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae), was abundant at Uriarra (7.1%) but quite rare at Kowen (0.6%).

Discussion

The geographic distribution and severity of damage of *A. orphana* has increased dramatically during the period of the surveys from 1994 to 1996. The outbreak is characterised by localised severe damage causing dieback and even death of trees. This is consistent with the previously recorded outbreak dynamics of the species in Tasmania (Elliott 1978). The risk of *A. orphana* damage has been, and continues to be, one of the major reasons why large areas of commercial plantings of *A. mearnsii* and *A. dealbata* have not been established in southeastern Australia. It was the aim of this project to establish trials in areas where *A. orphana* was likely to invade and cause significant damage so that options for control, such as the use of resistant genotypes, could be investigated. It is hoped that the beetle will build up to high population densities in the trial plantations in the near future.

Several other insect species have caused some damage to *A. mearnsii* in the trials established as part of this project. The most important of these are a number of hemipteran species; *Maconellicoccus australiensis*, *Acizza* sp. aff. *jucunda* and *Melanococcus albizziae* (Maskell) (Hemiptera: Pseudococcidae). These species have the potential to cause significant damage to *A. mearnsii*, particularly if it is stressed by poor site conditions. Wood-boring insects have caused some damage and are expected to cause greater damage as the trials mature. *Graphognathus leucoloma* caused 7% mortality in the young seedlings at Kowen by boring into the tap root during the first six months following planting. This was due to planting the trees in a legume dominated pasture which already supported large populations of the weevil, a known pest of pasture legumes. Wood-boring insects, including a platypodine beetle, have been observed to ring-bark branches on some trees at most sites. Larger wood-boring insects of the family Cossidae and Cerambycidae are relatively common in natural stands of mature *A. mearnsii* (Van den Berg 1982c), and may cause damage in plantations as they mature.

Defoliators have not caused much damage in the experimental trials in the first three years of growth. This may be due in part to the large number of natural enemies, particularly spiders and coccinellids, that were found in the plantation. All trials were small and located in areas where *A. mearnsii* and related acacias grow naturally. This may have allowed both herbivores and their enemies to migrate into plantations and maintain relatively stable populations.

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References

French, C. 1911. Handbook of the Destructive Insects of Victoria. Part V. Government Printer, Melbourne, Australia.

Froggatt, W.W. 1923. Forest Insects of Australia. Government Printer, Sydney, Australia.

Elliott, H.J. 1978. Studies on the fireblight beetle, *Pyrgoides orphana* (Erichson) (Coleoptera: Chrysomelidae) and its effect on the growth of silver wattle in Tasmania. Australian Forestry, 41, 160–166.

McKeown, K.C. 1942. Australian Insects. Royal Zoological Society of New South Wales, Sydney, Australia.

Searle, S.D. 1991. The Rise and Demise of the Black Wattle Bark Industry in Australia. CSIRO Division of Forestry, Yarralumla, Australia.

Van den Berg M.A. 1982a. Lepidoptera attacking *Acacia dealbata* Link., *Acacia decurrens* Willd., *Acacia longifolia* (Andr.) Willd., *Acacia mearnsii* De Wild. and *Acacia melanoxylon* R. Br. in eastern Australia. Phytophylactia, 14, 43–46.

Van den Berg M.A. 1982b. Hemiptera attacking *Acacia dealbata* Link., *Acacia decurrens* Willd., *Acacia longifolia* (Andr.) Willd., *Acacia mearnsii* De Wild. and *Acacia melanoxylon* R. Br. in Australia. Phytophylactia, 14, 47–50.

Van den Berg M.A. 1982c. Coleoptera attacking *Acacia dealbata* Link., *Acacia decurrens* Willd., *Acacia longifolia* (Andr.) Willd., *Acacia mearnsii* De Wild. and *Acacia melanoxylon* R. Br. in Australia. Phytophylactia, 14, 51–55.

Diagnosis of Nutrient Status of *Acacia mangium*

J.A. Simpson[1], P. Dart[2] and G. McCourt[2]

Abstract

Acacia mangium is an important commercial forest species of the tropics. Increasing attention is being paid to intensive management regimes, frequently involving the use of fertilisers, to maximise productivity. Foliar analysis techniques need to be developed for the species to diagnose nutrient deficiencies and to establish nutrient levels associated with maximum yield. Glasshouse investigations enabled descriptions of visual deficiency symptoms of N, P, K and the corresponding foliar nutrient concentrations. Pooled results from selected samplings of operational stands in a number of Southeast Asian countries suggest that: problems exist with the N nutrition of *A. mangium* plantations in China and the Philippines; P deficiency is a major problem in Kalimantan and China; and K deficiency is a serious problem in the stands sampled in Vietnam, Kalimantan and China. Problems with Mg and B are less frequent. A greater understanding of edaphic limitations and species nutritional requirements is urgently required, supported by further development of foliar analysis as a diagnostic and interpretative tool.

ONE of the important commercial forest plantation species of the tropics is *Acacia mangium*. There has been a major expansion of the estate of this species in recent times and this is expected to continue if increasing demands for timber in tropical countries, particularly in Asia, are to be addressed. Turvey (1994) estimated that there are 20 million hectares of *Imperata* grasslands in Southeast Asia, of which over half are in Indonesia. The lowland occurrences of these degraded lands are potentially suitable for acacia plantations. Some projections suggest that there will be more than 2 million ha of acacia plantations in this region within the next 10 years.

While the performance of the species is dependent on climatic, edaphic, biotic and genetic resources, increasing attention is being paid to intensive management regimes, frequently involving the use of fertilisers, to maximise productivity. The success of the species is due to its:

- vigorous growth;
- ability to compete with weeds;
- relative freedom from pests and diseases;
- good wood properties;
- ease of propagation and establishment; and
- ability to grow well on a wide range of sites, including sites with low pH, high exchangeable aluminium and soils of relatively low nutrient status.

There persists a notion, however, in some areas that the species is capable of rehabilitating severely degraded lands in a short time frame and with minimal silvicultural inputs. As a result of this perception, there are many examples of commercially unsuccessful plantations. The species has potential for community and social forestry planting schemes, provided that there are appropriate inputs.

To maximise productivity, while at the same time minimising or reversing environmental damage, it is necessary to understand the nutrient status of the soil and the crop. In order to know which fertilisers to add, the nutritional requirements of the crop must firstly be defined, the nutrient limitations to growth in unamended soil determined, and the fertiliser recommendations developed from field evaluations.

Foliar chemical analysis is a powerful tool in tree nutrition and fertiliser research, developed over the last century (Raupach 1967), but many difficulties still exist with its use. The technique is widely used to diagnose nutrient deficiencies of plants, provide a basis for fertiliser recommendations and monitor the effectiveness of fertiliser treatments. It has not

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worked where clearly visible symptoms of ill health exist in a stand, but much more precise data is required where severe deficiencies do not exist (van den Driessche 1974) and reviews by Armson (1967), Bates (1971), Dell (1996), Dell et al. (1995), Judd et al.(1996), Lambert (1984), Lavender (1970), Qureski and Srivastava (1966), Smith (1962), van den Driessche (1974), and Zech (1984).

Establishing deficiency levels at which visual symptoms appear is relatively easy, but defining levels where growth is limited and symptoms are either not apparent, or at critical levels above which little improvement in growth occurs, is much more difficult (Richards and Bevege 1972). Since productivity losses are invariably associated with nutrient deficiencies, there is a management need to establish critical foliar levels for the elements that commonly limit growth. The concept of critical concentrations is based on defining a reproducible functional relationship between nutrient concentration and yield.

Much of the research and development of the foliar analysis technique for forest species has been carried out on conifers. Sampling conditions have been defined and deficient, critical and acceptable foliar levels established for a wide range of elements. Less information is available for the broadleaved forest species where a wider range of problems with the technique is encountered. Nevertheless the technique has considerable potential for acacias where successful establishment of plantations is often dependent upon the judicious use of fertiliser.

This paper discusses the use of foliar analysis in the diagnosis of nutrient deficiencies in *A. mangium*, and as a means of monitoring the nutrient status of plantations.

Diagnosis of Nutrient Deficiencies

There are several techniques available for diagnosing nutrient deficiencies in plants:

- soil analysis;
- visual symptoms;
- foliar analysis;
- pot cultures; and
- field trials.

Most of these have been of limited benefit in forestry. For example, soil analysis has not been a particularly useful diagnostic tool for long-lived trees, even though much effort has gone into correlating soil chemical properties with growth of annual crops. Visual symptoms of nutrient deficiencies appear only when the nutrients in question are grossly deficient; such symptoms can also occasionally result from non-nutritional causes, and deficiencies of more than one element may result in similar symptoms.

Foliar analysis, where sound relationships can be established between foliar concentrations or ratios of particular nutrients and tree growth, has many potential advantages over other techniques.

The aim of foliar analysis is to determine threshold concentrations for nutrients below which deficiency limits plant growth (a diagnostic function) and the establishment of nutrient levels associated with maximum yield (a predictive function). Implicit in the concept of critical level is the assumption that all factors apart from the one under test are not limiting. Only if this condition is fulfilled can critical levels be established with any degree of certainty. In a situation where yield is dependent on two factors and their interaction, and where both vary simultaneously, the critical level of one factor will depend on the existing level of the other factor (Richards and Bevege 1969). Diagnostic and Recommendation Integrated System (DRIS) indices (Sumner 1977) and Graphic Vector Analysis (Weetman 1989) are advanced techniques developed to aid in the interpretation of foliar nutrient data. The success of these techniques is heavily dependent upon a detailed knowledge of critical foliar concentrations.

Many factors impact on the interpretation of foliar analysis. If maximum benefit is to be gained, it is necessary to understand the variations in foliar nutrient levels associated with:

- the genetic resource (Atipanumpai 1989);
- sampling (e.g. leaf age, crown position, time of year, intensity);
- plantation conditions (e.g. age, site, stocking, silvicultural treatments);
- season (e.g. temperature, rainfall); and
- analytical methods.

For results reported in this paper, standard sampling and analytical techniques were used. The youngest fully expanded leaves from the top one third of the crown from representative trees were collected, composited, oven dried, finely ground, and analysed.

Pot cultures carried out under glasshouse conditions with the field soil, using nutrient omission treatment designs, provide a relatively rapid and effective means of screening for limiting nutrients. However, direct extrapolation of results to field situations rarely prove a satisfactory guide either to levels of fertiliser required or to critical foliar nutrient concentrations.

Field trials are the ultimate means of diagnosing nutrient deficiencies and for designing operational fertiliser schedules. They are expensive to install and maintain and for maximum benefits, require a long time frame (rotation). If appropriately designed and managed, information on critical nutrient concentrations and nutrient adequacy levels can be obtained during the life of the trial and fertiliser rates calibrated against changes in foliar nutrient concentrations for particular soils. Foliar nutrient data greatly aids in the interpretation of fertiliser response data.

Glasshouse Investigations

For *A. mangium*, there has been little systematic investigation of the use of foliar analysis as an indicator of nutritional status, to relate various visual deficiency symptoms to foliar nutrient concentrations, nor has there been an attempt to utilise tissue analysis as an indicator of potential growth performance.

To address this, glasshouse trials conducted at the University of Queensland under the aegis of the Australian Centre for International Agricultural Research (ACIAR) Project FST/92/08, established visual deficiency symptoms associated with nitrogen (N), phosphorus (P) and potassium (K) and related these to foliar nutrient concentrations. The rates of elements tested were derived from predicted plant nutrient uptake using a computer simulation program (Asher and Blamey 1987). Treatments tested $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, 1 and 2 times predicted plant requirements. Plants were grown for up to 120 days in sterilised sand in pots constantly irrigated and held above a reservoir of aerated nutrient solution. Progressive harvests were undertaken. Regular measures of pH and nutrient solution elemental concentrations enabled these to be adjusted back to the starting values.

The plants were kept non-nodulated, and visual symptoms of N deficiency were phyllodes with a general chlorotic appearance with tissue colour ranging from light green to yellow-green. Phosphorus deficiency resulted in arrested seedling growth and development with a reddening of the lower stem, the older petioles, the rachis and the pinna rachis while the pinnule remained green to dark green in colour. There were, however, no readily apparent visual symptoms for P deficiency.

Potassium deficiency symptoms became obvious around 60 days after planting. Early symptoms were interveinal chlorosis of individual pinnules followed by a khaki/red-brown discoloration of the stem and the margins of the pinnules. For more advanced plants, K deficiency became very evident in the phyllodes as interveinal chlorosis and sometimes tissue death. In advanced cases of K deficiency, new tissue was severely chlorotic and almost white with tinges of red-pink pigmentation developing in the tissue. Stems of advanced K-deficient plants were 'soft' and would not support the weight of the developing foliage. For plants given the lower rates of K, pinnules remained 'closed' until later in the day, whereas at high K rates pinnules 'opened' earlier. Plant development in the experiments was strongly positively related to the quantity of test element applied.

At the 90-day harvest, increased N supply increased above-ground plant weight from 0.15 to 10.2 g/plant for the $\frac{1}{16}$ and $\times$ 1 treatments respectively. Equivalent increases for P were 0.20–10.0 and for K 3.11–10.3 g/plant. The corresponding increases in foliar nutrient concentrations (4th leaf from tip at 90 days) were N: 22.7–29.1 mg g^{-1} (ODW basis) for the $\frac{1}{4}$ and $\times$ 1 treatments respectively. Equivalent increases for P were from 0.6–1.0 mg g^{-1}. The leaf K concentration was 2.1–14.5 mg g^{-1}. Insufficient material was available for analysis from the lower rates of supply. Concentrations of P and K at the $\times$ 2 level of supply indicated luxury consumption. These data suggest acceptable foliar nutrient concentrations of: N > 25 mg g^{-1}, P 1.0 mg g^{-1}, and K 14 mg g^{-1}.

An extension of this work to study calcium (Ca) magnesium (Mg), sulfur (S) and boron (B) is planned.

Monitoring the Nutrient Status of Plantations

If productivity of plantations on the less fertile sites is to be improved, it will be necessary to monitor the nutrient status of the stands. Reliance on visual symptoms of nutrient disorders means that there already exists a severe nutrient stress situation as a result of which productivity is already adversely affected. Deficiencies of more than one element may exist, and this makes interpretation of symptoms difficult. For example, P deficiency can result in poor nodulation and N_2 fixation leading to N deficiency symptoms, yet there are no obvious visual deficiency symptoms for P.

Bevege and Richards (1971) proposed a crop logging system for exotic pines in Queensland. The basis of the scheme depended upon regular foliar sampling of representative permanent plots and tracking changes in foliar nutrient levels. By doing this the need for fertiliser additions could be predicted and applications made in advance of any productivity loss. The success of this system depends upon an adequate knowledge of the relationships between foliar nutrient concentration and growth, critical foliar nutrient concentrations, and the foliar nutrient response to fertiliser additions for the soils in question.

While foliar nutrient analysis has been used successfully and extensively over a long period in coniferous plantations to diagnose nutrient deficiencies, it has only more recently been employed for this purpose in hardwood plantations. Experience has now accumulated from eucalypt plantations but very little from acacias. Mead and Miller (1991) proposed diagnostic levels for *A. mangium* foliage in two categories:

- satisfactory concentrations of N > 30 mg g^{-1}, P 1.3–1.5 mg g^{-1}, K > 10 mg g^{-1}, Mg 1.5–2.0 mg g^{-1}; and
- critical levels of Ca < 2.0 mg g^{-1}, S < 1.0 mg g^{-1}, B < 10 µg g^{-1}, Zn 10 µg g^{-1}, Cu 3 µg g^{-1}.

Acacia mangium plantings in Indonesia, the Philippines and Vietnam are often described as suffering from the 'yellow mangium' syndrome. Foliar samples from paired healthy and deficient (yellow mangium) trees were collected from 26-month-old *A. mangium* in different compartments of industrial and trial plantings in the Philippines. Typical values for these comparisons were (mg g^{-1}):

- N — 11.5 deficient (D) and 24.1 healthy (H);
- P — 0.7 (D) and 2.2 (H);
- K — 3.71 (D) and 7.38 (H);
- Mg — 0.9 (D) and 2.3 (H);
- S — 0.7 (D) and 1.4 (H).

The results suggest that yellow mangium can result from N, P, K, Mg and/or S deficiency. In each of the comparisons cited there was only one element that was markedly deficient, except for P where both N and P were deficient. For boron, a leaf crinkle and young leaf abscission symptom was associated with 8 µg g^{-1} compared with 24 µg g^{-1} for symptomless plants. Care should be taken not to infer critical or optimal concentrations from these values. The healthy values cited do not necessarily represent critical or adequate concentrations. A much more rigorous systematic investigation is necessary to establish critical levels. Zech (1990) also found N, P and S limiting for *A. auriculiformis* growth in Northern Luzon in the Philippines. Shariff and Kadir (1994) from their work in Malaysia consider foliar N and K concentrations of 23.5 and 6.5 mg g^{-1} non limiting on one test soil and a foliar K concentration of 4.0 mg g^{-1} as limiting on a second test soil.

Foliar nutrient data from selected sampling of young *A. mangium* in a range of countries is presented in Table 1.

In interpreting these data the differences in sample selection, sampling methodology, site and silvicultural history, and laboratory methods need to be recognised. The cutoff points used to define deficient samples are based on the data reported in this paper but remain somewhat arbitrary. The most significant points illustrated by the Table 1 are:

- N concentrations vary markedly (9.8–27.0 mg g^{-1}) with China and the Philippines having the worst results;

Table 1. Nutrient concentrations of young *Acacia mangium* plantations. (Mean with the range shown in brackets. Percentage data is the proportion of samples of nominated concentration: N 20 mg g^{-1}, P 1.0 mg g^{-1} K 0.7 mg g^{-1}.)

N	P	K	Ca	Mg	Cu	Zn	B
		(mg g^{-1})				(µg g^{-1})	
Vietnam (North) (Mean of 9 samples aged 1–3 years)							
23.1	1.27	7.81	5.43	1.30	35	39	19
(13.9–27.0)	(0.61–3.23)	(3.48–20.5)	(2.46–9.89)	(1.09–1.71)	(16–57)	(28–52)	(8–30)
89%	67%	44%					
South Kalimantan (Mean of 10 samples aged 1–5 years)							
21.8	1.02	6.89	11.07	2.39	16	22	16
(18.8–25.5)	(0.69–2.36)	(4.75–9.35)	(3.73–17.9)	(1.99–3.35)	(8–23)	(13–35)	(10–22)
80%	30%	50%					
PR China (South) (Mean of 4 samples aged 4 years)							
* 19.2	0.83	2.67	5.28	1.59	7	17	17
** 20.6	0.99	3.47	5.43	1.55	8	20	17
(18.6–23.1)	(0.69–1.33)	(1.94–4.25)	(4.81–6.5)	(1.31–1.75)	(7–11)	(14–25)	(14–22)
38%	25%	0%					
Philippines (Mean of 61 samples aged 1–5 years)							
20.0	1.50	11.2	3.80	1.60	12	24	21
(9.8–25.2)	(0.7–3.0)	(6.3–18.6)	(0.6–6.9)	(0.9–3.5)	(3–20)	(7–39)	(8–43)
49%	88%	93%					
Australia (Mean of 2 samples aged 3 years)							
25.2	1.20	9.45	5.87	1.26	3	8	17

* Unfertilised ** Fertilised with N_{100} P_{50} K_{50} plus trace elements at establishment
Subscript numerals denote the quantity of the element applied

- P deficiency is a major problem in Kalimantan and China but the application of 50 kg per ha P at planting helps alleviate P stress (it is common practice in most countries to fertilise at planting with P);
- K deficiency is a serious problem in the stands sampled in Vietnam, Kalimantan and China; and
- Problems with Mg and B nutrition are less frequent and Ca, Mg, Zn, Mn, Cu were apparently not deficient.

While these data provide some guide as to the overall nutrient status of the selected stands in the plantation centres, interpretation of the results of individual site samples is of more value, but beyond the scope of this paper.

Conclusions

Foliar analysis is a useful tool for assessing the nutrient status of acacia plantations. Glasshouse studies have related foliar nutrient concentrations to the appearance of visual symptoms of N, P, K. Foliar nutrient data from selected stands in a range of countries indicated suboptimal foliar concentrations of N, P, K, Mg, S, B.

Future Work

A. mangium has the potential to become one of the major plantation species of the tropical lowlands of Southeast Asia. Much of the potential plantation would be on degraded lands where fertiliser additions will be required if sustainable productivity is to be optimised. It is essential therefore that greater attention be paid to developing a better understanding of the nutrient requirements of the species, and the edaphic limitations for each of the major planting areas. Further glasshouse investigations which include trials to identify and record nutrient deficiency symptoms and to screen plantation soils for limiting nutrients are required.

Well designed and executed field fertiliser trials are necessary for understanding the nutrient requirements of the species and for deriving site-specific fertiliser prescriptions. It is very desirable to further develop foliar analysis as a diagnostic and interpretative tool. Studies to better describe and correlate visual symptoms of nutrient disorders with foliar nutrient concentrations, identification of critical levels and ratios (including graphical vector analysis) are urgently required. Effects of season, age, and fertiliser additions on foliar nutrient concentrations need to be better understood to aid in interpretation of data. Sampling and analytical methodologies need to be standardised or calibrated to enhance extrapolation from these data. Foliar analysis provides a means for early identification of nutrient disorders and can be developed to allow timely corrective actions to be undertaken to optimise productivity and profitability of plantations.

Acacias are capable of biologically fixing N_2 and should not require the addition of N fertiliser. However, little is known of the N-fixing capacity of planted *A. mangium* and whether poor nodulation is contributing to N deficiency. N fixation is being measured using ^{15}N natural abundance techniques.

ACIAR Project 96/110 is currently investigating several aspects of acacia nutrition in Australia and the Philippines.

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References

Armson, K.A. 1967. Soil and plant analysis techniques as diagnostic criteria for evaluating fertiliser needs and treatment response. Forest Fertilisation Symposium at Gainsville, Florida. Tennessee Valley Authority, Muscle Shoals, Alabama, 155–166.

Asher, C.J. and Blamey, F.P.C. 1987. Experimental control of plant nutrient status using programmed nutrient addition. Journal of Plant Nutrition, 10, 1371–1380.

Atipanumpai, L. 1989. *Acacia mangium*: Studies on the genetic variation in ecological and physiological characteristics of a fast-growing plantation tree species. Acta Forestalia Fennica, 206, 36–46.

Bates, T.E. 1971. Factors affecting critical nutrient concentrations in plants and their evaluation: a review. Soil Science, 112, 116–130.

Bevege, D.I. and Richards, B.N. 1971. Principles and practice of foliar analysis as a basis for crop-logging in pine plantations II. Determination of critical phosphorus levels. Plant and Soil, 37, 159–169.

Dell, B. 1996. Diagnosis of nutrient deficiencies in eucalypts. In: Attiwill, P.M. and Adams, M.A. Nutrition of Eucalypts. CSIRO, Collingwood, Australia, 417–440.

Dell, B., Malajczuk, N. and Grove, T.S. 1995. Nutrient Disorders in Plantation Eucalypts. ACIAR Monograph 31, 110 p.

Judd, T.A., Attiwill, P.M. and Adams, M.A. 1996. Nutrient concentrations in eucalyptus: A synthesis in relation to differences between taxa, sites and components. In: Attiwill, P.M. and Adams, M.A. Nutrition of Eucalypts. CSIRO, Collingwood, Australia, 123–154.

Lambert, M.J. 1984. The use of foliar analysis in fertiliser research. In: Proceedings of IUFRO Symposium on Site and Productivity of Fast Growing Plantations. Pretoria and Pietermaritzburg, South Africa, Vol. 1, 269–291.

Lavender, D.P. 1970. Foliar analysis and how it is used, a review. School of Forestry, Oregon State University, Corvallis, Oregon, Research Note 52.

Mead, D.J. and Miller, R.R. 1991. The establishment and tending of *Acacia mangium*. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 116–122.

Qureski, I.M. and Srivastava, P.B.L. 1966. Foliar diagnosis and mineral nutrition of forest trees. Indian Forester, 92, 447–460.

Raupach, M. 1967. Soil and fertiliser requirements for forests of *Pinus radiata*. Advances in Agronomy, 19, 307–353.

Richards, B.N. and Bevege, D.I. 1969. Critical foliage concentrations of nitrogen and phosphorus as a guide to the nutrient status of *Araucaria* underplanted to *Pinus*. Plant and Soil, 31, 328–337.

Richards, B.N. and Bevege, D.I. 1972. Principles and practice of foliar analysis as a basis for crop-logging in pine plantations: I. Basic considerations. Plant and Soil, 36, 109–119.

Shariff, Amir Husni Mohd and Kadir, Wan Rasidah Wan Abdul 1994. Growth differences, fertility status and foliar deficiency levels of six-year old *Acacia mangium* on Bris Soils. Journal of Tropical Forest Science, 6, 230–238.

Smith, P.F. 1962. Mineral analysis of plant tissues. Annual Review of Plant Physiology, 13, 81–108.

Sumner, M.E. 1977. Use of DRIS system in foliar diagnosis of crops at high yield levels. Communications in Soil Science and Plant Analysis, 8, 251–268.

Turvey, N.G. 1994. Afforestation and rehabilitation of *Imperata* grasslands in Southeast Asia: identification of priorities for research, education, training and extension. ACIAR Technical Report No. 28, 52 p.

van den Driessche, R. 1974. Prediction of mineral nutrient status of trees by foliar analysis. Botanical Review, 40, 347–394.

Weetman, G.F. 1989. Graphical vector analysis technique for testing stand nutritional status. In: Dyck, W.J. and Mees, C.A., ed., Research Strategies for Long-term Site Productivity. Proceedings, IEA/BE A3 Workshop, Seattle, WA, August 1988. IEA/BE A3 Report No. 8., Forest Research Institute, New Zealand, Bulletin 152, 93–109.

Zech, W. 1984. Leaf analysis — a method to detect mineral deficiencies in fast growing plantations of West Africa. In: Proceedings of IUFRO Symposium on Site and Productivity of Fast Growing Plantations. Pretoria and Pietermaritzburg, South Africa, Vol. 2, 691–699.

Zech, W. 1990. Mineral deficiencies in forest plantations of North Luzon, Philippines. Tropical Ecology, 31, 22–31.

Responses in *Acacia* to Inoculation with Rhizobia

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Abstract

Temperate species of *Acacia*, *A. melanoxylon*, *A. mearnsii*, *A. implexa and A. dealbata*, inoculated with strains of the root-nodule bacteria *Rhizobium* and *Bradyrhizobium* spp. ('rhizobia'), were grown in the nursery for 4–6 months in plastic containers of soil. Responses to inoculation (indices of nitrogen fixation) were measured as nodule dry matter (DM), seedling height, seedling DM, nitrogenase activity (acetylene reduction activity — ARA), and the nitrogen content of inoculated and uninoculated plants. Estimates were made of the amount and rate of nitrogen fixation. All 29 strains formed nodules on *Acacia* host plants and most fixed at least some nitrogen. The best-performing strains increased nodule DM, seedling height, seedling DM and ARA by up to 2.1, 1.1, 2.8 and 7.3 times, respectively, and the differences between the best and poorest strains were statistically significant. Significant differences also occurred between six provenances of four *Acacia* species in their response to inoculation with selected strains. In *A. melanoxylon*, the rate of nitrogen fixation (the proportion of total plant nitrogen due to fixed nitrogen) for provenance 17263 was 72.4%, but was only 10.5% for provenance 16358. *A. implexa* had a rate of 53.4%, but *A. mearnsii* had a rate of only 10.4%. The shoots of *Acacia* seedlings contained 76% of the total nitrogen fixed by the plant. It is concluded that, in choosing effective strains for inoculants for lines of *Acacia*, careful consideration must be given to symbiotic compatibility at both the species and the provenance levels.

THE quantities of nitrogen produced worldwide by legume-rhizobia symbioses represent at least half of the biologically-fixed global total (Li 1989). Although inoculation with rhizobia (*Rhizobium* and *Bradyrhizobium* spp.) to augment legume nitrogen fixation has been studied and put into practice for more than a century, its use has been applied almost exclusively to crop and pasture legumes. Until recently, tree legumes received little attention. In particular, information about the symbioses of *Acacia* species is scanty.

Legume trees recently introduced into China from Australia include the fast-growing temperate *Acacia* species, *A. dealbata*, *A. implexa*, *A. mearnsii* and *A. melanoxylon*. They are tolerant of low soil fertility and periods of low temperature, and are becoming increasingly more prominent in the forests of South China (Hong 1989). They appear better adapted than *A. mangium* and *A. auriculiformis* to tropical and subtropical regions that experience occasional 'cold snaps'.

Preliminary observations made in our laboratory (Kang et al. these Proceedings) have indicated that most introduced acacias are poorly matched with most rhizobial strains that occur naturally in Chinese soils. It is essential, therefore, that they be inoculated with effective strains in order to optimise nitrogen fixation. In this paper, we report the results of experiments in which *A. dealbata*, *A. implexa*, *A. mearnsii* and *A. melanoxylon* were inoculated with selected strains of rhizobia. Measurements were made on seedling nodulation, plant growth and the amount and rate of nitrogen fixation. The findings will be applied in *Acacia* plantations in South China.

Materials and Methods

Isolation of rhizobia

The 29 rhizobial strains used in this work were all isolated from *Acacia* root nodules. Their origins are shown in Table 1.

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Table 1. Origin of strains of rhizobia.

Strain	Host	Location	Strain	Host	Location
LR020	*A. melanoxylon*	Longdong	LL013	*A. melanoxylon*	Xiaojiwo
LR005	"	"	LL004	"	"
LR006	"	"	LL001	"	"
LR003	"	"	LL009	"	"
LR022	"	"	LL018	"	"
LR012	"	"	LL007	"	"
LR011	"	"	LL011	"	"
LR032	"	RITF[1]	LL028	"	"
LR030	"	"	LL016	"	"
LR033	"	"	LL015	"	"
LL010	"	Xiaojiwo	IS002	*A. implexa*	Hekou
LL005	"	"	DH001	*A. dealbata*	Huaxian
LL027	"	"	MH001	*A. mangium*	"
LL019	"	"	AR003	*A. mearnsii*	"
LL002	"	"			

[1] Research Institute of Tropical Forestry

Nodules collected in the field were taken to the laboratory, washed in tap water, surface-sterilised by immersion in 95% ethanol for 15–30 seconds, then in 0.1% mercuric chloride for 3–5 minutes, rinsed several times in sterile distilled water, and crushed aseptically in a drop of a dilute plant nutrient solution. The crushed nodule suspension was streaked on to the surface of yeast mannitol agar (YMA) medium (Vincent 1970) in 9 cm petri dishes, and the plates were incubated in the dark at 28–30°C for 7–10 days. At the end of that time, pure culture isolates were picked from single colonies and maintained on YMA slopes in screw-cap bottles as a working collection.

Seedling establishment

Acacia seeds used in the experiments were supplied by the CSIRO Australian Tree Seed Centre. The seeds were desiccated overnight, immersed in concentrated sulphuric acid for 20–25 minutes, washed in 5–6 changes of sterile distilled water, allowed to imbibe for 30 minutes in the final change of water, and sown into a mixture of vermiculite and sand (1:1, v:v) which had been sterilised by autoclaving at 121°C. The acid treatment had the dual effect of softening and surface-sterilising the hard seed. When the seedling shoots were 3–4 cm in height and the roots 2–3 cm long, they were transplanted into polyethylene envelopes containing about 1 kg of a yellow clay loam soil.

Inoculation

Strains to be used for inoculation of *Acacia* seedlings were cultured in yeast mannitol broth shaken at 100 rpm at 28°C for 3–5 days. Inoculation was performed by applying 3 ml of an aqueous suspension of broth culture directly into the seedling rhizosphere, using a sterile syringe. There were 10–30 replicates of each inoculation treatment plus uninoculated control plants. The seedlings were grown in the nursery.

Observations

Seedling height, total dry matter (DM) and nodule DM were measured 4–6 months after inoculation. Plant samples were dried for two days at 80°C, finely ground, weighed, and the nitrogen content estimated by Kjeldahl digestion and a colorimetric determination. Nodule acetylene reduction activity (ARA), as a measure of nitrogen fixation, was determined with gas chromatography (NFLSPPRI 1974).

Data treatment

Calculations of total nitrogen, amount of nitrogen fixation, and nitrogen fixation rates were made using the following formulae:

- $Nt = (BM \times Nc)/100$
  [where Nt = total nitrogen content, BM = plant biomass, and Nc = % nitrogen content]
- $Na = Nti - Ntc$
  [where Na = amount of fixed nitrogen, Nti = total nitrogen content of inoculated plants, and Ntc = total nitrogen content of uninoculated plants (Martensson and Ljunggren 1984)]
- $\%Nfr = 100 \times (Na/Nt)$
  [where %Nfr = rate of nitrogen fixation (Fan et al. 1987), and Nt = total nitrogen content; rate of nitrogen fixation is analogous to Pfix, the proportion of plant nitrogen due to nitrogen fixation (Peoples et al. 1989)].

Results

A. melanoxylon — response to inoculation

The 29 strains of rhizobia used to inoculate *A. melanoxylon* were of diverse origin. All plants, including uninoculated controls, formed nodules (Table 2). For the best strains, nodule dry matter was more than double that of the control treatment. Nodules on control plants were fewer and smaller than on inoculated seedlings. The internal colour of control nodules was white and in contrast to the pink coloration of nodules on inoculated seedlings.

Inoculation with each of the 29 strains led to improved growth measured as seedling height and shoot DM (Figure 1). The best strain was LR006 which produced more than three times as much dry matter as the control. Differences between the better inoculation treatments and the control were significant ($P < 0.01$). For 23 of the strains, ARA was greater than for the uninoculated treatment (Table 3). The best strain was LL016, and strain LR006 also had relatively high activity.

Ding et al. (1991) recorded a strong correlation between nodule DM and nitrogen fixation. Overall, in this work, relationships between nodule DM (Table 2) and nitrogen fixation, measured as seedling DM (Figure 1b) and as ARA (Table 3), were not statistically significant (data not shown). However, the more effective of the 29 strains all rated consistently highly in all of the parameters used as indices of nitrogen fixation.

Acacia species and provenances within species — response to inoculation

There were two experiments. *Acacia dealbata* (1 provenance), *A. implexa* (1 provenance), *A. mearnsii* (3 provenances) and *A. melanoxylon* (3 provenances) were used. Judged on the basis of

Table 2. Effects of inoculation with 29 strains of rhizobia of diverse origin on the nodulation of *A. melanoxylon*. Nodulation measured as nodule number per plant and nodule dry matter (DM – mg per plant).

Strain	No. of nodules	Nodule DM	Strain	No. of nodules	Nodule DM
LL013	28.6	238	LR022	24.5	100
LL005	42.3	113	DH001	29.7	121
LL027	29.8	130	LR003	60.7	134
LL019	37.1	105	LR032	51.8	141
LL015	25.5	105	LL028	32.6	137
LL002	32.3	155	LR030	60.6	104
LL004	41.6	121	MH001	41.9	218
LL010	24.1	129	LR005	70.8	131
LL001	43.7	120	AR003	85.7	198
LL018	32.7	170	LR033	52.2	139
LR012	58.4	131	LL016	47.6	140
LL009	50.6	174	LR020	33.2	130
LL007	27.2	145	LR006	53.3	140
LS002	27.6	111	LL011	30.8	88
LR011	23.9	108	Uninoc.	35.2	98

Table 3. Acetylene reduction activity (ARA) of nodules of *A. melanoxylon* (μmol C_2H_2 per g fresh nodule per hr) inoculated with 29 strains of rhizobia of diverse origin.

Strain	ARA	Strain	ARA	Strain	ARA
LL013	2.37	LR012	0.35	LL028	1.61
LL005	1.06	LL009	1.09	LR030	2.55
LL027	7.64	LL007	1.63	MH001	1.51
LL019	1.50	IS002	1.46	LR005	1.27
LL015	2.32	LR011	2.29	AR003	1.45
LL002	2.62	LL011	0.58	LR033	2.13
LL004	0.61	LR022	1.85	LL016	3.50
LL010	0.07	DH001	1.14	LR020	2.46
LL001	0.37	LR003	0.37	LR006	2.34
LL018	1.28	LR032	1.97	Uninoc.	1.05

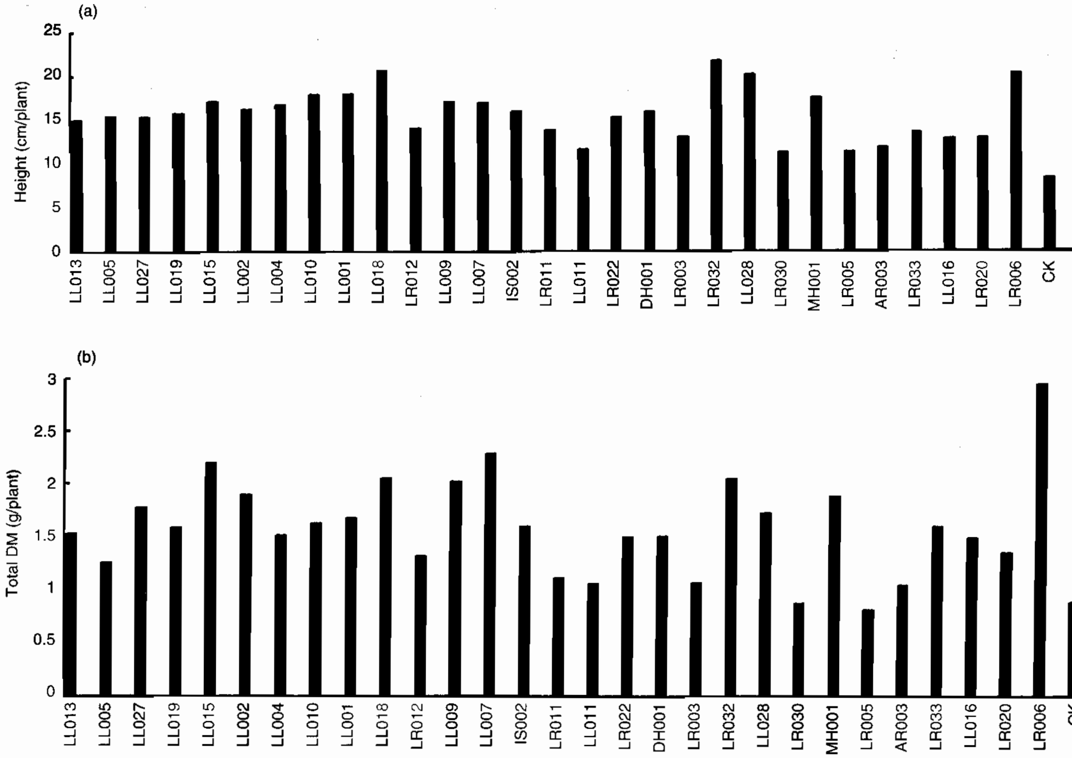

Figure 1. Effect of inoculation with 29 strains of rhizobia on *A. melanoxylon*: (a) seedling height; (b) seedling dry matter. (CK = uninoculated control)

performance in preliminary experiments, provenances of each species were inoculated with strains intended to fix nitrogen with that species. There were uninoculated control treatments for each provenance.

All treatments nodulated including the controls (Table 4). Response to inoculation was more pronounced when measured as nodule dry matter. *A. melanoxylon* 18021 did not respond. These nodulation results translated into responses in seedling height and shoot dry matter (Figure 2).

Data for nitrogen uptake and nitrogen fixation are shown in Table 5. Rates of nitrogen fixation varied from 72% for *A. melanoxylon* 17263 to 10% for *A. melanoxylon* 16358 and *A. dealbata*.

The distribution of fixed nitrogen

Inoculated and uninoculated control plants of *A. melanoxylon* provenance 17263 were partitioned into shoots, roots and nodules (data derived from Table 5). The distribution of fixed nitrogen in the various parts was calculated as the difference in the nitrogen contents of inoculated plants and controls. It was found that shoots contained 76% of the nitrogen fixed as a result of inoculation, the roots 16% and the nodules 8%. This result is consistent with the findings of Chen et al. (1981) relating to the distribution of fixed nitrogen in legume parts.

Discussion

In all experiments, uninoculated control plants formed nodules, presumably from contamination with strains of rhizobia endemic in the soil used as growth medium. Although this was a consistent feature of the experiments, it in no way invalidates the conclusions drawn from the results. While the endemic strains contaminating the control treatments formed nodules and fixed some nitrogen, they never displayed a high level of effectiveness with the various acacias. So because of the role of the controls in estimating the amount and rate of nitrogen fixation by inoculated treatments (expressions 2 and 3), the values given for fixed nitrogen are likely to be underestimates. The values should more properly be considered as 'nitrogen fixation due to inoculation'.

Table 4. Effect of inoculation with selected strains of rhizobia on the nodulation of *A. melanoxylon* (2 provenances), *A. mearnsii* (2 provenances), *A. dealbata* (1 provenance) and *A. implexa* (1 provenance). Nodulation measured as nodule number per plant and nodule dry matter (DM – mg per plant).

Species	Provenance	No. of nodules		Nodule DM	
		Inoculated	Control	Inoculated	Control
A melanoxylon	17263	112.6	58.5	891	541
	18021	33.0	39.9	228	265
A. mearnsii	16246	197.6	97.0	637	236
	16621	281.6	65.6	837	269
A. dealbata	16271	28.5	42.5	387	164
A. implexa	18859	69.0	17.4	529	187

Table 5. Effect of inoculation with selected strains of rhizobia on indices of nitrogen fixation by *A. implexa* (1 provenance), *A. melanoxylon* (2 provenances), *A. dealbata* (1 provenance) and *A. mearnsii* (provenance).

Species	Provenance	Nitrogen content (g)		Amount of nitrogen fixed (g)	Rate of nitrogen fixation (%)
		Inoculated	Control		
A. implexa	18859	1.87	0.87	1.00	53.4
A. melanoxylon	16358	3.33	2.98	0.35	10.5
	17263	3.67	1.01	2.66	72.4
A. dealbata	16271	3.20	2.20	1.00	31.2
A. mearnsii	Yunnan	2.61	2.34	0.27	10.4

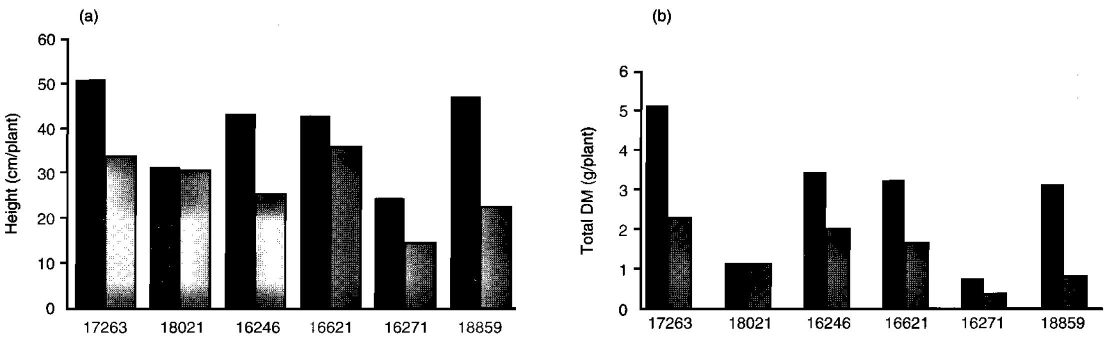

Figure 2. Effect of inoculation with selected strains of rhizobia on six species and provenances of *Acacia*: (a) seedling height; (b) seedling dry matter. Provenance numbers: *A. melanoxylon* 17263, 18021; *A. mearnsii* 16246, 16621; *A. dealbata* 16271; *A. implexa* 18859. Inoculated treatments indicated by black bars, uninoculated controls by shaded bars.

All of the strains of rhizobia tested entered into symbiosis with *Acacia*. However, there were significant differences between strains in the extent of nodulation, the magnitude of growth response and the amount and rate of nitrogen fixation which they induced in the host plants; Ge (1985) had a similar result with soybean strains. Moreover, there were substantial differences between species of *Acacia* and between provenances within species in the degree of response to inoculation with rhizobial strains selected for effectiveness of nitrogen fixation. It is clear that, in choosing effective strains for inoculants for lines of *Acacia*, careful consideration must be given to symbiotic compatibility at both species and provenance levels.

This study has shown that inoculation with effective rhizobia can increase *Acacia* growth rates in terms of height and biomass. The results indicate that effective rhizobial inoculation has great potential for increasing the productivity of *Acacia* in the forests of South China.

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References

Chen Huakui, Li Fudi, Chen Wenxin and Cao Yanzhen 1981. Soil Microbiology. Shanghai Science and Technology Publishing House, Shanghai, 146–147.

Ding Mingmao, Yi Weimin and Liao Lanyu 1991. Studies on the amount of nitrogen fixation by *Acacia auriculiformis* and *Acacia mangium*. Ecological Journal, 11 (3), 289–290.

Fan Hui, Ge Cheng and Xu Lingmei 1987. Studies of hydrogen absorption and release in the nodules of inoculated soybeans. Microbiology Bulletin, 14 (1), 3–6.

Ge Cheng 1985. New developments in research on the fast-growing rhizobia of soybean. Soybean Science, 4 (2), 159–163.

Hong Jusheng 1989. Research on Australian Broadleaf Trees. Chinese Forestry Publishing House, Beijing.

Li Qingkui 1989. Prospects for and development of soil science in China. Soil Journal, 26 (3), 207–216.

Martensson, A.M. and Ljunggren, H.D. 1984. A comparison between the acetylene method, the isotype dilution method and the total nitrogen difference method for measuring nitrogen fixation in lucerne (*Medicago sativa* L.) Plant and Soil, 81, 177–184.

NFLSPPRI [Nitrogen Fixation Laboratory of the Shanghai Plant Physiology Research Institute] 1974. Simplification of the acetylene-ethylene reduction quantitative analysis in nitrogen fixation research. Plant Journal, 16 (4), 382–384.

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, ACIAR, Canberra.

Vincent, J. M. 1970. A manual for the practical study of root-nodule bacteria. IBP Handbook No. 15. Blackwell, Oxford.

Matching Rhizobia and Temperate Species of *Acacia*

J. Brockwell[1]

Abstract

The literature and unpublished reports relating to the symbiosis between *Acacia* and its root-nodule bacteria (rhizobia) have been reviewed. The weight of evidence suggests that acacias fix useful quantities of nitrogen in the field, thereby conserving resources of soil nitrogen and perhaps acting as a source of nitrogen for other trees growing with them in mixed stands. *Acacia* species, and even provenances within species, are highly strain-specific in their requirement for effectively nitrogen-fixing rhizobial strains. Therefore, acacias introduced into new lands will require inoculation with effective rhizobia. Effective strains for acacias are probably most effectually selected on a species-by-species basis. Inoculation of acacias will be done most efficiently by sowing seed into rhizobia-rich nursery soil so that seedlings are well nodulated and fixing nitrogen when they are outplanted into plantations. The implications of these matters for inoculant preparation are discussed.

THE great family of legumes (Fabaceae) has three subfamilies: the Faboideae (or Papilionoideae), the Caesalpinioideae and the Mimosoideae (Wiersema et al. 1990). *Acacia* is the largest mimosoid genus containing at least 1200 species. Nearly 1000 species and subspecies occur naturally in Australia (Searle 1995). *Acacia* is also widely distributed in Asia and Africa, and occurs to a lesser extent in the Americas, but is uncommon in Europe. Representatives of the genus range from herbs (rare) to gigantic trees (e.g. Menninger 1962), but most are shrubs and small trees. Allen and Allen (1981) consider that only 75 species of *Acacia* have economic value, but this small number clearly takes no account of such useful generic characters as the provision of fuel wood, stabilisation for soil conservation, cultivation of shelter belts and street trees, beautification for gardens and recreational areas, and browse for grazing animals (Brockwell et al. 1995). More realistically, Searle (1996a) lists some 25 existing or potential uses for 42 temperate species of *Acacia*; the list is applicable to very many other species as well.

Nodulation with rhizobia appears almost universal amongst mimosoid plants. (In this paper, the term 'rhizobia' is used to describe *Acacia* root-nodule bacteria of the genera *Rhizobium* and *Bradyrhizobium*, and perhaps other as yet un-named genera.) Not all *Acacia* species have been examined for the presence of nodules. Accessing world-wide data up to 1974, Allen and Allen (1981) recorded 189 nodulated species of *Acacia*; examination of 11 other species had not revealed nodules up to that time. However, published information about specific *Rhizobium* requirements of different *Acacia* spp. which permit them to fix atmospheric nitrogen (N, N_2 fixation), is meagre and dispersed. In this contribution, we are charged with examining the literature relating to the symbiosis between *Acacia* and rhizobia to determine the extent of occurrence of host/bacterial specificity, i.e. the degree to which particular species must be matched with specific strains of rhizobia in order to fix N. This knowledge will allow informed decisions about how rhizobial inoculation of commercially cultivated acacias can best be managed to augment the N_2-fixing capacity of seedlings and adult trees.

Many microbiological and ecological factors have roles in the establishment of successful legume symbioses. These areas of temperate *Acacia* N_2 fixation have received little attention. Therefore, it has sometimes been necessary in this paper to draw on experience with other legume/rhizobia associations and extrapolate from them to *Acacia* symbioses. Use has also been made of symbiotic information relating to tropical *Acacia* species.

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Cross Nodulation

The cross nodulation concept, also known as cross inoculation, was developed in early studies of the symbiosis between legumes and root-nodule bacteria (Fred et al. 1932). The concept dictates that taxonomically related groups of legumes are nodulated by particular rhizobia, and that those rhizobia will nodulate across all legumes in the group (cross nodulation group) but will not nodulate plants in other cross nodulation groups. Examples of cross nodulation groups include:

- the genus *Trifolium* nodulated by *R. leguminosarum* bv. *trifolii*;
- the genera *Medicago*, *Melilotus* and *Trigonella* nodulated by *R. meliloti*; and
- generic members of the tribe Vicieae — *Lathyrus*, *Lens*, *Pisum*, *Vicia*, *Vavilovia* — all nodulated by *R. leguminosarum* bv. *viciae*.

The concept of cross nodulation makes a convenient guide for manufacturers of commercial legume inoculants used in agriculture because it allows them to use a single strain of rhizobium, and therefore a single inoculant, for a number of different legumes of the same cross nodulation group. For instance, in Australia, *R. leguminosarum* bv. *trifolii* strain TA1 is the sole rhizobial component of commercial inoculant for eight species of *Trifolium*: white, red, strawberry, alsike, berseem, purple, suckling and cluster clovers.

However, cross nodulation merely implies that a rhizobial strain has the ability to form nodules on the legumes in its cross nodulation group. It does not necessarily mean that those nodules will fix nitrogen. The genus *Trifolium* provides examples of this constraint. Clovers of the Mediterranean region fix N with one particular set of strains of *R. leguminosarum* bv. *trifolii*, whereas clovers of Central African origin require a distinctly different set of strains for N_2 fixation. Clovers from the Caucasus Mountains form a third cluster of rhizobial requirement for N_2 fixation, clovers from the Rocky Mountains form a fourth, and so on. (It would seem that the different rhizobial requirements of these various *Trifolium* clusters result from their symbioses with *R. leguminosarum* bv. *trifolii* having evolved in isolation from one another.) This characteristic is known as host specificity.

Cross nodulation in *Acacia* has similarities to cross nodulation in *Trifolium*. Strains of rhizobia that nodulate one species of *Acacia* have the capacity to form nodules on many, but not all, other *Acacia* spp.; and different acacias require specific strains to fix N. There are also differences between the two symbioses. *Trifolium* is nodulated by a single fast-growing biovar of the genus *Rhizobium*; *Acacia* forms nodules with fast- and slow-growing rhizobia of at least two genera, *Rhizobium* and *Bradyrhizobium*. The incidence of host specificity is far more pronounced in *Acacia* than in *Trifolium*; indeed, the specificity of rhizobial requirement for N_2 fixation in *Acacia* extends to provenances within species that grow in proximity to one another in the same forest.

Despite the paucity of literature about the symbiosis between *Acacia* and rhizobia, sufficient information exists to make it quite clear that the relationship is complex. Lawrie (1981, 1985) demonstrated that nodulation of Australian acacias was induced by both fast-growing *Rhizobium* and slow-growing *Bradyrhizobium*. Then Barnet et al. (1985) identified very-slow-growing rhizobia that formed nodules on *Acacia*. Similar observations have been reported for the rhizobia of African acacias (Habish and Khairi 1970; Dreyfus and Dommergues 1981). More recently, Yonga (1996) implicated a new genus (she called it *Pseudo-Bradyrhizobium*) in nodulating acacias. Pedley (1987) also considered that three genera were responsible for *Acacia* nodulation. Support for these hypotheses is provided by Young (1996) and Young and Haukka (1996) who showed that Rhizobiaceae is far more diverse than once believed.

Thompson et al. (1984) inoculated 64 species of *Acacia* with a diverse collection of 38 rhizobial strains. Their results, summarised in Table 1, showed that most strains nodulated most species, but that some species were relatively resistant to nodulation. Amongst species most readily nodulated were *A. dealbata*, *A. implexa*, *A. melanoxylon*, *A. mearnsii*, *A. mangium* and *A. auriculiformis*.

Table 1. Nodulation of 64 species of *Acacia* inoculated with a diverse collection of 38 rhizobial strains[1] (after Thompson et al. 1984).

Species nodulated	Strains that formed nodules			
	76–100%	51–76%	26–50%	0–25%
No.	43	11	6	4
%	67.2	17.2	9.4	6.2

[1] Most strains had been isolated from *Acacia* spp. or from other Australian natives; a few others were strains that were known to nodulate cowpea and symbiotically related legumes.

These data, of course, refer only to nodule formation, not to N_2 fixation. Information on (tropical) *Acacia* symbiosis derived from Yonga (1996) showed that the effectiveness of N_2 fixation of strains of rhizobia was relatively poor (Table 2), but that a strain isolated from a particular species was more capable of fixing N with that species than with others. Roughley (1987), Barnet (1988), Dart et al. (1991) and Miller et al. (1991) also found evidence of extreme variability in *Acacia* symbioses. Perhaps this is only to be expected in view of the great range of geographic, phenotypic and molecular differences among *Acacia* rhizobia (e.g. Barnet and Catt 1991; Yonga 1996; Odee et al. 1997; Lafay and Burdon 1998).

Table 2. Nitrogen-fixing capacity (%)[1] of six species of tropical *Acacia* in association with homologous and heterologous rhizobia (derived from Yonga 1996).

Species	Source of strains	
	Homologous[2]	Heterologous[2]
A. holosericea	58.0	35.0
A. difficilis	19.8	20.0
A. gonocarpa	55.8	28.0
A. mountfordiae	51.5	20.5
A. oncinocarpa	63.0	34.0
A. umbellata	60.5	22.5

[1] Fully effective in N_2 fixation = 100%.

[2] Homologous strains were isolated from the species on which they were tested for N_2 fixation; heterologous strains were isolated from species other than those on which they were tested. Each value for homologous strains (data column 1) is the mean for four strains; each value for heterologous strains (data column 2) is the mean for 20 strains.

Most of the work cited above dealt with relatively small numbers of species of *Acacia* and strains of rhizobia. Recently, however, as part of ACIAR project FST/92/27 Australian acacias for sustainable development in China, Vietnam and Australia, a comprehensive investigation of Australian *Acacia* symbioses was conducted. The main objective was to identify strains of rhizobia that form highly effective N_2-fixing associations with species of *Acacia* under consideration for introduction into China and Vietnam for the production of timber and fuelwood (Burdon 1996). Very many rhizobial strains were isolated from forest soils of southeastern Australia (Searle 1996b). In all, 67 provenances of a total of 20 species of *Acacia* (and other Australian leguminous shrubs) have been assessed for N_2 fixation in association with at least 10 strains of rhizobia. Some typical results are shown in Table 3 (Brown 1996). Initial analysis showed that the extent of strain variation and host specificity is considerable. The prospect of finding a single strain of rhizobia capable of fixing useful amounts of N with several *Acacia* species is negligible; Kang et al. (these Proceedings) reached a similar conclusion.

Table 3. Variation in the symbiotic N_2-fixing effectiveness of 16 *Acacia* spp. inoculated with rhizobial strains collected from sites where the acacias occurred. (Effectiveness is scaled by expressing N_2-fixing performance of individual host × strain combinations as a percentage of the performance of the best strain with that host; after Brown 1996.)

Species	Strains tested	N_2-fixing effectiveness (%)	
		Mean	Worst combination
A. cangaiensis	10	73.0	46.7
A. dealbata	90	55.8	3.9
A. deanei	10	80.6	53.2
A. decurrens	20	73.7	1.0
A. elata	10	69.2	28.6
A. fulva	30	75.1	6.8
A. glaucocarpa	10	78.7	44.6
A. implexa	40	82.5	60.9
A. irrorata	30	79.2	13.5
A. leucoclada	10	94.8	82.9
A. mearnsii	110	59.4	6.9
A. melanoxylon	80	60.6	11.3
A. nanodealbata	10	63.7	13.0
A. parramattensis	20	50.6	43.4
A. parvipinnula	10	79.9	70.6
A. trachyphloia	20	54.0	6.2

The Need for Inoculation

Inoculation for nodulation

These observations make it clear that choice of strains of rhizobia suitable for *Acacia* inoculants and the manufacture of the inoculants themselves will be arduous tasks. Before deciding how to proceed, we should ponder whether there is a genuine need to inoculate *Acacia* in order to induce nodule formation and N_2 fixation, or whether nodulation might be allowed to occur spontaneously. Brockwell et al. (1995) listed a series of 10 indicators to aid the diagnosis of the need for inoculation (Table 4). Let us consider application of these diagnostics to the introduction of *Acacia* to new lands.

Most of the 10 indicators prescribe that, in order to induce the formation of root nodules on introduced species, inoculation is mandatory. This prognosis would apply to Australian *Acacia* introduced into China and Vietnam where the genus has little or no silvicultural history. In particular, the indicator relating to host specificity asserts that, even where a species such as *A. mangium* has been grown previously, inoculation of new species would be necessary to ensure N_2 fixation. On the other hand, the indicators suggest that nothing would be achieved through inoculation in circumstances, e.g. in Australia, where a new *Acacia* is to be introduced into a forest where other species of *Acacia*, and their rhizobia, were already established.

Table 4. Diagnosis of the need to inoculate.

Allen and Allen (1961) — historical indicators

- The absence of the same or a symbiotically-related legume in the immediate past history of the land
- Poor nodulation when the same crop was grown on the land previously
- When the legume follows a non-leguminous crop in a rotation
- In land reclamation undertakings.

Roughley and Brockwell (1987) — microbiological queries

- How specific is the legume in its rhizobial requirements?
- What is the likelihood of effective rhizobia spreading from volunteer legumes?
- Has the legume been sown before and for how many seasons was it grown continuously?
- How long since the legume was last sown and, in the interim, were conditions likely to favour survival of the rhizobia?

Thies et al. (1991) — soil indices

- How large is the resident population of competitive rhizobia?
- What is the level of soil nitrogen (nitrate)?

Inoculation for nitrogen fixation

While inoculation is needed for the formation of effective root nodules, it would be futile if the fixed N contributed little or nothing to the well-being of the acacias, to the vigour of plantations or to the pool of N in forest soils. There have been many field investigations on the N_2-fixing capabilities of leguminous trees. The results of some of them are summarised in Table 5.

The data show that the amounts of N fixed by acacias were highly variable. In general, more N was fixed by other leguminous tree genera than by *Acacia*. It is not known to what extent ineffective or poorly effective rhizobia were implicated. Despite the relatively small quantities of N fixed by acacias, in the nine investigations where the proportion of total tree N due to N_2 fixation was calculated (Table 5), the values were 30–88%. This, of course, represents a 'sparing' of N that would otherwise have been extracted from the soil. N-sparing through N_2 fixation is a significant strategy for sustainability in agriculture and forestry (Herridge and Danso

Table 5. Estimate of N_2 fixation in leguminous trees. Derived from Peoples and Craswell (1992), Khanna (1998), and unpublished data.[1]

Genus	N_2 fixation		Period	Citation
	Amount fixed (kg/ha)	Proportion (%)		
Acacia	12	—	annual	Langkamp et al. 1979
Acacia	—	52–66	—	Peoples, Almendras and Dart[1]
Acacia	—	51–81	—	Dart and Almendras[1]
Acacia	—	84–88	—	Dart and Almendras[1]
Acacia	—	34–67	—	Dart and Almendras[1]
Acacia	—	69	—	Palmer[1]
Acacia	—	56	—	Palmer and Tatang[1]
Acacia	—	59	—	Palmer and Tatang[1]
Acacia	3–6	30	6.5 months	Cornet et al. 1985
Acacia	12–32	—	annual	Adams and Attiwell 1984
Acacia	<1	—	annual	Lawrie 1981
Acacia	200	—	annual	Orchard and Darb 1956
Acacia	32	—	annual	Turvey et al. 1983
Acacia	—	63	—	Ndoye et al.1995
Albizia	94	60	annual	Liya et al.1990
Albizia	—	55	—	Peoples, Almendras and Dart[1]
Calliandra	11	14	90 days	Peoples and Palmer[1]
Gliricidia	108	72	annual	Liya et al. 1990
Gliricidia	13	—	annual	Roskoski et al. 1982
Gliricidia	99	75	annual	Peoples and Palmer[1]
Gliricidia	—	60	annual	Peoples and Ladha[1]
Inga	35	—	annual	Roskoski 1981
Leucaena	110	—	annual	Hogberg and Kvarnstrom 1982
Leucaena	296–313	58–78	3 months	Zoharah et al. 1986
Leucaena	288–344	34–39	6 months	Sanginga et al. 1989
Leucaena	—	59–100	—	Yoneyama et al. 1990

1995; Peoples, Herridge and Ladha 1995; Peoples, Ladha and Herridge 1995; Khanna 1997).

In an elegant experiment in a southeastern Australian forest, Khanna (1997) grew *Acacia mearnsii* in mixed stands with *Eucalyptus globulus*. The presence of *Acacia* was associated with incremental growth of the eucalypts which was attributed to their enhanced N status. It was postulated that the improvement was brought about by underground transfer of N from the acacias to the eucalypts (e.g. Ofiri and Stern 1987), but the literature is often contradictory (citations by Peoples and Craswell 1992).

While it is difficult to quantify the benefits of *Acacia* N_2 fixation to forest economies in monetary terms, much of the available information is positive. For example, it is likely to improve nitrogen-sparing and silvicultural sustainability. This might be augmented by utilisation of effective inoculation in forest nurseries.

Inoculation policy

Although perhaps a less efficient fixer in the field than other tree legumes, *Acacia* often fixes useful quantities of N. It is a genus with an N-sparing characteristic, and may well transfer N to companion tree genera. When it is to be grown on new land, inoculation with effective rhizobia is necessary to ensure efficient N_2 fixation. It is submitted that the weight of evidence favours the use of rhizobial inoculation for *Acacia* spp. and that tactics for inoculant preparation and application should be considered. It makes good sense that *Acacia* inoculation should take place in the nursery when the seed is sown. If seedlings are nodulated effectively, fixing N efficiently and independent of soil N at the time of outplanting, the chances of successful establishment in the plantation will be much greater.

Inoculant Production

In order to obtain well nodulated *Acacia* seedlings for outplanting, it will be necessary either to inoculate the seed as it is sown or to ensure that the nursery soil for propagation of young seedlings is abundantly populated with effective rhizobia. The second strategy appears to be preferable.

Selection of strains

Drawing on published data and the experience of legume manufacturers, Brockwell et al. (1995) listed 15 criteria considered desirable for rhizobial strains for use in legume inoculants. Characters especially relevant to *Acacia* inoculation include:

- ability to form nodules and fix N on the target legume;
- ability to form nodules and fix N in the presence of soil nitrate;
- ability to persist in soil;
- possession of a wide host range; and
- ability to compete in nodule formation with populations of rhizobia already present in the soil.

Ability to form nodules

Obviously, in selecting rhizobia for inoculation of *Acacia*s, the ability to form effective nodules is of primary importance. Recent work using methods described by Gibson (1980) has identified strains that are highly effective in N_2 fixation for 20 temperate species of *Acacia*.

Activity in the presence of soil nitrate

It is a simple matter to prepare nursery soil that is not nitrate-rich.

Ability to persist in soil

The practical value of a persistence character in rhizobia for *Acacia* inoculation is doubtful. With annuals, such as crop legumes that are grown from time to time or self-regenerating annual pasture legumes, persistence of their rhizobia in the soil for several years or between seasons is an essential component leading to continuing plant productivity and N contribution to the soil. With perennial legumes it is different. Once nodules are formed, a continuing source of inoculation is virtually guaranteed. The environment for rhizobia within a nodule is analogous to pure culture. Nodules contain about 5×10^{10} rhizobia per gram fresh weight. In a plantation with 1000 acacias per hectare, each with 20 grams of nodules, there would be 1×10^{15} nodule-borne rhizobia per hectare, which equates to 200 000 rhizobia per gram of soil to 30 cm depth. Very few soils naturally contain more than 10 000 free-living rhizobia per gram.

As nodules on perennial legumes become aged and disintegrate, huge numbers of rhizobia are released at strategic locations where they represent a potent inoculum for reinfection and re-nodulation of the root system. Because non-nodule (i.e. free-living) rhizobia are so greatly outnumbered, the question of competitive persistence amongst inoculum and non-inoculum strains does not arise. What this implies is that a strain of rhizobia which has formed abundant nodules on an *Acacia* seedling in the nursery will almost certainly continue to nodulate the tree when it is outplanted.

Possession of a wide host range

It is unrealistic to hope to find rhizobia with a wide host range for *Acacia* species. Selection of effective strains will be done most efficiently on a species-by-species basis (Dart et al. 1991).

Ability to compete

The question of competitiveness of an inoculant strain with other rhizobia need not be a concern where populations of potentially competitive rhizobia in nursery soil are small or non-existent. This circumstance would be readily achievable where soil for growth of *Acacia* seedlings is contained in polyethylene propagation cylinders.

Multistrain inoculants

It is the custom in Australia to use a single inoculant strain in a legume inoculant. This has the advantage of facilitating quality control. However, it has the disadvantage of restricting the scope (host range) of any particular inoculant. It is common practice in most other countries to produce multistrain inoculants. Somasegaran and Bohlool (1990) made an extensive comparison of multistrain and single-strain inoculants. They found that in almost all cases the effectiveness of a multistrain inoculant exceeded or equalled the performance of the best strain in that inoculant. Multistrain inoculants may be necessary to achieve successful nodulation and satisfactory N_2 fixation with a target species of *Acacia* where host specificity extends down to the provenance level. They will be mandatory whenever it is proposed to use the one inoculant for more than one species.

Making inoculants

Keyser et al. (1992) regard the properties of a good carrier for legume inoculant as:

- high water-holding capacity;
- non-toxic to rhizobia;
- easy to sterilise by autoclaving or gamma irradiation;
- readily and inexpensively available;
- sufficiently adhesive for effectual application to seed;
- pH buffering capacity; and
- ion-exchange capacities.

Finely-ground peat meets most of the criteria. Unfortunately, deposits of peat often do not occur naturally in tropical climates, so the search for alternative legume inoculant carriers has been extensive (Thompson 1980; Brockwell et al. 1995). Only a vermiculite carrier has been sufficiently apt to find its way into commerce (Graham-Weiss et al. 1987; Paau 1989). Sterile peat (Roughley and Vincent 1967) remains the preferred carrier. Small-scale fermenters appear best suited to the production of broths for the preparation of *Acacia* inoculants. Hoben and Somasegaran (1992) and Somasegaran et al. (1992) have described suitable equipment.

Inoculant application

There are two options for applying inoculant to obtain nodulation of *Acacia* seedlings — seed inoculation and soil inoculation. The primary aim of seed inoculation is to maximise survival of inoculant during the period between its application to the seed and the development of a legume rhizosphere which it can colonise. The principle is illustrated in Figure 1 (Brockwell 1962). The illustration emphasises the significance of high rates of inoculation in achieving this objective and optimising subsequent nodulation and N_2 fixation. With seed inoculation, the inoculum is concentrated on the testa, and is required to move from that point to the places where infection foci occur on the roots of the young seedling.

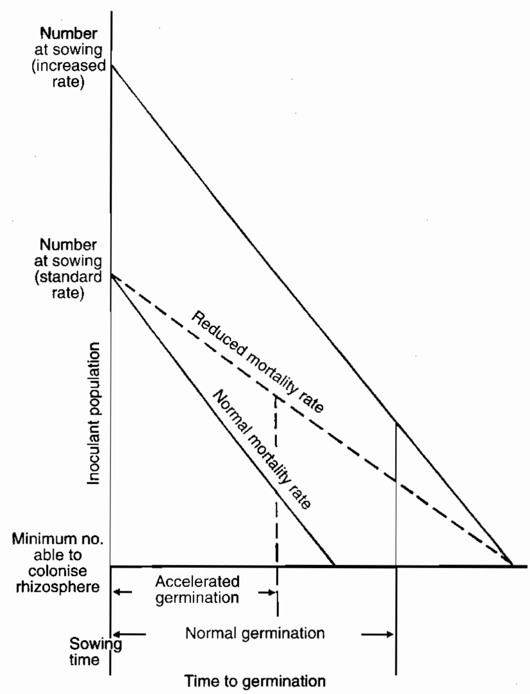

Figure 1. A schematic illustration of basic factors involved in improving the likelihoodof nodulation following rhizobial inoculation of legume seed: (i) reducing mortality rate, (ii) increasing rate of inoculant application, (iii) decreasing time to germination (after Brockwell 1962).

Soil inoculation would provide a *Rhizobium*-rich medium with large dispersed populations of the bacteria strategically located to infect and nodulate the seedling roots immediately they become infectable. Soil inoculation lends itself to a system where nursery practice involves the use of containers of soil for propagation of seedling trees.

Other Issues

Rhizobia-rich nursery soil

Findings that well-nodulated acacias can be produced under nursery conditions are the key to a silvicultural system for the establishment of healthy, well-nodulated, mineral-N-independent *Acacia* spp. in the forests of South China (Brockwell 1996; Kang et al. (these Proceedings)). The next microbiological step in making this a reality is to demonstrate to foresters a simple, effective procedure for preparing a pre-inoculated nursery soil that will provide well-nodulated seedlings of any *Acacia* species ready for outplanting. As part of an extension to ACIAR project FST/92/27, it is proposed to develop a four-step procedure (broth culture, peat culture, organic soil, inoculated soil) for preparing rhizobia-rich nursery soil for growing well-nodulated *Acacia* seedlings. This will involve: enumeration of rhizobial populations at each step (Brockwell 1963, as modified by Brockwell et al. 1975, and Grassia and Brockwell 1978); measurement of seedling nodulation and growth; and, desirably, appraisal of subsequent growth of outplantings with and without applied mineral N.

Inoculant composition

The main issues raised in this paper indicate that, ideally, each *Acacia* species should have a unique inoculant. Each such inoculant should comprise two or three rhizobial strains to cater for host-specificity differences between provenances within species. Practically, this is cumbersome. It would obviously be more efficient for inoculant manufacturers and users alike if one inoculant could serve for several species. This might be achieved with multistrain inoculants. An example might be an inoculant for three *Acacia* spp. comprising six strains, two of which were highly effective for *A. implexa*, two highly effective for *A. mearnsii*, and two highly effective for *A. melanoxylon*. Commercial inoculants, containing up to six strains, are known to have been produced. Gault (1987) has shown that broth cultures of two or three strains of *R. leguminosarum* bv. *trifolii*, and *R. meliloti*, can be introduced into a peat carrier and multiply there independently of one another.

Before such multistrain inoculants can become a reality for *Acacia* species, it will be necessary to confirm that acacias, like many temperate legumes (e.g. Robinson 1969; Masterson and Sherwood 1974), exercise a selective preference for effective strains from a mixed rhizobial microflora. For instance, from a multistrain inoculant, *A. implexa* will be nodulated by rhizobia effective for it, *A. mearnsii* will be nodulated by *A. mearnsii* strains, and so on. Examination of this proposition will be another objective of the extension to ACIAR project FST/92/27. *Acacia* species can be grown under bacteriological control in assemblies containing a medium of well-washed vermiculite moistened with N-free McKnight's (1949) plant nutrient solution. Thornton (1930) and Gibson (1963) tubes will be the assemblies used for aseptic culture of acacias and rhizobia.

At present, there is no comprehensive collection of *Acacia* rhizobia preserved anywhere in the world. The strains collected (Searle 1996b) and tested (Burdon 1996) as part of ACIAR project FST/92/27, represent a resource of great value. They are to be kept freeze-dried in multiple ampoules, and a decision will be taken about where they will be housed. Irrespective of the outcome, a strong case can be made for the establishment of a genetic resource centre for *Acacia* rhizobia at some central site in Asia where there is active involvement in utilisation of exotic *Acacia*s. The Longdong (Guangzhou) laboratory of the Research Institute of Tropical Forestry might be a suitable location.

Seed and rhizobia packages for species assessment

A further issue relates to nursery and field trials of exotic acacias. Certain institutions maintain seed banks of *Acacia* spp. which are accessible to forestry researchers. It would be sensible to put in place a mechanism whereby seed of *Acacia* spp. for experimental purposes is supplied in a package accompanied by a peat culture of a specific effective strain, or strains, of rhizobia. (Agar cultures may be unsatisfactory for field experimentation — Brockwell 1977.) This would ensure that symbiotic expression of N_2-fixing capacity is taken into account in making species assessments.

Conclusions

As a nodulating legume, *Acacia* is a genus with the capacity to supply much or all of its requirements for N by fixation of atmospheric N_2. The evidence indicates that this characteristic benefits acacias growing in the field. Also, by reducing the demand of the trees for soil N, it contributes to forest sustainability.

As a genus, *Acacia* forms nodules with a diverse suite of rhizobia, themselves representing two or more bacterial genera. However, most strains able to form nodules on acacias fix little or no N. Exotic acacias introduced into new lands are unlikely to encounter effective strains among the populations of rhizobia already resident in the soil. Inoculation will be needed.

Because of the high level of host specificity for N_2-fixing rhizobia between *Acacia* species, and even between provenances within species, it will be necessary to select effective inoculant strains on a species-by-species basis. Investigations as part of ACIAR project FST/92/27 have already identified effective rhizobial strains for 20 temperate *Acacia* species. However, the likelihood of locating a single strain that is highly effective for more than one species appears remote. Indeed, because of host specificity between provenances, it would be prudent in preparing inoculant to use two or three strains for each species.

Any protocol that demands a separate inoculant for every species is undesirably cumbersome. It is proposed as a feasible alternative to have multistrain inoculants that will work for up to three *Acacia* species. For example, a six-strain inoculant good for *A. implexa*, *A. mearnsii and A. melanoxylon* would contain two strains effective for each, all in the same packet of peat.

An effective means to obtain well nodulated *Acacia* trees might be to sow seed into a rhizobia-rich nursery soil so that seedlings are effectively nodulated at outplanting. A four-step process for preparing the soil is proposed: broth culture, peat culture, organic soil, inoculated soil. Each step involves an increase in the volume of 'medium' and each medium supports rhizobial multiplication. At the fourth step, a large volume of inoculated soil, supporting a large total population of rhizobia, would be available for seeding *Acacia*s in the nursery. This proposition remains to be tested.

It is submitted that *Acacia* seedlings effectively fixing N at the time of outplanting will be more vigorous than non-nodulated or poorly nodulated plants dependent on soil N. They will have better prospects for survival and establishment in the plantation, and will make less demand on N resources in the soil.

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References

Adams, M.A. and Attiwell, P.M. 1984. Role of *Acacia* spp. in nutrient balance and cycling in regenerating *Eucalyptus regnans* F. Muell. forests. II. Field studies of acetylene reduction. Australian Journal of Botany, 32, 217–223.

Allen, E.K. and Allen, O.N. 1961. The scope of nodulation in the Leguminoseae. In: Recent Advances in Botany. Volume 1. Proceedings of the Ninth International Botanical Congress. Toronto, University of Toronto Press, 585–588.

Allen, O.N. and Allen, E.K. 1981. The Leguminoseae. A Source Book of Characteristics, Uses, and Nodulation. Madison WI, University of Wisconsin Press, 812 p.

Barnet, Y.M. 1988. Nitrogen-fixing symbioses with Australian native legumes. In: Murrell, W.G. and Kennedy, I.R., ed., Microbiology in Action. Letchworth, UK, Research Studies Press, 81–92.

Barnet, Y.M. and Catt, P.C. 1991. Distribution and characteristics of root-nodule bacteria isolated from Australian *Acacia* spp. Plant and Soil, 135, 109–120.

Barnet, Y.M., Catt, P.C. and Hearne, D.H. 1985. Biological nitrogen fixation and root-nodule bacteria (*Rhizobium* sp. and *Bradyrhizobium* sp.) in two rehabilitating sand dune areas planted with *Acacia* spp. Australian Journal of Botany, 33, 595–610.

Brockwell, J. 1962. Studies on seed pelleting as an aid to legume seed inoculation. I. Coating materials, adhesives, and methods of inoculation. Australian Journal of Agricultural Research, 13, 638–649.

Brockwell, J. 1963. Accuracy of a plant-infection test for counting populations of *Rhizobium trifolii*. Applied Microbiology, 11, 377–383.

Brockwell, J. 1977. Application of legume seed inoculants. In: Hardy, R.W.F. and Gibson, A.H., ed., A Treatise on Dinitrogen Fixation. Section IV. Agronomy and Ecology. New York, John Wiley and Sons, 277–309.

Brockwell, J. 1996. Report on appraisal of the China component of subproject B: 'Effectiveness and persistence of *Acacia* rhizobia', June 1996. In: Brown, A.G., ed., Australian Acacias for Sustainable Development in China, Vietnam and Australia. ACIAR Project 9227. Review Report January-September 1996, Canberra, CSIRO Forestry and Forest Products, 57–63.

Brockwell, J., Bottomley, P.J. and Thies, J.E. 1995. Manipulation of rhizobia microflora for improving legume productivity and soil fertility: A critical assessment. Plant and Soil, 174, 143–180.

Brockwell, J., Diatloff, A., Grassia, A. and Robinson, A.C. 1975. Use of wild soybean (*Glycine ussuriensis* Regel and Maack) as a test plant in dilution-nodulation frequency tests for counting *Rhizobium japonicum*. Soil Biology and Biochemistry, 17, 305–311.

Brown, A.G. 1996. Subproject B. Effectiveness and persistence of *Acacia* rhizobia. In: Brown, A.G., ed., Australian Acacias for Sustainable Development in China, Vietnam and Australia. ACIAR Project 9227. Second Annual Report January-December 1995, Canberra, CSIRO Forestry and Forest Products, 9–12.

Burdon, J.J. 1996. Subproject B. Australian component. Effectiveness and persistence of *Acacia* rhizobia. In: Brown, A.G., ed., Australian Acacias for Sustainable Development in China, Vietnam and Australia. ACIAR Project 9227. Review Report January–September 1996. Canberra, CSIRO Forestry and Forest Products, 47–51.

Cornet, F., Otto, C., Rinaudo, G., Diem, H.G. and Dommergues, Y. 1985. Nitrogen fixation by *Acacia holosericea* grown in field-simulating conditions. Acta Oecologica Plantarum, 6, 211–218.

Dart, P., Umali-Garcia, M. and Almendras, A. 1991. Role of symbiotic associations in nutrition of tropical acacias. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Canberra, ACIAR, 13–19.

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

Fred, E.B., Baldwin, I.L. and McCoy, E. 1932. Root Nodule Bacteria and Leguminous Plants. University of Wisconsin Studies in Science No. 5. Madison WI, University of Wisconsin Press, 343 p.

Gault, R.R. 1987. A study of the survival of, and competition between, strains of *Rhizobium* spp. during the production and use of mixed-strain inoculants. MSc Thesis, Macquarie University, Sydney, 177 p.

Gibson, A.H. 1963. Physical environment and symbiotic nitrogen fixation. I. The effect of root temperature on recently nodulated *Trifolium subterraneum* plants. Australian Journal of Biological Sciences, 15, 37–49.

Gibson, A.H. 1980. Methods for legumes in glasshouses and controlled environment cabinets. In: Bergersen, F.J., ed., Methods for Evaluating Biological Nitrogen Fixation. Chichester, UK, John Wiley and Sons, 139–184.

Graham-Weiss, L., Bennett, M.L. and Paau, A.S. 1987. Production of bacterial inoculants by direct fermentation on nutrient-supplemented vermiculite. Applied and Environmental Microbiology, 53, 2138–2140.

Grassia, A. and Brockwell, J. 1978. Enumeration of rhizobia from a plant-infection dilution assay using test plants grown in vermiculate. Soil Biology and Biochemistry, 10, 101–104.

Habish, H.A. and Khairi, S.M. 1970. Effect of certain soil conditions on nodulation of *Acacia* spp. Experimental Agriculture, 6, 171–176.

Herridge, D.F. and Danso, S.K.A. 1995. Enhancing crop legume N_2 fixation through selection and breeding. Plant and Soil, 174, 51–82.

Hoben, H.J. and Somasegaran, P. 1992. A small glass fermentor for the production of *Rhizobium* inoculum. World Journal of Microbiology and Biotechnology, 6, 333–334.

Hogberg, P. and Kvarnstrom, M. 1982. Nitrogen fixation by the woody legume *Leucaena leucocephala* in Tanzania. Plant and Soil, 66, 21–28.

Keyser, H.H., Somasegaran, P. and Bohlool, B.B. 1992. Rhizobial ecology and technology. In: Metting, F.B. Jr, ed., Applications in Agricultural and Environmental Management, New York, Marcel Dekker, 205–226.

Khanna, P.K. 1997. Comparison of growth and nutrition of young monocultures and mixed stands of *Eucalyptus globulus* and *Acacia mearnsii*. Forest Ecology and Management, 94, 105–113.

Khanna, P.K. 1998. Nutrient cycling under mixed-species tree systems in southeast Asia. Forest Ecology and Management (in Press).

Lafay, B. and Burdon, J.J. 1998. Diversity of native rhizobia in south-eastern Australia. Applied and Environmental Microbiology (in Press).

Langkamp, P.J., Swinden, L.B. and Dalling, M.J. 1979. Nitrogen fixation (acetylene reduction) by *Acacia pellita* on areas restored after mining at Groote Eylandt, Northern Territory. Australian Journal of Botany, 27, 353–361.

Lawrie, A.C. 1981. Nitrogen fixation by native Australian legumes. Australian Journal of Botany, 29, 143–157.

Lawrie, A.C. 1985. Relationships among rhizobia from native Australian legumes. Applied and Environmental Microbiology, 45, 1822–1828.

Liya, S.M., Odu, C.T.I., Agboola, A.A. and Mulongoy, K. 1990. Estimation of N_2 fixation by nitrogen fixing trees in the subhumid tropics using ^{15}N dilution and difference methods. Paper presented at the Fourth Meeting of the African Association for Biological Nitrogen Fixation, IITA, Ibadan, Nigeria.

Masterson, C.L. and Sherwood, M.T. 1974. Selection of *Rhizobium trifolii* strains by white and subterranean clovers. Irish Journal of Agricultural Research, 13, 91–99.

McKnight, T. 1949. Efficiency of isolates of *Rhizobium* in the cowpea group, with proposed additions to this group. Queensland Journal of Agricultural Science, 6, 61–76.

Menninger, E.A. 1962. Flowering Trees of the World — For Tropics and Warm Climates. New York, Heathside Press, 336 p.

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

Ndoye, I., Gueye, M., Danso, S.K.A. and Dreyfus, B. 1995. Nitrogen fixation in *Faidherbia albida*, *Acacia raddiana*, *Acacia senegal* and *Acacia seyal* estimated using the ^{15}N isotope dilution technique. Plant and Soil, 172, 175–180.

Odee, D.W., Sutherland, J.M., Makatiani, E.T., McInroy, S.G. and Sprent, J.I. 1997. Phenotypic characteristics and composition of rhizobia associated with woody legumes growing in diverse Kenyan conditions. Plant and Soil, 188, 65–75.

Ofori, F. and Stern, W.R. 1987. Cereal-legume intercropping systems. Advances in Agronomy, 41, 41–90.

Orchard, E.R. and Darb, G.D. 1956. Fertility changes under continual wattle culture with special reference to nitrogen and base status of the soil. Transactions of the Sixth International Congress of Soil Science, Vol. D, 305–310.

Paau, A.S. 1989. Improvement of rhizobial inoculants. Applied and Environmental Microbiology, 55, 862–865.

Pedley, L. 1987. Australian acacias: taxonomy and phytogeography. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries, ACIAR Proceedings No. 16. Canberra, ACIAR, 11–16.

Peoples, M.B. and Craswell, E.T. 1992. Biological nitrogen fixation: Investments, expectations and actual contributions to agriculture. Plant and Soil, 141, 13–39.

Peoples, M.B., Herridge, D.F. and Ladha, J.K. 1995. Biological nitrogen fixation: An efficient source of nitrogen for agricultural production? Plant and Soil, 174, 3–28.

Peoples, M.B., Ladha, J.K. and Herridge, D.F. 1995. Enhancing legume N_2 fixation through plant and soil management. Plant and Soil, 174, 83–101.

Robinson, A.C. 1969. Host selection for effective *Rhizobium trifolii* by red clover and subterranean clover in the field. Australian Journal of Agricultural Research, 20, 1053–1060.

Roskoski, J.P. 1981. Nodulation and N_2-fixation by *Inga jinicuil*, a woody legume in coffee plantations. I. Measurements of nodule biomass and field C_2H_2 reduction rates. Plant and Soil, 59, 201–206.

Roskoski, J.P., Montana, J., van Kessel, C. and Castilleja, G. 1982. Nitrogen fixation by tropical woody legumes: Potential source of soil enrichment. In: Graham, P.H. and Harris, S.C., ed., Biological Nitrogen Fixation Technology for Tropical Agriculture. Cali, Colombia, CIAT, 447–454.

Roughley, R.J. 1987. Acacias and their root-nodule bacteria. In: Turnbull J.W., ed., Australian Acacias in Developing Countries, ACIAR Proceedings No. 16. Canberra, ACIAR, 45–49.

Roughley, R.J. and Brockwell, J. 1987. Grain legumes and soil microorganisms. In: de Kantzow, D.R. and May, M.G., ed., Grain Legumes 1987 Research and Production Seminar, AIAS Occasional Publication No. 28. Sydney, Australian Institute of Agricultural Science, 66–69.

Roughley, R.J. and Vincent, J.M. 1967. Growth and survival of *Rhizobium* spp. in peat culture. Journal of Applied Bacteriology, 30, 362–376.

Sanginga, N., Mulongoy, K. and Ayanaba, A. 1989. Nitrogen fixation in field-inoculated *Leucaena* leucocephala (Lam.) de Wit estimated by the ^{15}N and the difference methods. Plant and Soil, 117, 269–274.

Searle, S. 1995. Australia acacias, no longer the forgotten genus. IFA (Institute of Foresters of Australia) Newsletter, 36 (2), 9–15.

Searle, S. 1996a. Wood and non-wood uses of temperate Australian acacias. Proceedings of the 1996 Australian Forest Growers Conference 'Investing in Future Wood Supply'. In: Farm Forestry and Plantations, 1–71.

Searle, S.D. 1996b. Collections of nodules, soil and foliage conducted by CSIRO Forestry and Forest Products (Subproject A) for CSIRO Division of Plant Industry's rhizobia research. In: Brown, A.G., ed., Australian Acacias for Sustainable Development in China, Vietnam and Australia. ACIAR Project 9227. Second Annual Report January-December 1995. Canberra, CSIRO Forestry and Forest Products, 117–120.

Somasegaran, P. and Bohlool, B.B. 1990. Single-strain versus multistrain inoculation: effect of soil mineral N availability on rhizobial strain effectiveness and competition for nodulation on chick-pea, soybean and dry bean. Applied and Environmental Microbiology, 56, 3298–3303.

Somasegaran, P., Hoben, H.J. and Bohlool, B.B. 1992. A medium-scale fermentor for mass culture of rhizobia. World Journal of Microbiology and Biotechnology, 8, 335–336.

Thies, J.E., Singleton, P.W. and Bohlool, B.B. 1991. Influence of the size of indigenous rhizobial populations on establishment and symbiotic performance of introduced rhizobia on field-grown legumes. Applied and Environmental Microbiology, 57, 19–28.

Thompson, J.A. 1980. Production and quality control of legume inoculants. In: Bergersen, F.J., ed., Methods for Evaluating Biological Nitrogen Fixation. Chichester, UK, John Wiley and Sons, 489–533.

Thompson, S.C., Gemell, G. and Roughley, R.J. 1984. Host specificity for nodulation among Australian acacias. In: Kennedy, I.R. and Copeland, L., ed., Proceedings of the Seventh Australian Legume Nodulation Conference, AIAS Occasional Publication No. 12. Sydney, Australian Institute of Agricultural Science, 27–28.

Thornton, H.G. 1930. The early development of the root nodule of lucerne (*Medicago sativa* L.). Annals of Botany, London, 44, 385–392.

Turvey, N.D., Attiwell, P.M., Cameron, J.N. and Smethurst, P.J. 1983. Growth of planted pine trees in response to variation in the densities of naturally regenerated acacias. Forest Ecology and Management, 7, 103–117.

Wiersema, J.H., Kirkbride, J.H. Jr and Gunn, C.R. 1990. Legume (Fabaceae) Nomenclature in the USDA System. US Department of Agriculture, USDA Technical Bulletin. No. 1757, 572 p.

Yoneyama, T., Murakami, T., Boonkerd, N., Wadisirisuk, P., Siripin, S. and Kuono, K. 1990. Natural ^{15}N abundance in shrub and tree legumes, casuarina, and non N_2 fixing plants in Thailand. Plant and Soil, 128, 287–292.

Yonga, M.M. 1996. Symbiotic characteristics and genetic diversity of rhizobia nodulating some native leguminous trees and shrubs. PhD thesis, Australian National University, Canberra, 181 p.

Young, J.P.W. 1996. Phylogeny and taxonomy of rhizobia. Plant and Soil, 189, 45–52.

Young, J.P.W. and Haukka, K.E. 1996. Diversity and phylogeny of rhizobia. New Phytologist, 133, 87–94.

Zoharah, A.H., Sharifuddin, H.A.H. and Subramaniam, R. 1986. Nitrogen fixation by *Leucaena leucocephala* as measured by ^{15}N dilution technique. Pertanika, 9, 17–22.

Acacias and Mine Rehabilitation: The Need for Inoculating Acacias with Mycorrhizal Fungi

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Abstract

A field trial was conducted to determine the need for inoculating acacias with mycorrhizal fungi, and a pot experiment aimed to quantify the benefits of endomycorrhizal fungi to acacias. Results of the field trial suggested that little, if any, volunteer colonisation of mycorrhizal fungi occurs on mine spoils, and the provision of even a thin layer of topsoil acts as an excellent source of mycorrhizal inocula. The pot trial with *A. holosericea* and *A. nilotica* showed marked growth improvement to inoculation with three mycorrhizal species (*Glomus aggregatum*, *Gigaspora albida* and *Glomus mosseae*); the latter was the most effective on acacias.

ACACIAS form an essential component of mine revegetation programs throughout Australia. This is particularly so in tropical Australia, where the mine spoils are difficult to revegetate with other native species. Acacias can grow well on depauparate spoils and allow other native species to colonise and take over with time, thus acting as succession species.

Acacias are commonly used in mine revegetation programs because of low seed cost and the ease with which the seeds can be collected, stored and broadcast on mine spoils (Turnbull 1987). Acacias are able to tolerate harsh soil conditions because they can withstand drought and establish symbiotic associations with rhizobia and mycorrhizal fungi. The role of rhizobia in improving growth of acacias has been demonstrated by Ashwath et al. (1995), and the importance of mycorrhizal fungi in plant growth is illustrated here.

Acacias establish symbiotic relationships with two types of mycorrhizal fungi: endomycorrhizal fungi (also known as vesicular-arbuscular mycorrhizal fungi, ('VAM') and ectomycorrhizal fungi. While the endomycorrhizal fungi seem to be predominant in most acacias (Table 1), ectomycorrhizal fungi and dual infection are not uncommon (Brundrett et al. 1996a,b). Endomycorrhizal fungi assist plants to:

- take up water (Safir et al. 1972);
- take up nutrients, particularly the scarce element phosphorus (Hayman 1985);
- increase absorptive surface of roots (Ragupathy and Mahadevan 1991, 1993); and
- provide resistance against infection by pathogens (Davis and Menge 1981; Chakravarthy and Mishra 1986).

Table 1. Mycorrhizal association of *Acacia* species (Reddell and Warren 1987).

Mycorrhizal type	*Acacia* spp
Ectomycorrhizal fungi	aneura, dealbata, decurrens, melanoxylon, mitchellii, pycnantha, platycarpa, rubida, salicina, sophorae, sparsiflora, verticillata
Endomycorrhizal fungi	albida, arabica, aulacocarpa, auriculiformis, concurrens, constricta, farnesiana, floribunda, goetzei, greggii, holosericea, latescens, mangium, mellifera, nigrescens, nilotica, nubica, polyacantha, pulchella, pyrifolia, raddiana, richii, saligna, senegal, seyal, suaveolens, torulosa
Endo- and ecto-mycorrhizal fungi	myrtifolia, redoxylon, rothii, simsii

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Thus, inoculation of acacias with effective strains of VAM fungi could alleviate phosphorus deficiency, increase plant growth and promote long-term sustainability on mine spoils (Mahadevan et al. 1989).

Acacias fix atmospheric nitrogen and hence they require higher concentrations of P compared to non-nitrogen fixing species. In addition, acacias have limited root hair (Dr S. Ragupathy, unpublished data), and their root system will be reduced when grown in harsh soils. Thus, symbiotic association of acacias with mycorrhizal fungi is important as it contributes to plant growth by increasing availability of P (directly) and N (indirectly) and expanding the effective root surface area.

Acacias have responded to inoculation with VAM fungi in a pot culture experiment (Cornet and Diem 1982) and in the field when pre-inoculated seedlings were used (Cornet et al. 1982). Cornet et al. (1982) found that inoculation of *Acacia raddiana* and *A. holosericea* with *Glomus mosseae* increased shoot weight by 170 and 850% respectively, and nodule weight by 10-12 fold. Similar growth responses occurred when the *Acacia* species were supplied with phosphate fertiliser in place of mycorrhizal fungi. This study also demonstrated beneficial effects of mycorrhizal fungi in enhancing drought tolerance of *A. raddiana*.

Disturbed mine sites often lack mycorrhizal fungi, and even if they contain some, their density and diversity will be so low that plants will not reap the full benefit of them (Brundrett et al. 1996a,b). Thus, inoculation of plants with mycorrhizal fungi has been suggested (Reddell and Milne 1992; Ganesan et al. 1992). Mycorrhizal fungi can be introduced into disturbed mine sites via the seeds, seedlings (if tube-stocks are used), or topsoil, or by spreading mycorrhizal spores on host roots. It is also possible that mycorrhizal fungi may be transmitted via dust and they are commonly disseminated by water, insects and animals as their spores are very tiny (45–1000 μm). Because of this possibility, some rehabilitation workers believe that, because mine spoils are usually surrounded by natural undisturbed sites, plants established on them need not be inoculated with mycorrhizal fungi.

Although it is possible that the plants established on mine spoils may be naturally inoculated by dust transmitted mycorrhizal fungi, to date very little data are available to demonstrate this possibility. Even if the mycorrhizal fungi are transferred via dust, it is highly unlikely that the density and diversity of mycorrhizal spores delivered to the rehabilitated sites via dust will be adequate to enhance plant growth. A number of studies demonstrate beneficial effects of mycorrhizal fungi in crop plants (Safir 1980), horticulture (Azcon-Agnilar and Barea 1997), and in mine rehabilitation (Jasper et al. 1991) but such studies are limited for tropical acacias. Thus, evaluation of the responses of tropical acacias to different species of mycorrhizal fungi (*Gigaspora albida*, *Glomus aggregatum* and *G. mosseae*) and relative performances of different strains of mycorrhizal fungi were considered essential to further exploit endomycorrhizal fungi in mine site revegetation programs.

This paper discusses results of two experiments — a field experiment to test infectivity of three *Acacia* species established on an uranium mine spoil, and a glasshouse experiment to assess potential role of endomycorrhizal fungi in improving acacia growth, their contribution to P nutrition, and the variability between different species of endomycorrhizal fungi.

Materials and Methods

Experiment 1

A field experiment was established in 1995 on the northern waste rock dump of Ranger Uranium Mine at Jabiru, Northern Territory. Two adjacent levelled sites were selected for the study. Site 1 was located immediately next to Site 2, but this was at a lower level. The lowering of the site was due to removal of waste rock material for tailings dam construction. Due to removal of part of the spoil, a fresh surface was created, so this site was chosen to test voluntary introduction of mycorrhizal fungi as part of another major experiment (see Ashwath et al. 1995). The land surface was graded to remove the top 5–10 cm layer, and was deep-ripped at two metre intervals. Site 2 was about eight metres higher than Site 1; it was deep-ripped at two metre intervals and spread with a thin layer of fresh topsoil from surrounding woodlands. The seeds contained in the topsoil had produced sparse cover of *A. oncinocarpa*.

In 1995, seedlings of *Acacia difficilis*, *A. oncinocarpa* and *A. umbellata*, were raised in a glasshouse in a sterile potting mix of perlite and vermiculite (1:1) and inoculated with different strains of rhizobia. These seedlings were transplanted into the riplines of Site 1 at a spacing of one metre between the seedlings. After four months of transplanting, every alternative seedling was harvested to determine shoot weights to assess their response to inoculation with rhizobia (Ashwath et al. 1995). The remaining seedlings were allowed to grow for a further two years with the aim of testing these seedlings for colonisation by mycorrhizal fungi from natural sources (e.g. dust from surrounding areas) and to examine persistence of introduced strains for rhizobia in the spoil.

In July 1997, root and soil samples were collected from the three *Acacia* species established on Site 1 two years beforehand. Similar samples were also collected from *Acacia oncinocarpa* plants from Site 2 and from *A. oncinocarpa* and *A. difficilis* plants from a natural undisturbed woodland located approximately 10 km north of the waste rock dump. The aim was to compare infectivity of plants established on a fresh spoil with those established provided with topsoil or growing in natural soils. The root and soil samples were collected within about 15 cm radius of main stem at a depth of 0–10 cm. The root samples were stored in 70% alcohol and the soil samples (which were dry at collection) were placed in paper bags and transported to Rockhampton to determine root infectivity, and spore density and diversity.

The roots were cleared and stained to determine mycorrhizal colonisation (Phillips and Hayman 1970). Trypan blue (0.5% in lactophenol) was used to stain the roots. The percentage of infection was estimated by the gridline intersection method (Giovannetti and Mosse 1980). VAM fungal spores were recorded after extraction of rhizosphere soil by wet sieving and decanting (Gerdemann and Nicolson 1963).

Experiment 2

A pot culture experiment was conducted in 1995 in a polythene-covered greenhouse at Botany Field Research Laboratory, University of Madras, India. Polyethylene bags (2 litre capacity) were filled with sterilised soil mix (sand:red soil = 2:1). The soil mix had a pH of 7, EC 3.6 dS/m, organic matter 0.4%, and phosphorus 2.9 mg/kg.

Seeds of *Acacia holosericea* (kindly supplied by the Environmental Research Institute, Jabiru, NT) and *A. nilotica* (collected around Madras, India) were surface sterilised with 5% hydrogen peroxide and treated with boiling water for three minutes. Following thorough washing with distilled water, the seeds were sown (at two seeds per bag) in the polythene bags. Four weeks after sowing, uniform seedlings were selected and inoculated with the spores of the following endomycorrhizal fungi:

- Control — no inoculation,
- *Gigasopora albida*,
- *Glomus aggregatum*,
- *Glomus mosseae*, and
- *Glomus aggregatum* and *Gigasopora albida* (1:1).

The inoculum consisted of 0.2 g of chopped onion roots (inoculated with pure cultures of the above species) and 0.8 g of the soil which contained about 450 spores. The inoculum was buried around the stem at a depth of 5 cm. The pure cultures had been isolated from field soils, identified according to Schenck and Pérez (1987) and Raman and Mohankumar (1988) and maintained in pots containing sandy soil using onions as host plants. For each treatment, 20 pots were used.

Observations of plant height, stem circumference, mycorrhizal infectivity, and number of spores/100 g of soil were determined. Plants were harvested 90 days after inoculation, roots and shoots separated, and the roots washed free of soil. The dried shoots and roots were analysed for phosphorus (Jackson 1962). The procedures of determining mycorrhizal infectivity and spore density were the same as those described in Experiment 1.

Results and Discussion

Colonisation of acacia by mycorrhizal fungi

Marked differences in mycorrhizal infectivity are evident between plants grown:

- in a freshly exposed uranium mine spoil (Site 1),
- on a similar spoil treated with fresh topsoil (Site 2), and
- a natural undisturbed soil.

The results are shown in Table 2.

In the fresh mine spoil, even two years after transplanting, none of the *A. oncinocarpa* or *A. umbellata* roots were colonised, and only a few plants (three out of five) of *A. difficilis* showed hyphal growth (no vesicles or arbuscles). In contrast, the *A. oncinocarpa* plants growing in a similar mine spoil, but treated with topsoil had 20–70% mycorrhizal infectivity. This was comparable to that shown by the plants growing in natural undisturbed sites. *A. difficilis* had up to 65% infectivity in natural soil, but only hyphal growth in the mine spoil. No comparison could be made for *A. umbellata* as this species did not occur in the local natural soil. The average numbers of VAM propagules in natural soils and WRD treated with topsoil were 921–1308 and 413–602 propagules/100 g soil, respectively.

The fact that none of *A. oncinocarpa* plants were colonised by mycorrhizal fungi in mine spoil even after two years, and all were colonised in a similar mine spoil containing fresh topsoil, clearly demonstrates the need to inoculate plants with mycorrhizal fungi in order for them to assist plants established on mine spoils. However, this experiment also demonstrates that mycorrhizal fungi do not readily colonise mine spoils, and hence there is a need to introduce these to mine sites by some means, for improving both plant establishment and long-term sustainability.

Table 2. Mycorrhizal infectivity and spore density in a uranium mine waste rock dump (WRD), with and without topsoil.

Species/plants	WRD		WRD + topsoil		Undisturbed woodland	
	Infectivity %	Spores/100 g	Infectivity %	Spores/100 g	Infectivity %	Spores/100 g
A. oncinocarpa						
1	0	—	20	413	50	1174
2	0	—	35	520	hyphae	1049
3	0	—	70	602	30	921
4	0	—	—	—	—	—
5	0	—	—	—	—	—
A. difficilis						
1	hyphae	—	—	—	hyphae	946
2	hyphae	—	—	—	40	1245
3	hyphae	—	—	—	65	1308
4	0	—	—	—	—	—
5	0	—	—	—	—	—
A. umbellata						
1	0	—	—	—	—	—
2	0	—	—	—	—	—
3	0	—	—	—	—	—
4	0	—	—	—	—	—
5	0	—	—	—	—	—

Establishment of plants on mine spoils is challenging, especially where a wide range of plant species is required by the mining companies to satisfy revegetation goals (SSARR 1991, page A65). In such circumstances, reduced growth of some species can result in them being dominated by fast growing species which may not require mycorrhizal association. This situation could lead to failure of the mining companies to meet their revegetation goals. Thus, introduction of mycorrhizal fungi provides an equal opportunity to all species being established.

Techniques now being developed to introduce mycorrhizal fungi onto mine sites may be expensive to adapt, or may not be suitable to all mines. Thus, alternative, natural, and possibly cheaper methods of introducing mycorrhizal fungi (e.g. using topsoil) should be relied upon in revegetation programs. Use of topsoil has been discounted by some revegetation workers due to the danger of its carrying weed seeds. Should this be the problem, weed seeds should be eradicated prior to collecting the topsoil. It is also known that the topsoil loses its biological activity if stored for long periods, particularly in the tropics (Reddell and Milne 1992). Thus, it is advisable to use fresh top soil as far as possible, and if this is not feasible, top soil should be collected at optimum time and it should be managed to minimise loss of biological activity during storage.

Better infectivity of plants on Site 2 could be due either to the inocula provided via fresh topsoil or to the transfer of inocula via dust over the seven years since their establishment. It is highly likely that it is the topsoil, not the dust, which has contributed to infectivity on this site. This is because the transfer of mycorrhizal fungi from natural soil via dust is restricted since this site is located c. 25 metres above the natural undisturbed soils and is away from mining activity. This view can be further supported from the lack of infection of *A. oncinocarpa* seedlings in Site 1 even after two years, despite being closer to natural woodlands and at a lower level than Site 2.

Experiment 2

Experiment 1 illustrates the importance of using topsoil for establishing mycorrhizal colonisation, but this does not demonstrate the actual benefits of mycorrhizal fungi to plant growth, or the effectiveness of different species of on plant growth; hence Experiment 2.

Mycorrhizal infectivity was tested at 30, 60 and 90 days after inoculation. At 30 days, both tap root and fibrous roots were infected in *A. holosericea* (10–20%), but in *A. nilotica*, only main roots showed infection (c. 5%). None of the uninoculated seedlings (control) exhibited any mycorrhizal colonisation. The infectivity increased with exposure time and this increment was greatest for *Glomus mosseae* followed by *Glomus aggregatum*.

Examination of roots indicated presence of both arbuscles and vesicles in both plant species, and for all VAM species except for *Gigaspora albida* which contained only arbuscles. Plants inoculated with *Glomus aggregatum* and *Gigaspora albida*, however, showed both structures. As for root infectivity, spore numbers increased with time (Figure 1). The numbers were a lot higher in pots containing *A. holosericea* than *A. nilotica* and this corresponded with the infectivity. At 90 days, *Glomus aggregatum* produced the most number of spores in the soil (2400 spores/100 g soil) and *Gigaspora albida* the least.

Comparison between *A. holosericea* and *A. nilotica* suggests a close correlation between spore number and root infectivity (Figure 1). This relationship, however, does not seem to hold true when a single strain is considered. For example, in *Gigaspora albida* the spore numbers were low but the infectivity rate was similar to other species. The correlation between mycorrhizal infectivity and the number of extra-matrical chlamydospores in the pot experiments were consistent with previous observations (Allen and Allen 1980).

Inoculation with mycorrhizal fungi significantly improved plant height and stem girth of *A. holosericea* and *A. nilotica* plants after 90 days (Figure 2). Ragupathy and Mahadevan (1995) reported similar growth improvements in *Peltophorum pterocarpum* in response to *G. mosseae* inoculation. The two *Acacia* species showed similar responses for plant height, but their responses in terms of stem girth differed, with *A. holosericea* being less responsive than *A. nilotica*. Inoculation improved the quantity of P accumulated in the shoot and root in both species and hence, in this pot experiment, improved plant growth would have resulted from improved uptake of P by inoculated plants (as they were regularly watered).

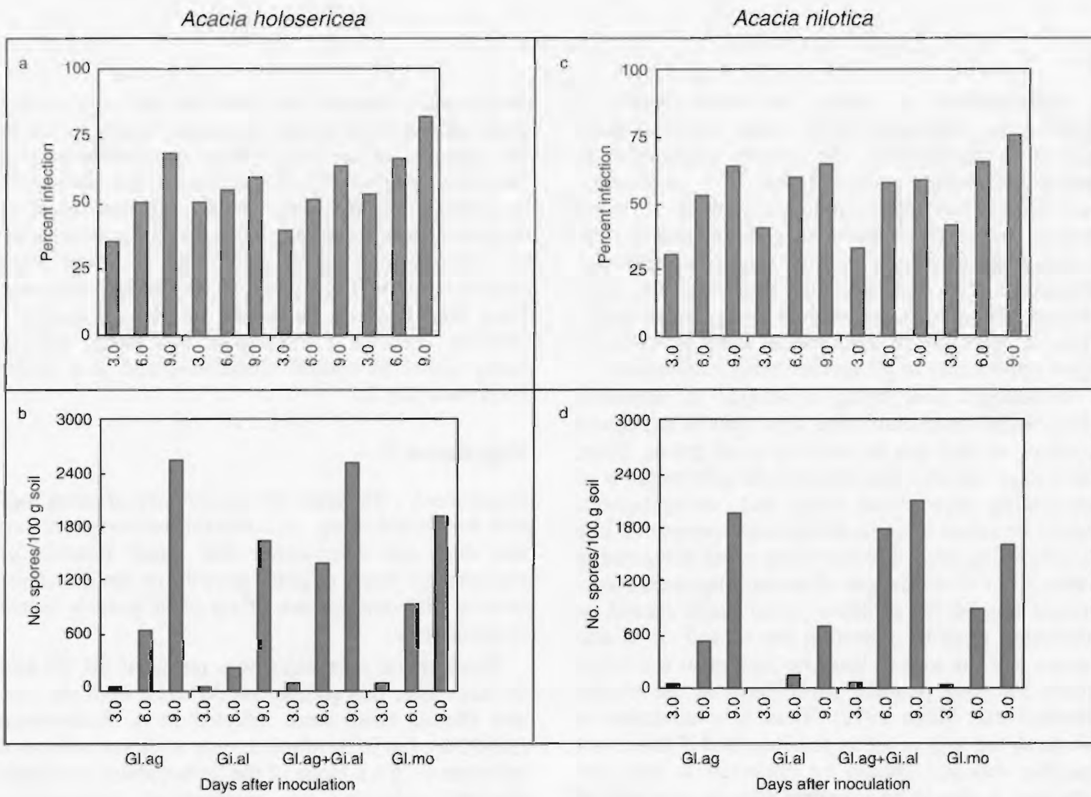

Figure 1. Effect of inoculation of *A. holosericea* (a, b) and *A. nilotica* (c, d) with different species of mycorrhizal fungi on root infectivity and spore number in the soil. Note: Gl.ag = *Glomus aggregatum*, Gi.al. = *Gigaspora albida*, Gl.ag. + Gi.al. = *Glomus aggregatum + Gigaspora albida*, Gl.mo. = *Glomus mosseae*.

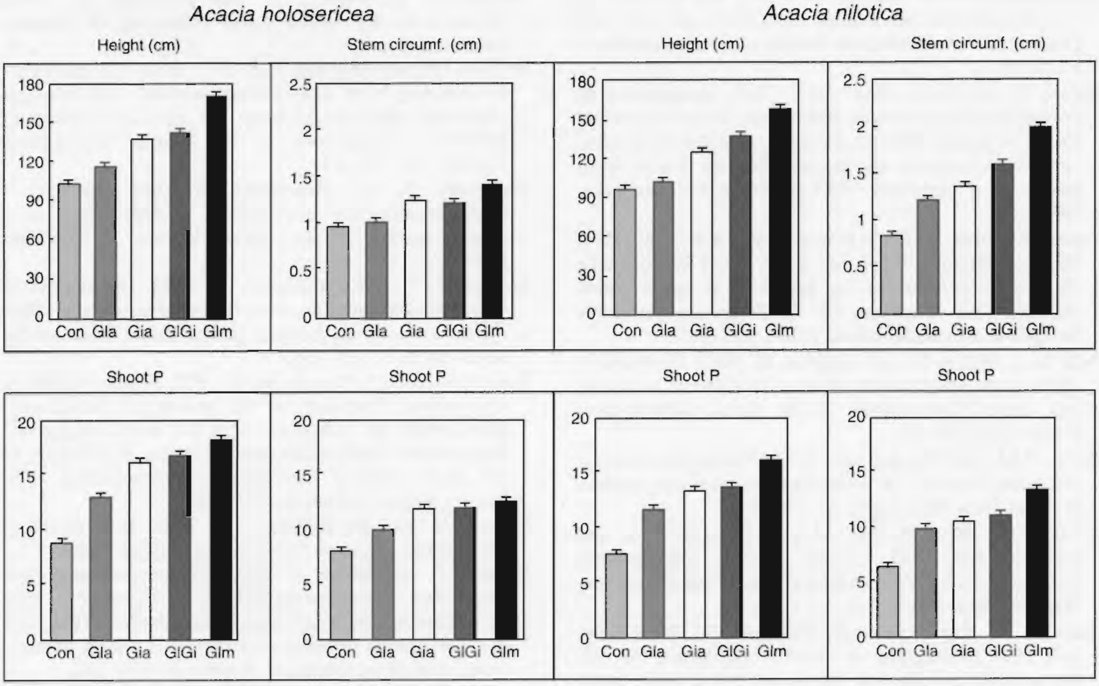

Figure 2. Effect of inoculation of *A. holosericea* and *A. nilotica* with different species of mycorrhizal fungi on shoot height, stem circumference Shoot P content (mg/plant) and root P content (mg/plant). Note for abbreviations, see Fig. 1. Values are means ± SE (n = 5).

Mycorrhizal species also showed significant differences in their effectiveness. *Glomus mosseae* was most effective and *Glomus aggregatum* the least. Dual inoculation gave no additional benefit to plant growth, and the plant performance in this treatment was similar to that shown by *Gigaspora albida* alone. The lack of improved response in dual inoculation contrasts with the general conclusions of Daft et al. (1983) and the observations of De la Cruz et al. (1983) in *Acacia auriculiformis* and *A. mangium*. These investigations suggest that the further study is needed on dual inoculation, infecting VAM species, and their inter-relationships.

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References

Allen, E.B. and Allen, M.F. 1980. Natural re-establishment of vesicular arbuscular mycorrhizae following strip mine reclamation. Wyoming Journal of Applied Ecology, 17, 139–147.

Ashwath, N., Gibson, A.H., Yonga, M., McInnes, A., Malden, J. and Bayliss, B. 1995. Selection of *Rhizobium* strains from improved nitrogen fixation in mine site revegetation. Proceedings of the 20th Environmental Workshop of the Mineral Council of Australia, Canberra, 345–352.

Azcon, R. and Ocampo, N.A. 1980. Factors affecting the vesicular arbuscular infection and mycorrhizal dependency of thirteen wheat cultivars. New Phytologist, 87, 677–685.

Azcon-Agnilar, C. and Barea, J.M. 1997. Applying mycorrhiza biotechnology to horticulture: Significance and potential. Scientia Horticulture, 68, 1–24.

Brundrett, M., Ashwath, N. and Jasper, D. 1996a. Mycorrhizas in the Kakadu region of tropical Australia. Part I. Propagules of mycorrhizal fungi and soil properties in natural habitats. Plant and Soil, 184, 159–171.

Brundrett, M., Ashwath, N. and Jasper, D. 1996b. Mycorrhizas in the Kakadu region of tropical Australia. Part II. Propagules of mycorrhizal fungi and soil properties in disturbed habitats. Plant and Soil, 184, 172–184.

Chakravarthy, P. and Mishra, R.R. 1986. The influence of VA mycorrhizae on wilting of *Albizzia procera* and *Dalbergia sissoo*. European Journal of Forest Pathology, 16, 91–97.

Cornet, F. and Diem, H.G. 1982. Etude comparative de l'efficacité des souches de *Rhizobium* d'*Acacia* isolés du sol au Senegal et effet de la double symbiose *Rhizobium — Glomus mosseae* sur la croissance de *Acacia holosericea* et *A. raddiana*. Bois et Forets des Tropiques, 198, 3–15.

Cornet, F., Diem, H.G. and Dommergues, Y.R. 1982. Effet de l'inoculation avec *Glomus mosseae* sur la croissance de *Acacia holosericea* en pépinière et après transplantation sur la terrain. In: INRA les mycorrhizaes: biologie et utilisation. Dijon, INRA, 287–293.

Daft, M.J., Mosse, B. and Hogarth, H. 1983. Competitive interactions amongst four species of *Glomus* on maize and onion. Transactions of the British Mycological Society, 80, 339–345.

Davis, R.M. and Menge, J.A. 1981. *Phytophthora parasitica* and intensity of vesicular-arbuscular mycorrhizae in citrus. New Phytologist, 87, 705–715.

De la Cruz, R.E., Manalo, M.Q., Aggangan, N.S. and Tambalo, J.D. 1983. Growth of three legume trees inoculated with VA-mycorrhizal fungi and *Rhizobium*. Plant and Soil, 108, 111–115.

Ganesan, V., Ragupapthy, S., Parthipan, B., Rjini Rani, D.B. and Mahadevan A. 1992. Distribution of VA mycorrhizal fungi in coal lignite and calcite mine spoils of India. Biology and Fertility of Soils. 12, 131–136.

Gerdemann, J.W. and Nicolson, T.H. 1963. Spores of mycorrhizal endogone species extracted from soil by wet sieving and decanting. Transactions of the British Mycological Society, 46, 235–244.

Giovannetti, M. and Mosse. B. 1980. An evaluation of techniques for measuring vesicular arbuscular mycorrhizal infection in roots. New Phytologist, 84, 489–500.

Hayman, D.A. 1975. Phosphorus cycling by soil microorganisms and plant roots. In: Walker, N., ed., Soil Microbiology. London, Butterworth, 69–71.

Huang, R.S. and Tang, R.S. 1988. Production of vesicular arbuscular mycorrhizal sporocarps, *Glomus aggregatum* on fiberglass screens. Plant and Soil, 108, 233–235.

Jackson, M.L. 1962. Soil chemical analysis. London, Constable, 498 p.

Jasper, D.A., Robson, A.D. and Abbott, L.K. 1991. Hyphae of VA mycorrhizal fungus maintain infectivity in dry soil, except when the soil is disturbed. New Phytologist, 12, 101–107.

Mahadevan, A., Raman, N. and Natarajan, K. 1989. Mycorrhizae for Green Asia. University of Madras, Madras, 351 p.

Phillips, J.M. and Hayman, D.A. 1970. Improved procedure for clearing roots and staining parasitic and vesicular arbuscular mycorrhizal fungi for rapid assessment of infection. Transactions of the British Mycological Society, 55, 158–161.

Ragupathy, S. and Mahadevan, A. 1991. Ecology of vesicular-arbuscular mycorrhizal (VAM) fungi in a coastal tropical forest. Indian Journal of Microbial Ecology, 2, 1–9.

Ragupathy, S. and Mahadevan, A. 1993. Distribution of vesicular-arbuscular mycorrhizae in the plants and rhizosphere soils of the tropical plains, Tamil Nadu, India. Mycorrhiza, 3, 123–136.

Ragupathy, S. and Mahadevan, A. 1995. Effect of different mycorrhizal treatments on the growth of *Peltophorum pterocarpus*. In: Adholeya, Alok and Singh, Sujan, ed., Mycorrhizae: biofertilizers for the future. Proceedings of the third National Conference on Mycorrhiza, Tata Energy Research Institute, 390–393.

Raman, N. and Mohankumar, V. 1988. Techniques in mycorrhizal research. University of Madras, India.

Reddell, P. and Milne, T. 1992. Mycorrhizal and other specialised nutrient-acquisition strategies: their occurrence in woodland plants from Kakadu and their role in rehabilitation of waste rock dumps at a local uranium mine. Australian Journal of Botany, 40, 223–242.

Reddell, P. and Warren, R. 1987. Inoculation of acacias with mycorrhizal fungi: Potential benefits. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. Proceedings of an International Workshop held at the Forestry Training Centre, Gympie, Australia, 4–7 August 1986. ACIAR Proceedings No. 16, 50–53.

Safir, G.R. 1980. Vesicular-arbuscular mycorrhiza and crop productivity. In: Carlson, P.S., ed., The biology of crop productivity. New York, Academic Press, 231–249.

Safir, G.R., Boyer, J.S. and Gerdemann, J.W. 1972. Nutrient status and mycorrhizal enhancement of water transport in soybeans. Plant Physiology, 49, 700–703.

Schenk, N. C. and Pérez, Y. 1987. Manual for the identification of VA mycorrhizal fungi. University of Florida, Gainesville, Florida, USA.

SSARR 1992. Annual report 1991-92. Supervising scientist for the Alligator Rivers Region, Canberra.

Turnbull, J.W. 1987. Australian Acacias in Developing Countries. Proceedings of an International Workshop held at the Forestry Training Centre, Gympie, Australia, 4–7 August 1986. ACIAR Proceedings No. 16, 196 p.

Contribution of Acacias to the Growth and Nutrient Status of Eucalypts in Mixed-species Stands at Ratchaburi, Thailand

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Abstract

The long-term sustainability of eucalypt and acacia plantations (monocultures) is being questioned because of possible adverse effects on nutrient cycling and nutrition of trees leading to decreased productivity. To test whether plantations with mixed species may offer an alternative, *Eucalyptus camaldulensis* and *Acacia auriculiformis* were planted in mixtures at Ratchaburi Experimental Station, Thailand. The plantation contained five treatments at two tree densities. Above-ground growth was monitored periodically for four years. Height of eucalypts was not affected by acacia in mixtures. Acacia had higher tree sectional area at breast height and stem volume than eucalypts, pointing to greater competition for soil resources by acacia. Despite this, mean sectional area, annual increments in the sectional area and stem volume of eucalypts 48 months after planting showed major differences when growing in combination with acacia. Higher values of the above parameters were observed when the proportions of eucalypt and acacia were equal. Above-ground biomass and nutrient accumulation were measured at the time of first thinning of high-density plots when the trees were 28 months old. By then the amount of N accumulated in various tree components on a plot depended on the proportion of acacia in the mixture, whereas accumulation of other nutrients depended more on the species and their relative growth rates (i.e. the amount of biomass produced). The approximate amount of N fixed by acacia after 48 months (calculated by using total N difference method) ranged from 57 (25% acacia) to 201 kg/ha (75% acacia). The positive effect of acacia on the growth of eucalypts was probably related to improved N nutrition. The merits of growing acacia in mixtures on the growth of eucalypts are discussed.

EUCALYPTS and acacias are widely planted for their fast growth in monoculture plantations in Thailand and other countries in the tropics and sub-tropics. In the tropical regions of the world, plantation areas under eucalypt and acacia in 1990 were estimated as 10.1 and 3.4 million ha respectively, of which 52% of eucalypt and 93% of acacia plantations are in the tropical Asia and Pacific regions (Pandey 1995). For example, in Thailand the total plantation area (excluding rubber), both government and private, is estimated at about 1.2 m ha consisting of eucalypt (0.35 m ha), teak (0.26 m ha) and other plantation species (0.51 m ha). *Eucalyptus camaldulensis* is a preferred species in Thailand with considerable area planted during the past decade.

Fast-growing eucalypt plantations are, however, coming under increasing criticism worldwide for various reasons, including the possible deterioration of soil properties and the associated decline in productivity of subsequent rotations. Nitrogen drain is a major concern with short rotations and complete above-ground biomass removal. Therefore, alternative silvicultural methods achieving fast growth of eucalypts without causing site deterioration are being sought, for example, growing eucalypts in mixture with N-fixing trees. Examples are *Acacia* in Hawaii (De Bell et al. 1985) and Australia (Khanna 1997)

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and *Albizia* in Hawaii (Binkley et al. 1992; De Bell et al. 1997). Nutrient cycling in monocultures can differ from that in a mixed species stand with a N-fixing tree (NFT) component (Binkley 1992; Khanna 1998) which may be related to:

- the direct effect of addition of N by NFT;
- indirect effects due to interactions of N addition;
- enhanced competition for nutrients between mixed-species; or
- other factors affecting inputs and outputs of nutrients.

An excellent review on mixed-species plantations in the tropics and sub-tropics (FAO 1992) concluded that suitable studies and data are lacking for evaluation of mixed-species stands as an ecologically useful and economically viable option for land management. In this paper, the growth and nutrient accumulation of a mixed species (eucalypt–acacia) plantation in Thailand is presented.

Site Description and Methods

The study site is located at the Paktor Experimental Station of the Royal Forest Department, about 50 km from the provincial town of Ratchaburi. Prior to planting the site carried a degraded open woodland (secondary dry deciduous forest) of no economic value. The soil type at the site is a brown podsolic; mean annual temperature is 29.3°C, and mean annual rainfall is 980 mm. The site was cleared at the end of 1991 and after removing woody components, debris was burnt on the site (broadcast burn). The site was ploughed to a depth of about 25 cm. The trees were planted in July 1992.

The design of the experiment was a split-plot with four replicates (blocks). Each block was divided into two main plots representing two planting densities: (D1) low density (4 × 2 m), and (D2) high density (2 × 2 m). Each main plot had five subplots representing treatment mixtures of *Eucalyptus camaldulensis* (E) and *Acacia auriculiformis* (A): (1) 100%E, (2) 75%E+25%A, (3) 50%E+50%A, (4) 25%E+75%A, and (5) 100%A. In treatment (3) eucalypts and acacias were planted in alternate rows, whereas in treatments (2) and (4) the alternate rows (between the rows of eucalypt and acacia respectively) contained alternate trees of acacia and eucalypt.

Each treatment was assigned randomly. Each subplot was surrounded by a buffer area 4 m wide. The size of the subplot was 30 × 32 m (91 or 169 measured trees), with a total experimental area of 3.96 ha. The design provided the possibility of comparing treatments after thinning the high-density plots (converted to the low density). High-density plots were thinned when trees were 28 months old, or after three major growing seasons. Stem wood was removed and slash was left (uniformly distributed) on each subplot.

The growth monitoring programs included: the assessment of plant survival and the periodic monitoring of plant heights (H) and stem diameters at 1.3 m tree height (dbh). Volume (V) was estimated on the assumption that the stems were conical in shape. Growth data were analysed by using the statistical package GENSTAT.

To calculate above-ground biomass of wood, bark, branches, twigs and leaves from the first thinnings (28 months after planting) of the 2 × 2 m plots, biomass equations were developed by using data from 28 sample trees of different diameter classes of *E. camaldulensis* and 32 sample trees of *A. auriculiformis*. For chemical analysis (N, P, K, Ca and Mg) of the tree components, the standard laboratory methods were employed (Heffernan 1985).

Results and Discussion

Survival, tree height, stem diameter and volume

Survival of both acacias and eucalypts was high (>95%) in all plots. Periodically measured mean height growth of eucalypt and acacia is presented in Figure 1. Statistical analysis indicated no height differences among treatments, except eucalypts at 48 months after planting when trees in plots with 50% or more acacia were 0.6 m taller ($p < 0.02$) than those with a lower proportion of acacia. Height increments between 36 and 48 months were also significant for density ($p < 0.01$). Any effect of acacia on eucalypts (e.g. better N nutrition) may not always result in height differences. Moreover the highly dynamic nature of the canopy at the time of measurements (mostly summer) may have made it difficult to record small differences in tree heights. Mean height at 48 months after planting for various treatments were 9.9–11.4 m for eucalypts and 10.5–11.5 m for acacia.

The mean values of stem diameter (dbh), measured 48 months after planting, were 8.1–8.5 (low density) and 7.1–8.1 cm (high density) in eucalypts, while the corresponding values for acacias were 10.5–11.8 and uniform 9.6 cm. Mean dbh values were significantly ($p < 0.05$) higher at low tree densities and the acacias had higher mean dbh than eucalypts (data not shown).

At low tree densities, stem sectional areas (SA) at 1.3 m tree height measured 48 months after planting were much higher for acacias than for eucalypts (Table 1). The SA of the eucalypts was not affected by mixtures, but there was a trend ($p < 0.03$) for SA of acacia to linearly decrease with an increasing proportion of acacia in the mixture. Current annual

SA increments of acacia were 3.2–4.3 times higher than those of eucalypt when both were growing in a mixture. These high growth rates of acacia were expected to cause significant competition to eucalypt for water and nutrients like phosphorus. However, the SA increments of eucalypts were not adversely affected, but showed growth rates similar to those observed for the pure eucalypt stand. Eucalypts growing in a 50:50 combination with acacia had the highest (though not significant) mean tree SA of all the treatments after 48 months.

Table 1. Stem sectional area (SA) (48 months) and annual SA increments (36-48 months) of eucalypt and acacia from 4 × 2 m spacing. Standard error of difference (sed) values are given for comparing means.

Mixtures	SA cm²/tree		SA-inc cm²/tree	
	Eucalypt	Acacia	Eucalypt	Acacia
100E	57.6	—	10.7	—
75E + 25A	56.4	114.1	9.6	41.4
50E + 50A	61.7	96.5	10.7	33.6
25E + 75A	55.6	99.1	9.1	30.6
100A	—	91.4	—	28.0
Sed	5.22	7.80	1.20	2.75

Total stand volume produced after 48 months increased from 31 to 56 m^3/ha, depending upon the proportion of acacia in the mixture and the density of planting; there were some notable exceptions where growth of either eucalypts (mixture 4, of low density) or acacias (mixture 2, of high density) were suppressed (Figure 2). If the volume of wood produced by the pure eucalypt stand (mixture 1) with low density is compared with that of mixed stands at high density, there was clear evidence of a positive effect of acacias on the growth of eucalypts (except in 25E+75A mixture with low density where eucalypts were suppressed). This positive effect of acacia was evident especially at high density when the thinning was done at 28 months; presumably this thinning removed competition for soil resources (such as water and other nutrients) but made additional N available. Consequently the growth of eucalypt after removal of acacia in the 50E+50A treatment had caught up with the volume of eucalypts in the pure stand with low density, and was expected to exceed it in future years.

Annual stem volume increments at the time of pre-thinning (18–28 months after planting), and for

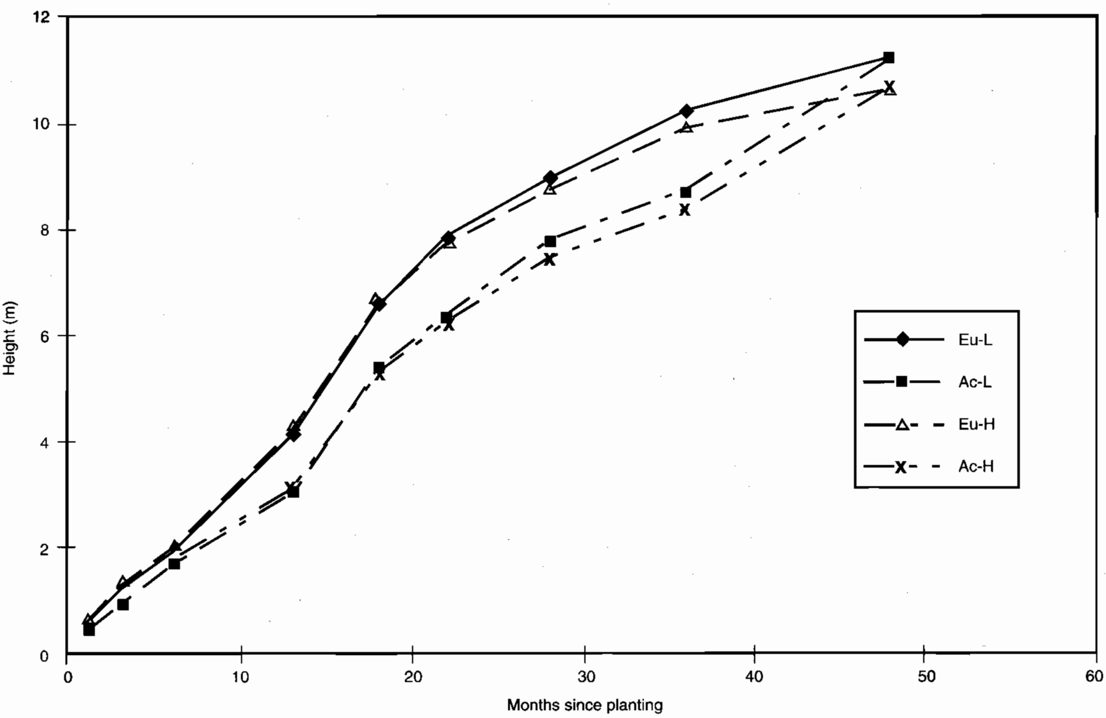

Figure 1. Height development in eucalypt (Eu) and acacia (Ac) with two planting densities (L = low, H = high).

the period between 36–48 months, showed the following results (Table 2):

- For 18–28 months, stem volume increment was higher on the high density plots for both eucalypt and acacia than on the low density plots.

At comparable stocking, acacia had much higher volume increments than eucalypts on this site; thus the total production of mixed stands was higher than that of pure eucalypt stands.

- Volume increments in eucalypts tended to decrease with time in all cases, but the degree of decrease varied depending upon the proportion of acacia present and whether the plots were thinned or not; the lowest decrease (16%) was observed in eucalypts from the thinned plots and those with acacia in 50:50 proportions.
- After thinning, the three treatments (100E, 75E+25A, and 50E+50A) contained no acacia (due to experimental layout), and comparison of growth rates could be made between the three and with 100E of low density plots; plots which previously had a 50:50 mixture showed the highest eucalypt growth rate (8.38 m^3/ha) of all which is significantly (15% higher than the pure stand, which grew 7.27 m^3/ha).

Table 2. Annual volume increments (m^3/ha) of eucalypts and acacias for 18–28 months and 36–48 months. Low (4 × 2 m) and high density (2 × 2 m). Standard error of difference (sed) values are given for comparing means.

Mixtures	Low density		High density	
	28 months	48 months	28 months	48 months
Eucalypt				
100E	11.62	7.27	14.66	6.15
75E	9.16	5.20	10.31	6.31
50E	6.77	4.25	9.98	8.38
25E	2.31	1.06	5.46	4.29
Sed	0.81	0.64	0.81	0.64
Acacia				
25A	3.70	6.05	4.35	—
50A	7.39	11.13	9.55	—
75A	13.52	19.36	14.80	10.51
100A	15.31	21.88	20.51	20.96
Sed	1.35	1.46	1.35	1.27
Eucalypt + acacia				
100E	11.62	7.27	14.66	6.15
75E+25A	12.86	11.25	14.66	6.31
50E+50A	14.17	15.38	19.53	8.38
25E+75A	15.82	20.42	20.26	14.81
100A	15.31	21.88	20.51	20.96
Sed	1.53	1.50	1.53	1.50

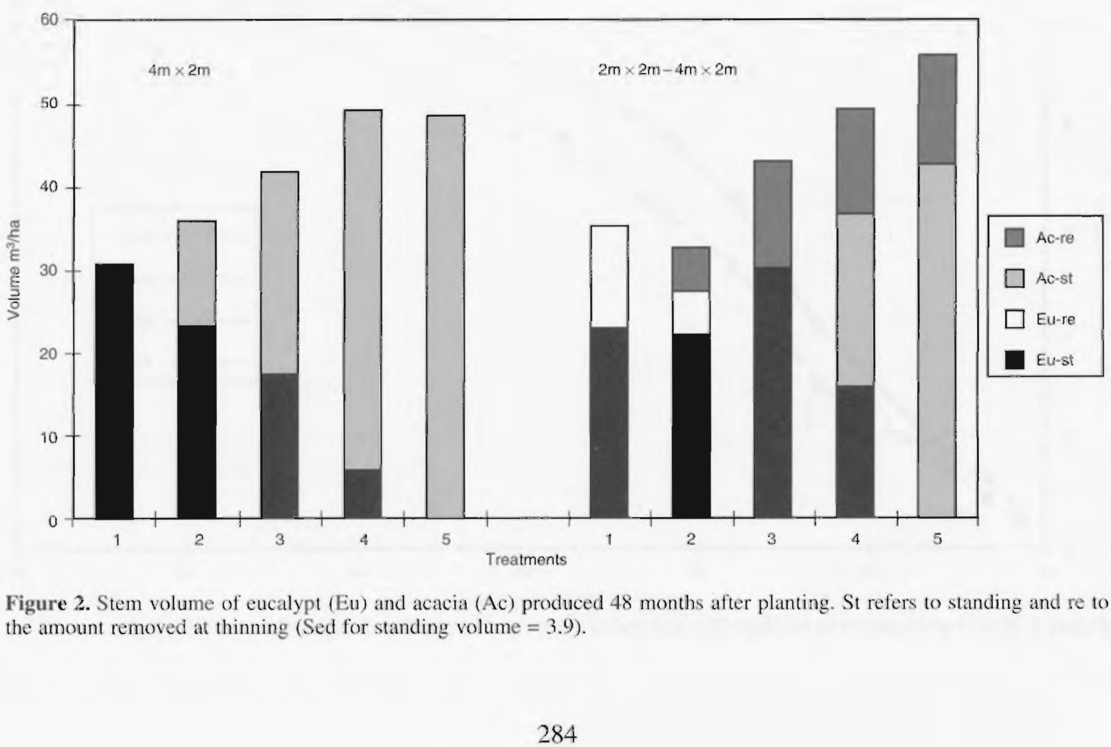

Figure 2. Stem volume of eucalypt (Eu) and acacia (Ac) produced 48 months after planting. St refers to standing and re to the amount removed at thinning (Sed for standing volume = 3.9).

Removal of wood and nutrients during thinning

Wood, bark and some small branches were removed from the site during thinning and the other biomass components were left on the site to decompose. The calculation of biomass removed from the site was therefore based on the wood and bark material. Total stem volume of acacia and eucalypt removed during thinning accounted for 43–48% of the standing volume at 28 months and 10.5–13.3 m^3/ha (BA = 3.3–4.3 m^2/ha) depending upon the treatment (Table 3). Only acacia was removed from treatments 50E + 50A, 25E + 75A, and 100A, but trees removed from the 75E + 25A treatment also included eucalypt. As wood and bark components of acacia contained higher concentrations of nitrogen than those of eucalypt, the amount of nitrogen removed was 26–63 kg according to the proportion of acacia biomass removed (Table 3). The amounts of other nutrients removed from the site during thinning did not follow any specific pattern, but were more related to the total biomass removed (Table 3).

Table 3: Stem volume, basal area and nutrients removed by eucalypt (euc) and acacia (aca) from 2 × 2 m plots during thinning.

	Mixtures				
	100E	75E + 25A	50E + 50A	25E + 75A	100A
	Total basal area (m^2/ha)				
Euc	3.39	1.48	0.05	0.05	
Aca		1.83	4.01	4.00	4.26
Euc + aca	3.39	3.31	4.06	4.05	4.26
	Total stem volume (m^3/ha)				
Euc	12.14	5.03	0.12	0.15	
Aca		5.48	12.79	12.90	13.31
Euc + aca	12.14	10.51	12.91	13.05	13.31
	Percentage of standing volume removed				
Euc	48	29	1	2	
Aca		100	100	65	46
Euc + aca	48	46	43	45	46
	Nutrients removed (kg/ha)				
Nitrogen	25.8	28.3	42.3	51.5	63.1
Phosphorus	5.2	3.5	5.1	5.8	4.5
Potassium	34.0	26.8	35.5	37.9	38.8
Calcium	82.0	73.9	76.2	70.7	62.4
Magnesium	5.6	5.0	5.7	5.2	4.5

N status of eucalypts and estimates of N fixed by acacias

The amount of nitrogen accumulated in different treatments was calculated by using the concentrations in different tree components measured at 28 months, and various above-ground components of eucalypt and acacia which were obtained by using biomass equations. For biomass equations, stem volume was used as the independent variable. Above-ground biomass accumulated at 28 months after thinning ranged from 15 to17 t/ha on low density and from 19 to 25 t/ha on high density plots (Table 4). By that time, the amount of N accumulated in the above-ground vegetation was 71–134 and 100–196 kg/ha on low and high density plots, respectively. By 48 months the amount of N accumulated by the low density plots was 119–331 kg/ha.

If N removed during thinning is accounted for (Table 3), then the amounts of N accumulated by pure eucalypt and acacia stands in high density plots were 117 and 354 kg/ha respectively. If the modification of total N difference method as suggested by Khanna (1998) is used to assess the amount of N fixed by acacia, the values in kg/ha for different mixtures on the low density plot becomes: 57 (25% acacia), 116 (50% acacia), 201 (75% acacia) during a four-year period. These values are conservative estimates because N accumulated in the below-ground components was not accounted for.

Table 4: Biomass and nitrogen in the above-ground components of eucalypt and acacia, 28 and 48 months after planting. Description of mixtures and density are given in the text.

Mixtures	Biomass (t/ha)		Nitrogen (kg/ha)	
	28 mo.	48 mo.	28 mo.	48 mo.
Low density				
E100	14.9	24.9	71	119
E75 + A25	15.4	29.2	85	176
E50 + A50	16.1	34.1	104	236
E25 + A75	17.3	40.3	134	321
A100	15.4	39.8	128	331
High density				
E100	20.7	18.9	100	91
E75 + A25	18.7	18.2	104	83
E50 + A50	24.5	24.7	154	113
E25 + A75	23.7	29.8	170	201
A100	23.5	35.0	196	291

Discussion

Three important factors which affect many above-ground and below-ground interactions between species growing in mixtures are:

- the proportion of mixtures,
- density of planting, and
- age of the trees.

The effects of these three factors determine the competition between species for site resources.

Above-ground competition is related to sharing of physical resources (interception of light, rainfall-borne and air-borne nutrients, space), whereas below-ground competition includes sharing of available nutrients (especially P) and water. Some of the interactions among species may act to reduce competition (e.g. N supply by NFTs); others, by contrast, may facilitate processes such as photosynthesis and betterment of microclimate (e.g. temperature, moisture and wind speed) (Ong and Huxley 1996).

Increased growth of eucalypts at 4 years (the mean tree sectional area, and the sectional area increments between 3 and 4 years) was observed when they were grown in mixture with acacia, especially when the two species were growing in equal proportions. Acacias had higher growth rates than eucalypts and must be posing strong competition for other resources such as phosphorus and water.

Despite this strong competition from acacias, eucalypts attained higher total sectional area and sectional area increment per tree when in equal proportions with acacia, suggesting that the advantage of additional N made available from N-fixation by acacia outweighed losses due to competition. Similar results were presented for mixtures of *Eucalyptus globulus* and *Acacia mearnsii* by Khanna (1997). In their study on eucalypt and albizia mixtures, Binkley et al. (1992) observed the greatest biomass, above-ground net primary production and annual increment in the 34% *Eucalyptus*/66% *Albizia* treatment at age six years. They attributed this to a combination of factors relating to greater nutrient use efficiency of *Eucalyptus* and greater nutrient cycling under *Albizia*, resulting in greater light capture and high light use efficiency in mixed stands.

The results presented here are restricted to the first few years of plantation establishment, and may change during the subsequent phases of the plantation rotation. For example, between-tree (and between-species) competition for water and light will become more important as the plantations grow older. However the establishment phase is important for acquisition of nutrients for the development of tree canopy. Demand on soil nutrients may decrease after the tree canopy has fully developed due to an increase in 'internal' nutrient cycling. In plantation trials where acacia clearly promoted eucalypt growth, stimulation occurred before a substantial amount of acacia leaves had been shed to release nitrogen via decomposition and mineralisation (Khanna 1997). Thus the decomposition of fine roots of acacia could be a major source of nitrogen for eucalypts in the early phases of growth.

The usefulness of growing mixed species compared to monoculture will depend on any positive effects of mixed stands on productivity of the target species and site fertility as well as on the silvicultural options of managing mixtures. Incentives for the adoption of mixed species plantations as alternatives to monocultures include economic considerations (higher productivity), plantation health (reduced losses due to disease and insect attacks), sustainability and diversification of wood products. A recent study in humid neotropics by Montagnini et al. (1995) showed better plantation health and economic considerations of growing mixed-species plantations compared with those of single species.

Eucalyptus and *Acacia* plantations have become a very important wood resource in countries of Mediterranean, subtropical and tropical climates. Most soils on which these plantations grow are either deficient in nitrogen or may become deficient in succeeding rotations of eucalypts. While nitrogen can be easily added in the form of mineral fertiliser to obtain high wood yields, this may be too expensive in many developing countries. Also mineral fertiliser addition often causes negative effects, both 'on site' (by causing soil acidification) and 'off-site' (including leaching of nitrate into the groundwater, volatilisation of ammonia, and emission of nitrous oxide (which acts as a greenhouse gas).

Another way of enriching the forest stand with nitrogen is the introduction of N-fixing plants such as acacia, albizia, leucaenea, casuarina and others. The use of N-fixing trees species instead of mineral fertiliser may also allow their harvesting a few years after plantation establishment, when the system is enriched in nitrogen. This may be particularly interesting in developing countries or for farm forestry where the wood can be used as fuel and the leaves as fodder. Conservative estimates of N fixed by acacia in a 50:50 stand with eucalypt are 30 kg/ha/yr for the first 4 years, enough to replenish a significant proportion of N lost from the system with the final harvest. Including nitrogen-fixing trees with eucalypts in a high density tree planting during the initial phases of plantation establishment can lead to other gains such as reduced weed control, reduced soil erosion on steep slopes, and better nutrient cycling due to earlier litterfall.

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References

Binkley, D. 1992. Mixtures of N_2-fixing and non-N_2-fixing species. In: Cannell, M.G.R., Malcolm, D.C. and Robertson, P.A., ed., The Ecology of Mixed-Species Stands of Trees. Blackwell Scientific Publishers, London, 99–123.

Binkley, D., Dunkin, K.A., De Bell, D. and Ryan, M.G. 1992. Production and nutrient cycling in mixed plantations of *Eucalyptus* and *Albizia* in Hawaii. Forest Science, 38, 393–408.

De Bell, D.S., Cole, T.G. and Whitesell, C.D. 1997. Growth, development, and yield in pure and mixed stands of *Eucalyptus* and *Albizia*. Forest Science, 43, 256–298.

De Bell, D.S., Whitesell, C.D. and Schubert, T.H. 1985. Mixed plantations of *Eucalyptus* and leguminous trees enhance biomass production. Research Paper, Pacific-Southwest Forest and Range Experiment Station, USDA Forest Service, No. PSW-175, 6 p.

FAO. 1992. Mixed and pure forest plantations in the tropics and sub-tropics. FAO Forestry paper 103 (based on the work of T.J. Wormald), FAO, Rome, 152 p.

Heffernan, B. 1985. A Handbook of Methods of Inorganic Chemical Analysis of Forest Soils, Foliage and Water. Division of Forestry, CSIRO, Canberra.

Khanna, P.K. 1997. Comparison of growth and nutrition of young monocultures and mixed stands of *Eucalyptus globulus* and *Acacia mearnsii*. Forest Ecology and Management, 94, 105–113.

— 1998. Nutrient cycling under mixed-species tree systems in Southeast Asia. Agroforestry Systems, 38, 99–120.

Montagnini, F., Gonzalez, E. Porras, C. and Rheingans, R. 1995. Mixed and pure forest plantations in the humid neotropics: a comparison of early growth, pest damage and establishment costs. Commonwealth Forestry Review, 74, 306–314.

Ong, C.K. and Huxley, P., ed. 1996. Tree-crop Interactions: a Physiological Approach. Wallingford UK, CAB International, 386 p.

Pandey, D. 1995. Forest resources assessment 1990. Tropical forest plantation resources. FAO Forestry Paper 128, FAO, Swedish University of Agricultural Sciences, Swedish International Development Cooperation Agency, 81 p.

Segregation in Putative F_2 Hybrids of *Acacia mangium* and *A. auriculiformis*

A.J. Metcalfe and K.C. Woo[1]

Abstract

This study investigates the comparative growth performance of seedling populations of *Acacia mangium* and *Acacia auriculiformis* and their putative F2 hybrids. The F2 population had intermediate phyllode morphology (length:width ratio), and showed large segregation in seedling plant height and photosynthetic activity compared with the *A. mangium* and *A. auriculiformis* populations. The population means for plant height, biomass production and phyllode photosynthetic activity of the F2 population were the lowest amongst the three seedling populations. When the tallest seedlings in the three populations were compared, the putative F2 hybrids were inferior in height but had intermediate internode length and branching density. It seems that putative F2 hybrids of *A. mangium* and *A. auriculiformis* are unlikely to be a useful genetic resource in tropical forestry.

CURRENT expansion in forest plantations in Southeast Asia involves extensive planting of *Acacia mangium* and, to a much lesser degree, *A. auriculiformis*. There are substantial genetic variations within most populations for a wide range of quantitative and qualitative traits (Awang and Taylor 1993; Harwood et al. 1991; Cole et al. 1994). Interspecific F_1 hybrids of these two species which occur naturally are superior in growth and form to the parental species (Pinso and Nasi 1991; Kha 1996; Royampaeng et al. (these Proceedings)). Like their parents, the hybrids can be propagated vegetatively, and clonal forestry of selected F_1 hybrids is now a reality. Furthermore, the hybrids are fertile and their seeds have, in turn, become a potential resource for farmers as well as plantation managers and researchers. But there is no published information on these putative F_2 hybrids and their value in forestry remains to be determined.

This study compares the growth performance of a population of putative F_2 hybrids with *A. mangium* and *A. auriculiformis*. The F_2 population was found to be inferior in growth and form to *A. mangium* and *A. auriculiformis*. The results showed that putative F_2 hybrids will not be a useful genetic resource.

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Materials and Methods

Seed source

Seeds of *A mangium* and *A auriculiformis* were donated by the Australian Tree Seed Centre, CSIRO Forestry and Forest Products (Canberra) and those of the putative F_2 were collected by Mr Apisit Simsiri at the Gene Conservation Research Centre at Sakaerat, Thailand. The three seedlots were:

- *A auriculiformis* (16355/BVG935; Bensbach, W. Province, PNG);
- *A. mangium* (16938/K20; Kini, W. Province, PNG); and
- Putative F_2 interspecific hybrids — seeds collected from an outstanding open pollinated putative F_1 interspecific hybrid in an *A. mangium* stand in Sakaerat, Thailand.

Plant culture and measurements

Seeds were treated with boiling water prior to sowing into sand. Seedlings were transplanted 7–10 days after germination into 3.5 litre pots using a homogenous potting mix composed of 17% thunder-peat + 50% topsoil + 33% river-sand with 6 g/l osmocote (19% N, 2.6% P, 10% K, 4% S). Plants were raised in a 25% shadehouse where daily irradiance and humidity during growth was 1600–1800 mol m^{-2} s^{-1} and 60–70% respectively. Plants

(40 per seedlot) were arranged in a completely randomised block design and watered twice daily without further nutrient supplement. Maximum photosynthesis (A_{max}) was determined between 0830 and 1200 hours with a *LiCOR 6200* portable gas analysis system. Plant height, phyllode length and width, lateral stem density and main stem internode distance were determined in weeks 13 and 18. Seedlings were harvested at week 22, divided into shoot and root components, oven-dried (80°C) for 5 days, and their dry weight determined.

Results and Discussion

The three seedling populations had distinctly different phyllode morphology (Table 1). *A. mangium* had the largest phyllodes, but the phyllode length:width ratio was about half of those for *A. auriculiformis* and F_2 seedlings. These values are similar to published data for these species (Kha 1996; Kijkar 1992; Gan and Sim 1992; Royampaeng (these proceedings)). Most of the F_2 seedlings had phyllodes similar to those of *A. auriculiformis*, but a few had phyllodes resembling those of *A. mangium* (data not shown).

Table 1. Mean phyllode length, width and length:width ratio in three different acacia populations (values are means ± SE).

Population	Length (cm)	Width (cm)	Length:width ratio
A. auriculiformis	17.3 ± 0.6	3.3 ± 0.3	5.71 ± 0.33
A. mangium	23.4 ± 0.4	8.7 ± 0.4	2.68 ± 0.17
F_2 hybrid	17.3 ± 0.5	3.3 ± 0.4	4.89 ± 0.26
$LSD_{0.05}$	3.7	1.8	0.92

Compared with *A. auriculiformis* and *A. mangium*, the F_2 seedlings showed extensive segregation for plant height 20–80 cm (Figure 1), while those of

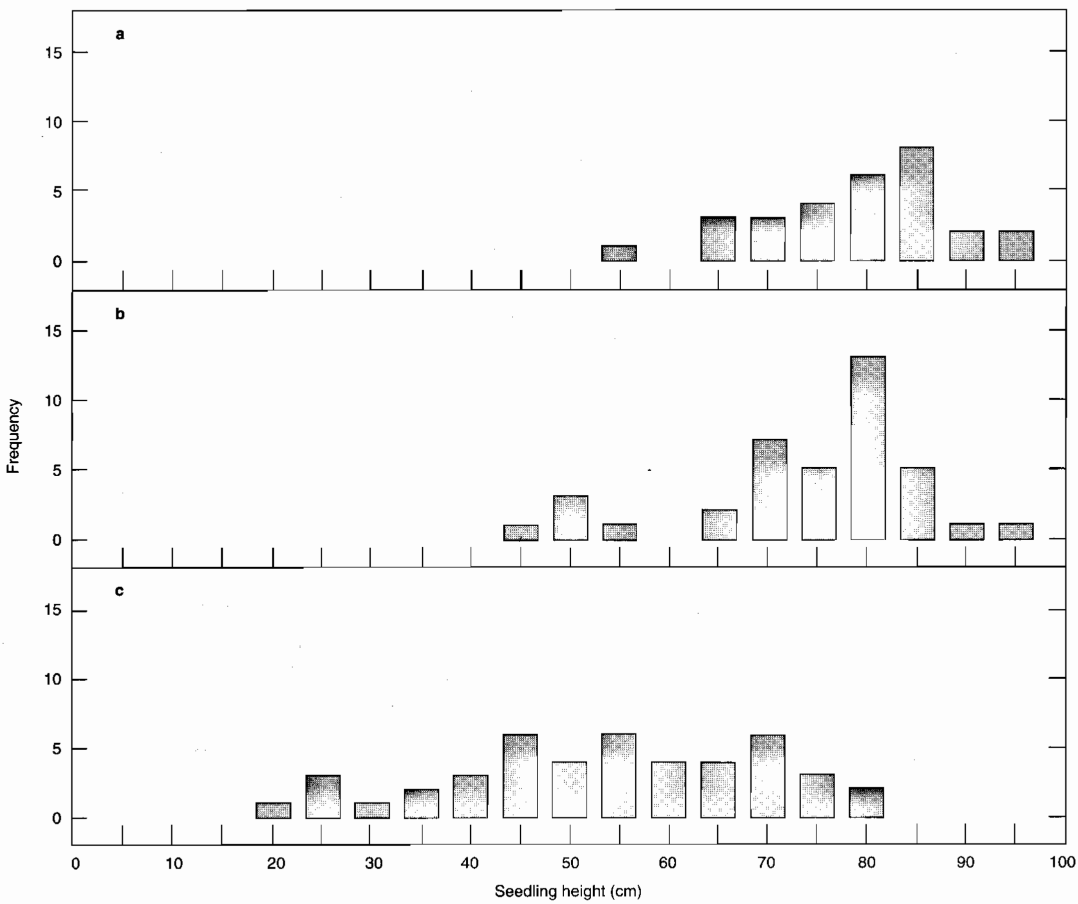

Figure 1. Frequency distribution of mean plant height in seedling populations of: (a) *Acacia auriculiformis*, (b) *Acacia mangium*, and (c) putative F_2 hybrids.

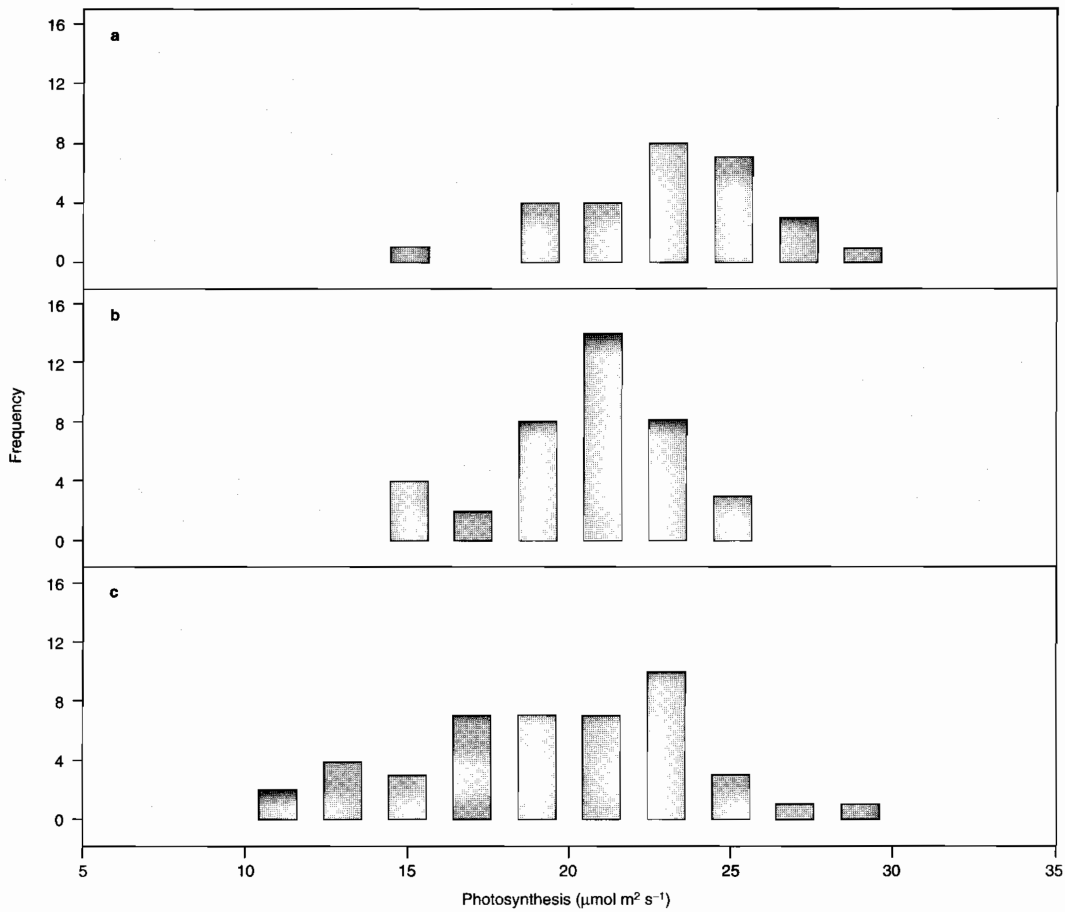

Figure 2. Frequency distribution of mean phyllode photosynthesis (Amax) in seedling populations of: (a) *Acacia auriculiformis*, (b) *Acacia mangium*, and (c) putative F2 hybrids.

A. auriculiformis and *A. mangium* were 65–80 cm. Phyllode photosynthetic activity of the F_2 seedlot had a wider distribution than the other two seedlots (Figure 2). Evidently segregation had occurred for both these parameters in the putative F_2 hybrids.

Table 2. Photosynthetic activity, height and shoot dry weight of three populations of acacia seedlings (values are means ± SE).

Population	Height (cm)	Photosynthesis (μmol m^{-2} s^{-1})	Shoot dry weight (g)
A. auriculiformis	78.7 ± 1.8	23.0 ± 0.6	110 ± 2
A. mangium	69.4 ± 1.8	20.5 ± 0.4	117 ± 6
F_2 hybrid	54.0 ± 2.5	19.4 ± 0.7	75 ± 10
$LSD_{0.05}$	5.8	1.6	12.3

The mean photosynthetic rate was greatest in *A. auriculiformis,* intermediate in *A. mangium*, and lowest in the F_2 hybrids (Table 2). Similar results were obtained for plant height and shoot dry weight. Clearly, the F_2 hybrids were inferior in growth to *A. mangium* and *A. auriculiformis*.

Internode length and branching (main stem) density were used as indicators of plant form. Higher internode length and lower branching density indicate good form and the opposite, poor form. Table 3 shows that *A. mangium* had the best form, and *A. auriculiformis* the worst. The putative F_2 hybrids had an intermediate value for internode length, but similar branching density to that of *A mangium.*

Table 3. Mean internode length and branching density of three acacia seedling populations (values are means ± SE).

Population	Internode length (cm)	Branching density (stem m^{-1})
A. auriculiformis	2.04 ± 0.15	15.6 ± 2.1
A. mangium	5.31 ± 0.29	6.2 ± 1.1
F_2 hybrid	2.87 ± 0.13	6.2 ± 0.9
$LSD_{0.05}$	1.18	5.9

The growth and form of the six tallest seedlings in each population were also examined. There was no significant difference in height between these sub-populations (Table 4). The tallest putative F_2 seedlings had intermediate values for both internode length and branching density compared to *A. auriculiformis* and *A. mangium*. These values did not differ greatly from the population means in Table 3 indicating that the F_2 hybrids were still considerably inferior in form compared with *A. mangium*.

Table 4. Mean height, internode length and branching density in the tallest seedlings of three acacia populations (values are means ± SE).

Population	Height (cm)	Internode length (cm)	Branching density (stem m^{-1})
A. auriculiformis	154.5 ± 1.7	2.64 ± 0.17	12.1 ± 1.2
A. mangium	154.5 ± 5.6	5.56 ± 0.25	6.4 ± 0.6
F_2 hybrid	147.1 ± 3.8	3.51 ± 0.14	9.6 ± 1.1
$LSD_{0.05}$	13.5	0.77	4.0

Conclusions

The evidence presented in this study clearly shows that the overall growth and form of the putative F_2 seedlings were inferior to both *A. mangium* and *A. auriculiformis*, even though the tallest seedlings in all three populations were similar in height. The F_2 population also showed extensive segregation of plant height and photosynthetic capacity. The results indicate that the F_2 hybrids will not be a useful genetic resource. Their poor growth performance and form could possibly be associated with adverse meiotic events that might have occurred in the putative F_1 parent because of its heterozygosity, a phenomenon commonly known as hybrid breakdown (Pinso and Nasi 1991; Hayward et al. 1993). If this were true, it would decrease the genetic potential of the F_1 hybrids for breeding and quality seed production, but it does not diminish the value of using exceptional F_1 interspecific (Am × Aa) genotypes for clonal forestry.

References

Awang, K. and Taylor, D. 1993. *Acacia mangium*: Growing and Utilisation. MPTS Monograph Series No. 3, Winrock International and FAO of the UN, Bangkok, Thailand.

Cole, S.P., Woo, K.C., Eamus, D., Harwood, C.E. and Haines, M.W. 1994. Field measurements of net photosynthesis and related parameters in four provenances of *Acacia auriculiformis*. Australian Journal of Botany, 42, 457–470.

Gan, E. and Sim, B.L. 1992. Nursery identification of hybrid seedlings in open pollinated seedlots. In: Carron, L.T. and Aken, K.M., ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37, 17–21.

Harwood, C.E., Matheson, A.C., Gororo, N., and Haines, M.W. 1991. Seed orchards of *Acacia auriculiformis* at Melville Island, Northern Territory, Australia. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35, 87–91.

Hayward, M.D., Bosemark, N.O. and Romagosa, I. 1993. Plant Breeding: Principles and Prospects. Chapman and Hall, London.

Kha, L.D. 1996. Studies on natural hybrids of *Acacia mangium* and *A. auriculiformis* in Vietnam. In: Dieters, M.J., Matheson, A.C., Nikles, D.J., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI-IUFRO conference, Caloundra, Queensland, Australia, 328–337.

Kijkar S. 1992. Handbook: Vegetative Propagation of *Acacia mangium* × *Acacia auriculiformis*. ASEAN-Canada Forest Tree Seed Centre, Saraburi, Thailand, 19 p.

Pinso, C. and Nasi, R. 1991. The potential use of *Acacia mangium* × *Acacia auriculiformis* hybrid in Sabah. In: Carron, L.T. and Aken, K.M., ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37, 17–21.

Genetic Improvement and Physiology of *Acacia auriculiformis*

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Abstract

This paper discusses aspects of the ACIAR Project 9310 on the genetic improvement and physiology of *Acacia auriculiformis* Cunn. ex Benth. Controlled pollination of inter-provenance and intra-provenance crosses of *A. auriculiformis*, and inter-specific crosses between *A. auriculiformis* and *A. mangium*, was carried out in a breeding population of selected parents in 1995 and 1996. The hybrid seeds produced were to be planted in the following wet season in Australia and Thailand. The role of physiological parameters was also investigated. Total phyllode area was strongly correlated with total biomass (r^2 = 0.78) and shoot dry weight (r^2 = 0.89) in acacia seedlings, indicating that this is a useful selection parameter for growth performance in *A. auriculiformis*. However, it is difficult to determine the total leaf area of a single tree accurately, even though it is simple to determine the specific leaf area which is correlated with total leaf area and which would serve as a growth indicator for this species. The staple carbon isotope (Δ) composition of phyllodes, which is used as an indicator of water-use efficiency, was determined for trees from a clonal seed orchard of *A. auriculiformis* growing in an irrigated and an unirrigated site in Darwin. The Δ values from the unirrigated site were significantly smaller than those from the irrigated site because plants use less water for growth (i.e. they are more water-efficient) in the unirrigated site. The ranking of genotypes was similar for both sites, suggesting that water-use efficiency may be under strong genetic control in these clones.

ACACIA *auriculiformis* Cunn. ex Benth. occurs naturally in Australia in the Northern Territory (NT) and northern Queensland, and on the southern border between the Western province of Papua New Guinea (PNG) and Irian Jaya (Boland et al. 1990). The pulpwood potential of this species is comparable to that of high quality eucalyptus (Logan 1987). The wood can be used for timber, poles, fuelwood and charcoal-making; it is a promising alternative to *Eucalyptus camaldulensis* for plantation forestry in the seasonally dry tropics. It is widely planted throughout Southeast Asia, but most of the trees have crooked and forked stems which have severely restricted their utilisation.

Tree improvement programs and international provenance trials in many countries, including Thailand, have indicated significant differences in growth and form both within and between provenance regions (Pinyopusarerk 1987; Harwood et al. 1991; Awang and Venkateswarlu 1994; Coles et al. 1994). Generally, trees of the Queensland provenances have the longest clear bole, the PNG provenances have the highest biomass production, and the NT provenances are apparently the most drought-tolerant. These studies highlighted the adaptability and growth potential of this species, suggesting that a genetic improvement program could potentially produce genotypes of *A. auriculiformis* with good form, fast growth and enhanced adaptation to dry environment.

Progenies grown from seeds obtained in seed orchards showed strong out-crossing vigour (Montagu et al., these Proceedings). Heterosis is the term used by tree breeders to describe such characteristics; but, to our knowledge, there is little information on the physiological processes associated with the observed growth variations. Presumably, it involves factors that

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contribute positively to the total carbon budget of the tree; factors such as photosynthesis, canopy-size, drought-tolerance and recovery, C-partitioning to woody tissue, respiration, cost of construction of photosynthetic tissues, and specific leaf area. In our opinion, understanding the role of these factors remains an outstanding problem in acacia and tropical forest tree research.

This paper reports results obtained in the ACIAR FST/93/10 project on the genetic improvement and physiology of *A. auriculiformis* in Thailand, Vietnam and Australia. Only three aspects of the project will be discussed here:

- the production of hybrid seeds by controlled pollination;
- shade-house studies on the role of total leaf area in growth; and
- the application of stable carbon isotope composition (Δ) for evaluating water-use efficiency.

Results on other aspects of the project are reported in related publications in these Proceedings.

Materials and Methods

Controlled pollination

The breeding population of parent trees (three each of NT and PNG, and four of Queensland provenances) established at the Sakaerat Gene Conservation Station (lat. 14°13′N, long. 101°55′E; altitude, 420 m; mean annual rainfall, 1300 mm; mean temperature, 25.9°C) was described in Jirawarat et al. (1996). Controlled intra-provenance and inter-provenance crosses were carried out as an incomplete half-diallele of nine parents (three per provenance) in 1995, but this was reduced to a half diallele of six parents in 1996. Because of asynchronous flowering, pollen from NT provenances were stored in liquid nitrogen for over a month and used for some crosses with Queensland and PNG provenances and with *A. mangium*. There was no apparent difference in the percentage fruit-set obtained between fresh and stored pollen.

Isoenzyme analysis

The genotype of ten plus trees and their ramets in the breeding population were identified by isoenzyme analysis using 11 isoenzyme systems (Changtragoon and Finkeldey 1995). The isoenzyme systems used were:

- LAP — Leucine aminopeptidase (3.4.11.1);
- GOT — Glutamate-oxaloacetate transaminase (2.6.1.1);
- GDH — Glutamine dehydrogenase (1.4.1.3);
- IDH — Isocitrate dehydrogenase (1.1.1.42);
- 6-PGDH — 6-Phosphogluconate dehydrogenase (1.1.1.44);
- PGM — Phosphoglucose mutase (2.7.5.1);
- MDH — Malate dehydrogenase (1.1.1.37);
- G-6PDH — Glucose 6-phosphate dehydrogenase (1.1.1.49);
- DIA — Diaphorase (1.1.4.3);
- FDH — Formate dehydrogenase (1.6.99.3); and
- SKDH — Shikimate dehydrogenase (1.1.1.25).

Physiological studies

Total leaf area in shadehouse studies

Forty seedlings each of *A. auriculiformis* (16355/BVG935), *A. mangium* (16938/K20), and a putative F_2 hybrid were planted in a completely randomised block design in 25% shade (1600–1800 μmol% m^{-2} s^{-1}). The putative F_2 hybrids were grown from seeds collected from an outstanding open-pollinated putative natural F_1 *inter-specific* hybrid in a stand of *A. mangium* (16614/MM817, Mai Kussa, PNG). Plants were watered twice daily, and fertilised with *Osmocote* (31 g/pot; 19% N, 2.6% P, 10% K, 4% S). Five plants from each seedlot were harvested at 22 weeks, and the total leaf area determined with a *Delta T Area Meter*. Plants were separated into shoot and root components, oven-dried at 80° for five days, and the dry weight determined.

Total leaf area in field studies

Total leaf area, plant height, stem number, and dbh were determined for four selected seedlots in each provenance in the International Provenance Trial of *A. auriculiformis* in Lumpao Lumsai (Kanchanaburi Province) and Sakaerat (Saraburi Province), Thailand in April (dry season) and November (wet season) 1995 and March (dry season) 1996. Details of measurements are given in Puangchit et al. (1996).

Stable carbon isotope composition of dry matter

Leaf samples were collected from clonal seed orchards in each of an irrigated (Berrimah) and an unirrigated (Humpty Doo) site near Darwin (Montagu et al. 1996). Phyllodes were collected from the north, south, east and west side of the canopy from each of four ramets from 17 clones and oven-dried (80°C for 4 days). The dried material was ground to a fine powder of mean particle size 100 μm for stable carbon isotope analysis, and the discrimination in dry matter was calculated according to Hubick et al. (1988).

Results and Discussion

Controlled pollination and hybrid seeds

For simplicity, the seeds produced from individual crosses are grouped by individual provenance value (Table 1). Most crosses were done with two parents from each provenance: N1, N2, P1, P2, Q1, and Q2. Low yield was obtained for the N × N and N × Q crosses, but the total number of seeds produced in crosses between and within provenance groups was 117–255. Similar values were obtained for the *inter-specific* crosses. However, the differences observed between and within individual crosses were much greater. They varied from one seed produced for a N1 × N2 cross to 161 seeds for a P1 × N2 cross (data not shown in Table 1). The isoenzyme genotypes of N1 and N2 were practically identical (Changtragoon and Woo 1996); this suggests that the trees are probably half-sib, which might explain the low seed-yield obtained for this cross because *A. auriculiformis* is known to be a strong out-crosser (Moran et al. 1989).

Table 1. Hybrid seeds produced in crosses of *A. auriculiformis* and *A. mangium*.

Type of cross					
Inter-provenance		Intra-provenance		Inter-specific	
Cross	Seed #	Cross	Seed #	Cross	Seed #
N × Q	44	N × N	12	Aa × Am	96
N × P	148	P × P	255		
P × N	184	Q × Q	117		
P × Q	175				
Q × N	207				
Q × P	130				

Notes:
- The first parent represented in the cross is the female and the second, the male.
- Abbreviations: Northern Territory provenance (N); Papua New Guinea provenance (P); Queensland provenance of *A. auriculiformis* (Q).
- Aa = *A. auriculiformis*; Am = *A. mangium*.

The results above show that a breeding population of ramets can be used to produce known acacia hybrids quickly. But controlled hybridisation is time-consuming, and this problem can be compounded by variable flowering intensity and flowering time between provenances in the breeding population (Jirawarat et al. 1996). In this study, all three provenances of *A. auriculiformis* flowered from October to November, which shows that inter-provenance hybrids can be produced by open pollination during this period. *Bi-clonal* orchards have been used to obtain open-pollinated *inter-specific* hybrids of *A. auriculiformis* and *A. mangium*, but the yield was low (Griffin et al. 1991; Wickneswari and Norwati 1991).

To increase yield of hybrid seed it is essential to plant clones that flower synchronously in these bi-clonal orchards. However, there is extra cost and labour involved in identifying and confirming the hybrid genotypes produced. Controlled hybridisation of crosses between asynchronous trees with pollen stored in liquid nitrogen would overcome both the constraint imposed by asynchronous flowering and the cost of identifying the hybrid genotypes produced. But emasculating the tiny flowers in the spike is a difficult task that requires a good eye and nimble fingers. This may partly explain why controlled pollination has not been used more widely to produce acacia hybrids.

Alternatively, isoenzyme analysis could be used to identify crosses which could be pollinated without the need for emasculation, because the crossed progenies could subsequently be distinguished from their selfed counterparts by isoenzyme analysis. For example, the parents in the breeding population are putatively monomorphic for nine alleles (LAP, GOT, GDH, 6-PGDH, MDH, G6-PDH, DIA, FDH and SKDH), and polymorphic at the PGM-A, PGM-B and IDH-A loci (Table 3). The PGM-A locus had 4 putative alleles, the PGM-B locus, 3, and the IDH-A locus, 2. Thus, pollination of 91% of the 45 half-diallele crosses in this study can be carried out without emasculation, since the selfed progenies can be identified at a later stage by isoenzyme analysis (Changtragoon and Woo 1996). However, the high cost of isoenzyme analysis can be a deterrent for many researchers.

Table 2. Isoenzyme genotype of plus trees of *A. auriculiformis* in breeding population.

Putative gene loci	Isoenzyme genotype of parents								
	N1	N2	N3	P1	P2	P3	Q1	Q2	Q3
PGM-A	33	33	11	33	33	33	14	33	33
PGM-B	23	22	22	22	22	11	22	22	22
IDH-A	11	11	11	11	12	11	11	11	12

Notes:
- Abbreviations for isoenzymes: IDH = Isocitrate dehydrogenase (1.1.1.42); PGM = Phosphoglucose mutase (2.7.5.1).
- Abbreviations for provenances are identical to those given in Table 1.

The hybrid seeds produced will be planted out in Darwin and Thailand in the coming wet season. They will be used to analyse heterosis and physiological parameters associated with growth, and to evaluate the effect (if any) of maternal and paternal factors on growth in these genotypes.

Total leaf area

In higher plants, organic carbon is produced entirely by photosynthesis. Clearly, therefore, the growth potential of a plant is dependent on the total photosynthetic capacity of its leaves. In a shade-house experiment, the total phyllode area produced correlated strongly with total biomass and shoot dry-weight of seedlings in *A. mangium* and

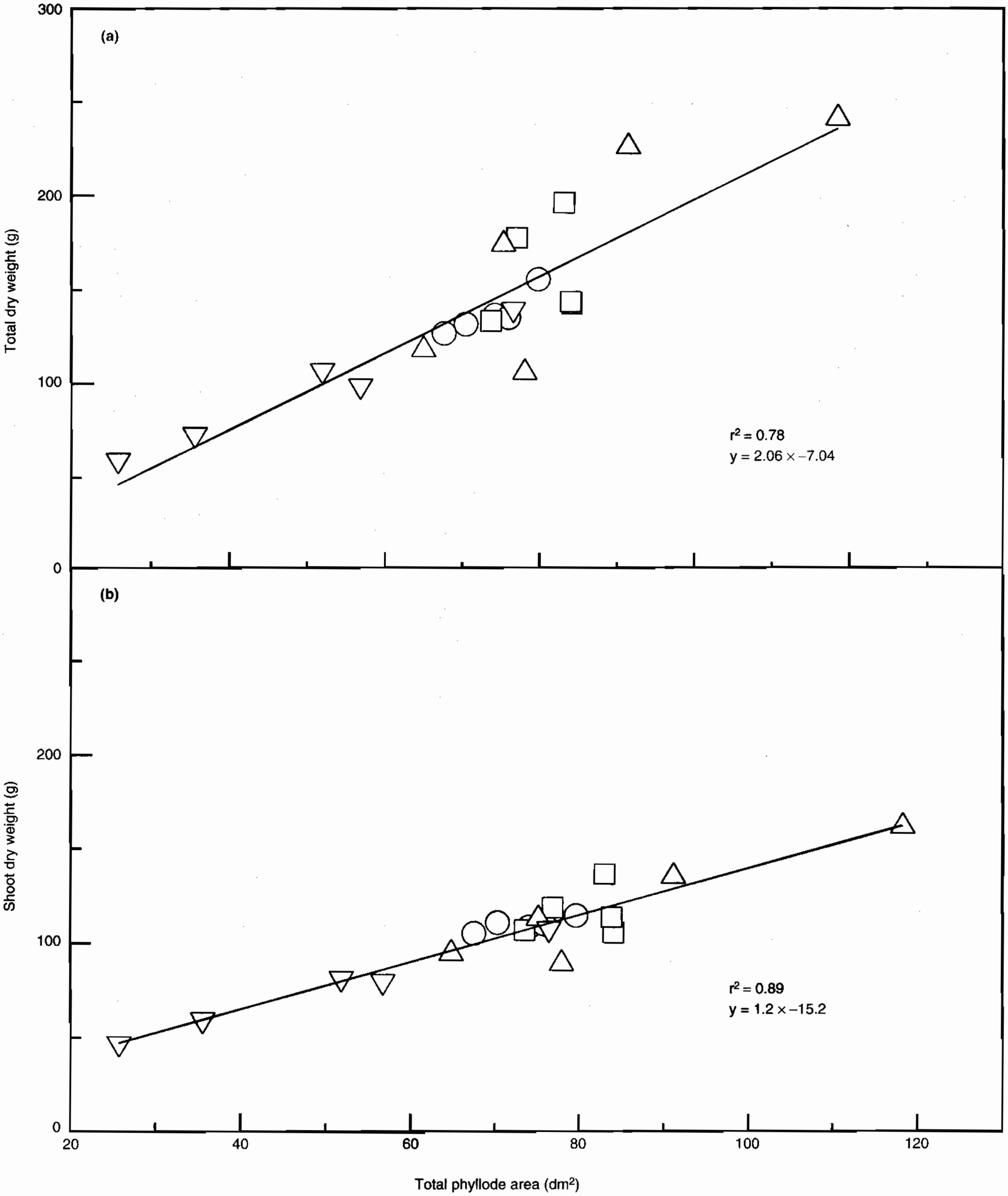

Figure 1. Relationship between total phyllode area and (a) total dry-weight and (b) shoot dry-weight in *A. auriculiformis* (○), *A. mangium* (□) and putative F_2 (▽) seedlings.

A. auriculiformis and their putative F_2 hybrids (Figure 1). This is a fundamental relationship for plant growth, and it is reasonable to expect that it would probably prevail, albeit in a less rigorous manner, in the field.

The growth (stem-volume increase) of six-year-old *A. auriculiformis* under a closed canopy could be attributed primarily to an increase in height because of the competition for light among the trees (Puangchit et al. 1996). The canopy size decreased considerably (up to 40%) during the dry season, and then increased to almost twice the size with new growth by the end of the wet season. Surprisingly, wet-season growth correlated better with canopy size at the end of the dry season, rather than the wet (Figure 2). Interestingly, unlike eucalypts which flushed in the middle of the dry season, *A. auriculiformis* started to flush only weeks after the wet season had begun; yet, photosynthetic activity in the phyllodes increased almost immediately with the first rain (Montagu and Woo, 1997). Under these conditions, a larger canopy at the end of the dry season would have an adaptive advantage in promoting growth in the following wet season in this species.

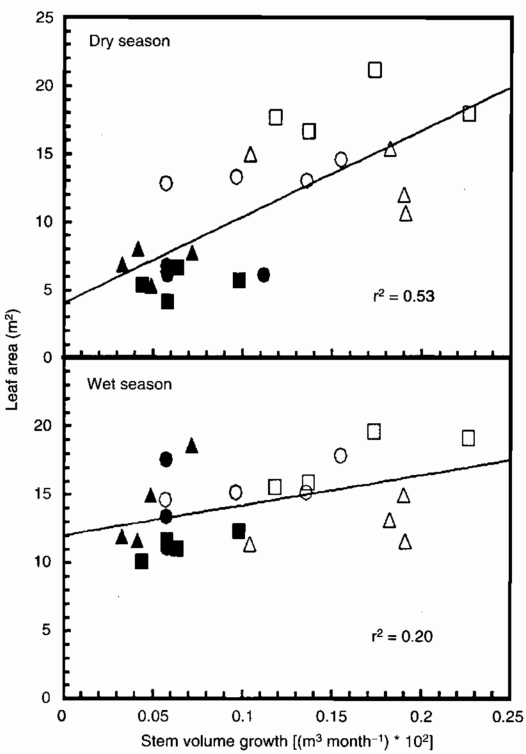

Figure 2. Relationship of stem-volume growth with canopy area at the end of (a) the dry season, and (b) the wet season in *A. auriculiformis*. The different symbols represent different provenances.

These studies show that seasonal variations can affect the relationship between leaf canopy and growth. In any case, the leaf-area index seems like a useful indicator for growth in *A. auriculiformis*. In practice, it is difficult to accurately determine total leaf-area of individual trees in the field. However, the specific leaf area is strongly correlated with total leaf area and biomass production in this species (Montagu and Woo (these Proceedings)). It is simple to determine SLA, and studies are in progress to assess its value as an indicator for plus tree selection under a wide range of environmental conditions.

In the field, canopy size and photosynthetic capacity are likely to be moderated by other physiological parameters such as:

- respiration,
- cost of construction of photosynthetic tissue,
- drought tolerance and recovery,
- carbon partitioning between woody and photosynthetic tissues, and
- specific leaf area.

The impact of these factors on the growth and wood production of plus trees in acacia species requires further studies.

Carbon isotope composition and water-use efficiency

Studies with peanuts (Hubick et al. 1988) and wheat (Farquhar and Richards 1984) indicated that stable carbon isotope discrimination (Δ) is negatively correlated with water-use efficiency, but positively correlated with grain-yield and dry-matter production in field-grown wheat (Condon et al. 1987). The Δ values of acacia ramets growing in an irrigated site are significantly greater than those in an unirrigated site (Table 3). Variations between clones were significant, and there was no apparent interaction between site and clones. In other words, the ranking of clones by their Δ values was not significantly affected by site (Figure 3). The results suggest that water-use efficiency is under some form of genetic control in *A. auriculiformis*; but more evidence is required before this parameter could be used as an indicator of water-use efficiency in this species.

Table 3. Stable carbon isotope composition (Δ) in phyllodes from 17 clones of *A. auriculiformis* growing on wet (irrigated) and dry (unirrigated) sites in Darwin, Northern Territory, Australia.

Parameter	n	(Δ) × 103	
		Wet site	Dry site
Mean P	68	21.16 ± 0.09 <0.01	20.02 ± 0.13 <0.01

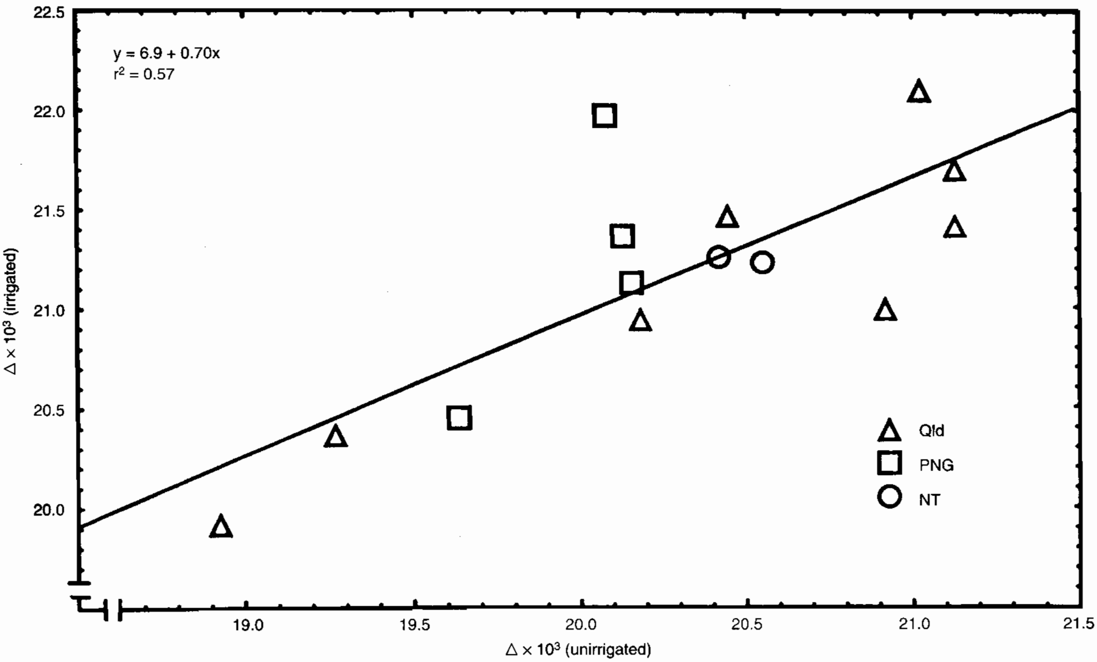

Figure 3. Correlation of stable carbon isotope composition (Δ) between clones of *A. auriculiformis* growing on irrigated and unirrigated sites.

Conclusion

There are three conclusions to be drawn from this study. Firstly, many hybrid seeds were produced by controlled pollination of intra-provenance and inter-provenance crosses of *A. auriculiformis*, and inter-specific crosses between *A. auriculiformis* and *A. mangium*. They are sufficiently promising to be planted in Australia and Thailand in the next wet season. Secondly, total leaf area was strongly correlated with biomass production in *A. auriculiformis* and, in a closed canopy environment, growth was better correlated with canopy leaf-area in the dry season rather than the wet. The results indicate that leaf area may be used as an indicator for growth in this species; however, seasonal variations could influence the strategy adopted for growth by this species. Finally, there is evidence to suggest that water-use efficiency might be under some form of genetic control in *A. auriculiformis*.

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References

Awang, K. and Venkateswarlu, P. 1994. Compendium of Research on *Acacia auriculiformis* Carried Out under the MPTS Research Network in Asia. MPTS Network, F/FRED Project, Winrock International and USAID.

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, 159–180.

Changtragoon, S. and Finkeldey, R. 1995. Inheritance of isozyme phenotypes of *Pinus merkusii*. Journal of Tropical Forest Science, 8, 167–177.

Changtragoon, S. and Woo, K.C. 1996. Application of isoenzyme gene markers in the breeding of *Acacia auriculiformis* hybrids. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry, Proceedings of QFRI-IUFRO Conference, 27 October–1 November 1996, Caloundra, Queensland, Australia, 189–190.

Coles, S.P., Woo, K.C., Eamus, D.E., Harwood, C.E. and Haines, M.W. 1994. Field measurement of net photosynthesis and related parameters in four provenances of *Acacia auriculiformis*. Australian Journal of Botany, 42, 457–470.

Condon, A.G., Richards, R.A. and Farquhar, G.D. 1987. Carbon isotope discrimination is positively correlated with grain yield and dry matter production in field-grown wheat. Crop Science, 27, 996–1001.

Farquhar, G.D. and Richards, R.A. 1984. Isotopic discrimination of plan carbon correlates with water-use efficiency of wheat genotypes. Australian Journal of Plant Physiology, 11, 539–552.

Griffin, A.R., Yong, C.Y., Wickneswari, R. and Chia, E. 1991. Mass production of hybrid seed of *Acacia mangium* × *Acacia auriculiformis* in bi-clonal seed orchards. In: Carron, L.T. and Aken, K.M., ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37, 70–75.

Harwood, C.E., Matheson, A.C., Gororo, N. and Haines, M.W. 1991 Seed orchards of *Acacia auriculiformis* at Melville Island, Northern Territory, Australia. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35, 87–91.

Hubick, K.T., Shorter, R. and Farquhar, G.D. 1988. Hereditability and genotype × environment interactions of carbon isotope discrimination and transpiration efficiency in peanuts (*Arachis hypogaea* L.). Australian Journal of Plant Physiology, 15, 799–813.

Jiwarawat, P., Luangviriyasaeng, V. and Woo, K.C. 1996. Hybrid seeds of *Acacia auriculiformis*. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry, Proceedings of QFRI-IUFRO Conference, 27 October–1 November 1996, Caloundra, Queensland, Australia, 234–237.

Logan, A.F. 1987. Australian acacias for pulpwood. In: Turnbull, J.W. ed., Australian Acacias in Developing Countries, ACIAR Proceedings No. 16, 84–94.

Montagu, K. and Woo, K.C. 1997. Recovery of photosynthesis following seasonal drought in the wet-dry tropics — the key to rapid growth of *Acacia auriculiformis*. In: Proceedings of the Australian Society for Biochemistry and Molecular Biology, Combined conference abstracts, Vol. 29, Symposium, 12, 1.

Montagu, K.D., Woo, K.C., Harwood, C.E. and Metcalfe, A.J. 1996. Tree growth and form in a clonal seed orchard of *Acacia auriculiformis*. In: Dieters, M.J., Matheson, A.C., Nickles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry, 379–381.

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

Pinyopusarerk, K. 1987. Improving *Acacia auriculiformis* through selection and breeding in Thailand. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, 147–150.

Puangchit, L., Woo, K.C. and Montagu, K.D. 1996. Physiology of *Acacia auriculiformis*: implications for genetic improvement. In: Dieters, M.J., Matheson, A.C., Nickles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry, 384–385.

Wickneswari, R., and Norwati, M. 1991. Pod production and hybrid seed yield of *Acacia mangium* and *Acacia auriculiformis*. In: Carron, L.T. and Aken, K.M., ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37, 57–62.

Growth, Marcottability and Photosynthetic Rate of *Acacia crassicarpa* Provenances at Serdang, Malaysia

Kamis Awang, Sulaiman Jamahari, Arifin Awang Zulkifli and Nor Aini Abd Shukor[1]

Abstract

A trial of eight provenances of *Acacia crassicarpa* A. Cunn. Ex Benth. was assessed for survival and growth at the age of two years. Three provenances were from Queensland, Australia, four from Papua New Guinea, and one from Irian Jaya, Indonesia. In addition, the marcottability and photosynthetic rate of four selected provenances were also studied. All provenances survived well (>94%), but they differed significantly ($p < 0.01$) in their growth performance. All provenances had more than 43% of their trees with single stems. For timber production, the provenance from Irian Jaya (Samlleberr) and two provenances from Queensland (Olive River and Jardine River-Bamaga) were identified as promising. The success of marcotting of four of the provenances was high (>73%), with the more vigorous provenances giving higher rates. Significant differences were found in the photosynthetic rates of the four selected provenances. However, the rate did not appear to correlate with the vigour of the provenance.

ONE of the humid/subhumid tropical acacias with potential for wood production for fuelwood, timber and pulp, *Acacia crassicarpa* A. Cunn. ex Benth., is native to northeastern Queensland, Australia, southwestern Papua New Guinea, and southeastern Irian Jaya, Indonesia (Harwood 1992; Thomson 1994). It fixes nitrogen, grows rapidly, and competes effectively with weedy grasses. It appears able to tolerate a wide range of soil textures, with pH between 4 and 8, a dry season of up to 6 months, and annual rainfall as low as 900 mm.

However, many of the acacia plantations in the Asian tropical regions are based on *Acacia mangium* and *Acacia auriculiformis* (Pinyopusarerk 1992). Early reports on the evaluation of several *A. crassicarpa* provenances indicate that their growth is at least as good as *A. mangium* and *A. auriculiformis* in Thailand (Chittachumnonk and Sirilak 1991), Malaysia (Sim and Gan 1991), Sri Lanka (Weerawardane and Vivekanandan 1991), Hainan Island, China (Yang and Zeng 1991), Vietnam (Kha and Nghia 1991), and Laos (Latsamay 1991). These provenance trials of *A. crassicarpa* have also demonstrated the superior vigour of provenances from Western Province, Papua New Guinea over those from north Queensland (Thomson 1994). In Malaysia, the introduction of *A. crassicarpa* has been limited to Sabah (Sim and Gan 1991). This paper reports on the growth, marcottability, and photosynthesis of eight *A. crassicarpa* provenances in a trial at Serdang, Peninsular Malaysia.

Materials and Methods

Trial establishment

Eight seedlots of *A. crassicarpa* provided by the Australian Tree Seed Centre were used. The seeds were collected from the species' natural distribution in northern Queensland, Australia, Papua New Guinea and Irian Jaya, Indonesia. This is one of the first provenance trials to include a seedlot from Irian Jaya for comparison with Papua New Guinean and Australian seed sources. Table 1 shows details of seed origin.

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Table 1. Details of the eight provenances of seedlots of *Acacia crassicarpa*.

Trial No.	CSIRO Seedlot No.	Provenance	Lat. (S)	Long. (E)	Alt. (m)	No. of parents
1	16128	Jardine River – Bamaga, Qld	11°02′	142°22′	20	15
2	17943	Olive River, Qld	12°19′	142°50′	60	5
3	17944	Claudie River, Qld	12°48′	143°18′	20	4
4	16598	Bimadebun Village, PNG	8°37′	141°55′	25	40
5	17548	Oriomio Old Zim, PNG	8°48′	143°06′	20	5
6	17552	Bensbach, PNG	8°53′	141°17′	25	35
7	17561	Limal-Malam, PNG	8°40′	142°43′	40	30
8	17849	Samlleberr, Irian Jaya, Ind	8°20′	141°00′	40	5

Qld = Queensland, Australia; PNG = Papua New Guinea; Ind = Indonesia

The field trial was established in January 1992 at Universiti Putra Malaysia (UPM) Farm, Serdang (latitude 3°02′N, longitude 101°42′E, altitude 32 m) representing a humid site under *Imperata cylindrica* grass. Mean annual rainfall is 2140 mm and mean annual temperature 26°C. The site experiences an average windspeed of 0.86 m/second, receiving a daily average of 5.8 hours of sunshine and an annual evaporation of 1527 mm. The soil is fine-loamy, mixed, Typic Hapludults, isohyperthermic and udic, pH 4.4. The site was fully cultivated before planting. A randomised complete block design with six replicates was used. Each replicated plot consisted of 16 trees (4 × 4) spaced at 3 × 3 m. The plots were weeded every 3 months during the first year, and less frequently thereafter.

Growth assessment

Measurements of height, diameter at breast height (dbh), and survival were made for all trees every 6 months after planting. Square root of the sum of the squares of each individual stem was used to calculate dbh of multistemmed trees. At 24 months, trees were also individually assessed for form using three classes:

- Class 1. Tree with one main leading stem up to the tip. Branches are small, with a basal diameter less than 50% of the principal bole at the same height.
- Class 2. Tree with more than one leading stem originating at a height 50 cm above the ground; the branching bole is considered to be a stem if its basal diameter is equal to or greater than 50% of the diameter of the principal bole at the same height.
- Class 3. Tree with more than one leading stem originating below a height of 50 cm above the ground; the distinction of a branching bole is the same as for Class 2.

The two years' data were analysed for variance, and provenance means were compared using Studentised Range Test. *MPTStat*, a statistical package developed by the Forestry/Fuelwood Research and Development Project of Winrock International, was used for the analyses.

Marcotting

Also known as air-layering, marcotting is a form of vegetative propagation, that initiates root formation by girdling or slitting a small portion of a twig and enclosing it in a moist rooting medium. Once sufficient roots have been formed, the terminal end of the twig is detached and planted out. Four provenances (Olive River, Queensland; Limal-Malam, Papua New Guinea; Claudie River, Queensland; and Bimadebun Village, Papua New Guinea) were chosen for a marcotting study at the age of 2.5 years. The first two represented the more vigorous provenances, while the latter two represented the slower ones. For each provenance, two positions of the live crown of sample trees (upper and lower) were selected and treated with or without hormone. The hormone used was Seradix 3, containing 0.8% 4-indole-3-butyric acid. Each treatment had 15 samples.

For this purpose, branches 10–40 mm in diameter were chosen from vigorous trees. The branches were girdled by removing 40 mm wide ring of the bark. Moist rooting medium was then placed around the girdled area and wrapped in a transparent polyethylene film, which was tied at both ends. The rooting medium was a 1:1 mixture of coconut fibres and forest topsoil. After about 2 months, the rooted branches were detached and potted in polyethylene bags (30 × 25 cm flat) and kept in a greenhouse. The ramets were pruned to reduce excessive transpiration. The rooting percentage of the sampled branches and the survival percentage of the potted ramets after one month were determined.

Stomatal characteristics, photosynthetic and respiratory measurements

At the age of 3 years, measurements of photosynthesis, respiration and several stomatal characteristics of four of the provenances were conducted. The provenances selected were Samlleberr (Indonesia), Olive River (Queensland), Bensbach (Papua New Guinea), and Claudie River (Queensland) representing two top growth performers, one intermediate, and one poor performer.

For determination of stomatal density, length and width, two trees were randomly selected for each provenance. From each tree, six leaves (i.e. phyllodes) were sampled from three different crown positions — upper, middle and lower. An impression of the abaxial surface was made using nail varnish. The number of stomata and their length and width were measured under a microscope at 100× and 400× magnifications respectively.

For measurement of photosynthesis, respiration and stomatal conductance, small twigs with four–five leaves were taken from the upper, middle and lower parts of live crowns. They were placed in a half pail of water and immediately brought to the laboratory. Before taking the measurements, the twig was put into a 500 ml conical flask containing water and acclimatised under the measuring conditions for 15 minutes. Only one healthy, mature leaf, second from the tip of the twig, was selected. For each position, four leaves were selected in each provenance.

Measurements of photosynthesis and stomatal conductance were made with a *LI-COR LI-6200 Portable Photosynthesis System* connected to a *LI-6250 CO_2 Analyser* under five photon flux densities: 10, 40, 120, 240 and 400 molm^{-2}s^{-1}. Dark respiration was also measured with the same system. Laboratory air temperature was 29.8–34.5°C and relative humidity 38–50% during measurements. Only summarised results on the mean values of measurements at all photon flux densities and for the three crown positions are presented here. These mean values were compared using 'Duncan's Multiple Range Test' (Table 5).

Results

Growth performance

At the age of 2 years, survival for all provenances was high, 94.5–100%, and showed no statistical differences between them (Table 2). Lowest survival was recorded for the Bimadebun Village provenance from Papua New Guinea, while the Jardine River provenance from Queensland had 100% survival.

However, the provenances showed significant differences in their height and diameter growth (Table 2). Significant differences were also recorded among provenances from Queensland and Papua New Guinea. The overall ranking based on the mean of the ranks assigned for each parameter indicates that the Samlleberr provenance from Irian Jaya, Indonesia was the best performer, followed by two provenances from Queensland (Olive River and Jardine River). The poorest provenance was from Claudie River, Queensland. The four provenances from Papua New Guinea (Bimadebun Village, Oriomo Old Zim, Bensbach and Limal-Malam) were intermediate in their performance.

Tree form also differed markedly among the provenances (Table 3). Single-stemmed trees (Class 1) were the most prominent among the provenances. However, the number of trees within this class was low, 43.9–64.4%. The top three most vigorous provenances (Samlleberr, Indonesia, and Olive River and Jardine River, Queensland) also had the highest percentage of single-stemmed trees with values of 64.4, 56.6 and 49.0% respectively.

Table 2. Performance of 2-year-old *Acacia crassicarpa* provenances.

Provenance	Survival (%)	Height (m)	Diameter, bh (cm)	Composite ranking
Jardine River – Bamaga, Qld	100.0 a	8.8 abc	8.5 abd	3
Olive River, Qld	97.7 a	9.4 abcd	9.6 ae	2
Claudie River, Qld	97.7 a	6.7	7.1 bc	
Bimadebun Village, PNG	94.5 a	7.4 ab	7.5 ab	8
Oriomio Old Zim, PNG	97.8 a	8.2 ab	7.8 b	5
Bensbach, PNG	97.7 a	8.9 abcde	8.4 adbdf	4
Limal-Malam, PNG	96.7 a	8.6 a	9.4 a	5
Samlleberr, Irian Jaya, Ind	98.8 a	9.0 abcde	9.6 ae	1
ANOVA results	NS	**	**	

Notes
Means having the same suffixes are not significantly different at p = 0.05
NS = not significant at p = 0.05
** = significant at p = 0.01
Composite ranking = Means of survival + height + diameter

Table 3. Percentage of trees in tree-form classes of various provenances of *Acacia crassicarpa*.

	Tree-form classes		
	1	2	3
Jardine River – Bamaga, Qld	49.0	16.7	34.3
Olive River, Qld	56.0	14.9	28.5
Claudie River, Qld	48.5	36.9	14.6
Bimadebun Village, PNG	46.3	24.2	29.5
Oriomio Old Zim, PNG	43.9	40.6	15.5
Bensbach, PNG	46.5	25.8	27.7
Limal-Malam, PNG	45.6	26.7	27.7
Samlleberr, Irian Jaya, Ind	64.4	15.8	19.8

Marcottability

Generally, rooting percentage was high with means ranging from 74.9–91.6% (Table 4). The provenance from Limal-Malam (Papua New Guinea) recorded the highest rooting percentage, followed by provenances from Olive River (Queensland), Bimadebun Village (Papua New Guinea), and finally the provenance from Claudie River (Queensland) with the lowest rooting percentage. For all provenances, branches from the upper crowns recorded better rooting success, with provenances from Limal-Malam and Olive River attaining 100% rooting. Generally, slightly better rooting was recorded in branches treated with Seradix 3 than those without hormone. This effect was particularly pronounced in branches from the upper crowns.

After potting, the ramets from all provenances generally survived well with percentages >73% (Table 4). As in rooting percentage, the ramets of provenances from Limal-Malam and Olive River had higher survival rates than those from Claudie River and Bimadebun Village. For all the provenances, the ramets from the upper crowns had markedly higher survival rates than those from the lower crowns, particularly in Limal-Malam and Olive River which recorded 100% survival. Application of hormone did not result in improvement of survival rate of the ramets for all the provenances, except for Limal-Malam and Claudie River. For these provenances, branches treated with Seradix 3 all survived, while those untreated with hormone recorded reduced survival particularly in Claudie River provenance.

Stomatal characteristics, photosynthesis and respiration

The results in Table 5 indicate that the provenance from Bensbach, Papua New Guinea had the highest stomatal density, followed by provenances from Claudie River and Olive River, Queensland, and Samlleberr, Indonesia. The differences were mostly significant. In contrast, the differences among the provenances in terms of stomatal size (length and width) were generally not significant. The Bensbach provenance also had a significantly higher photosynthetic rate than the other three provenances, which did not differ significantly among themselves (Table 5). However, there were no significant differences in stomatal conductance and respiration rate between the four provenances.

Table 4. Effect of hormone and crown position on rooting and survival percentages of *A crassicarpa* ramets.

Provenance	Crown position	Rooting (%)			Survival (%)		
		Seradix 3	Control	Mean	Seradix 3	Control	Mean
Olive River, QLD	Upper	100.0	86.6	93.3	100.0	100.0	100.0
	Lower	66.6	73.3	69.9	75.0	66.6	70.8
	Mean	83.3	79.9	81.6	87.5	83.3	85.4
Limal Malam, PNG	Upper	100.0	86.6	93.3	100.0	100.0	100.0
	Lower	86.6	93.3	89.9	100.0	40.0	70.0
	Mean	93.3	89.9	91.6	100.0	70.0	85.0
Bimadebun Village, PNG	Upper	93.3	73.3	83.3	85.7	83.3	84.5
	Lower	80.0	60.0	70	60.0	66.6	63.3
	Mean	86.6	66.6	76.6	72.8	74.9	73.9
Claudie River, QLD	Upper	93.3	80.0	86.6	100.0	66.6	83.3
	Lower	60.0	66.6	63.3	100.0	25.5	62.7
	Mean	76.6	73.3	74.9	100.0	46.1	73.0

PNG = Papua New Guinea; QLD = Queensland

Table 5. Stomatal characteristics, photosynthesis and respiration of four *A. crassicarpa* provenances.

Factor	Provenance			
	Bensbach, PNG	Olive River, Qld	Samlleberr, Irian Jaya, Ind	Claudie River, Qld
Density (no. mm^{-2})	157.2 a	150.58 b	141.13 c	151.91 b
Length (microns)	33 a	29.75 a	33 a	35 a
Width (microns)	24.65 ab	22.74 b	24.33 ab	24.80 a
Photosynthetic rate ($\mu mol\ m^{-2}s^{-1}$)	13.19 a	3.116 b	3.743 b	6.988 b
Stomatal conductance ($\mu mol\ m^{-2}s^{-1}$)	1.43 a	1.687 a	1.224 a	1.095 a
Respiration rate ($\mu mol\ m^{-2}s^{-1}$)	0.85 a	0.77 a	0.70 a	0.91 a

Means with the same letters are not significantly different at 0.05 level using the Duncan Multiple Range Test (DMRT).

Discussion

The results indicate that all provenances survived well, with survival rates of 94–100%, but differed markedly in their growth in terms of height, diameter and tree form. These differences were associated with both inter- and intra-variations from the two provenance regions in New Guinea/Irian Jaya and northern Queensland. Although the results are preliminary, this variation indicates the presence of genetic diversity in the species within its distributional range. Based on vigour and tree form, the provenance from Indonesia (Samlleberr, Irian Jaya) and two from Queensland (Olive River and Jardine River–Bamaga) are the most promising, and could be selected for further planting.

Comparison of the results obtained here with those from other sites such as at Ba Vi (Vietnam) (Kha and Nghia 1991; Thomson 1994) suggests that the provenances evaluated exhibit strong genotype × environment interaction effect. That is, the performance of a particular provenance with respect to the others is not the same across sites. For example, the Jardine River–Bamaga from Queensland was the poorest performer at Ba Vi, while the Bimadebun Village provenance from Papua New Guinea, which was the poorest performer here, was the second top performer at Ba Vi. Williams and Luangviriyasaeng (1989) also found genotype–environment interaction with this species in Thailand. Therefore, further planting of the provenances recommended here should be restricted to sites similar to the trial site. It also implies that further testing of selected, promising provenances on other sites with different environmental conditions is needed. This should draw on the results obtained here, and those reported from similar trials in other countries.

One striking aspect about the overall results is the high growth rates obtained with the species. The ranges of calculated mean annual increments of height and dbh were 3.4–4.7 m and 3.6–4.8 cm respectively. In comparison, similar ranges for the top 10 of the 28 provenances of *A. auriculiformis* tested in adjacent plots were 3.0–3.5 m and 2.7–3.2 cm (Kamis Awang et al. 1994). Sim and Gan (1991) also reported the superiority of growth of *A. crassicarpa* over *A. auriculiformis*, *A. mangium*, *A. aulacocarpa* and *A. mearnsii* on four sites in Sabah, Malaysia. Similarly, Pinyopusarerk (1989) reported that a Papua New Guinean provenance averaged 10.8 m in height and 10.3 cm dbh at two years of age at Saitong, Thailand, slightly greater than the best provenance in this trial. This reinforces the view that *A. crassicarpa* has potential for industrial planting.

A preliminary attempt was made to link the differences in provenance vigour with their photosynthetic rates. However, as the results suggest, such a correlation appeared to be non-existent. This was illustrated by the fact that the provenance from Bensbach (Papua New Guinea) had a significantly higher photosynthetic rate than provenances from Samlleberr (Indonesia) and Olive River (Queensland) despite the latter two having higher vigour in terms of height and diameter growths. However, in many cases, net photosynthesis has been found to be poorly or negatively correlated with growth rate (Ledig and Perry 1969). Failure to account for seasonal changes in net photosynthetic rate is one of the primary causes for such poor correlations (Foote and Schaedle 1974). Other reasons could be differences in leaf area, pattern of carbon partitioning and variation in wood and root respiration.

Vegetative propagation is an important means of duplicating true-to-type individuals containing desired inherent characteristics. Marcotting is one of these techniques that could be used in tree improvement work. This possibility was explored in this study with four of the provenances. The results indicated that all the provenances could be easily marcotted. The more vigorous provenances as exemplified by those from Olive River and Limal-Malam were more successful than the slower ones.

This is very encouraging since the more vigorous provenances are the ones of interest for further propagation. Another interesting finding was that even without the addition of hormone, the success rate obtained was reasonably high. This would help to save cost in the long run. However, in order to obtain the best outcome, the results suggest that marcotting should be done on branches located at the upper half of the live crowns. This may pose some physical problems when dealing with tall trees.

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References

Chittachumnonk, P. and Sirilak, S. 1991. Performance of *Acacia* species in Thailand. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35, Canberra, 153–158.

Foote, K. and M. Schaedle. 1974. Seasonal field rates of photosynthesis and respiration in stem of *Populus tremuloides*. Plant Physiology Supplement, 53, 253–269.

Harwood, C. 1992. Spotlight on species: *Acacia crassicarpa*. Farm Forestry News, 5 (3), 10–11.

Kamis Awang, Nor Aini Ab. Shukor, Adjers, G., Bhumibhamon, S., Fan, F.J. and Venkateswarlu, P. 1994. Performance of *Acacia auriculiformis* provenances at 18 months on four sites. Journal of Tropical Forest Science, 7 (2), 251–261.

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

Latsamay, S. 1991. Australian acacias in Laos. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35, Canberra, 227–228.

Ledig, F.T. and Perry, T.O. 1969. Net assimilation rate and growth in loblolly pine seedlings. Forest Science, 15, 431–438.

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 and Shrubs in Developing Countries. ACIAR Monograph No. 10, Canberra, 109–127.

Pinyopusarerk, K. 1992. Australian collaborative research on tropical acacias. In: Kamis Awang and Taylor, D.A., ed., Tropical Acacias in East Asia and the Pacific. Proceedings of a First Meeting of the Consultative Group for Research and Development of Acacias (COGREDA) held in Phuket, Thailand, June 1–3, Bangkok. Winrock International, 8–14.

Sim, B.L. and Gan, E. 1991. Performance of Acacia species on four sites of Sabah Forest Industries. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35, Canberra, 159–165.

Thomson, L.A.J. 1994. *Acacia aulacocarpa, A. cincinnata, A. crassicarpa* and *A. wetarensis*: An annotated bibliography. Canberra, CSIRO Division of Forestry.

Weerawardane, N.D.R. and Vivekanandan, K. 1991. *Acacia* species and provenance trials in uplands of Sri Lanka. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35, Canberra, 166–169.

Williams, E.R. and Luangviriyasaeng, V. 1989. Statistical analysis of tree species trial and seedlot:site interaction in Thailand. In: Boland, D.J., ed., Trees for the Tropics: Growing Australian Multipurpose Trees and Shrubs in Developing Countries. ACIAR Monograph No. 10, Canberra, 145–152.

Yang, M. and Zeng, Y. 1991. Results from a four-year-old tropical *Acacia* species/provenance trial on Hainan Island, China. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35, Canberra, 170–172.

Provenance Variation in Water Relations of *Acacia auriculiformis* Grown in Thailand

Ladawan Puangchit, Parichat Rochanamethakul and Watinee Thongchet[1]

Abstract

Stomatal conductance, phyllode water potential and total phyllode area were measured in provenance trials of *Acacia auriculiformis* in Kanchanaburi province, western Thailand. The data were collected daily and seasonally from 7-year-old trees. Provenances and trees selected for the measurement originated from three regions, i.e. Northern Territory (NT), Queensland (Qld) and Papua New Guinea (PNG). Physiological differences among the three provenances were small and not significantly significant. The Queensland provenance had the smallest tree phyllode area and the Papua New Guinea provenance the largest. Stomatal conductance and phyllode water potential were high during the wet season, and low in the dry season.

THE establishment of forest plantations in Thailand has been intensified using indigenous and exotic tree species. In any planting programs, it is necessary to select improved materials of appropriate species. *Acacia auriculiformis* was first introduced to Thailand from Australia as an ornamental tree in 1935, and has been used in reforestation since 1960 (Luangviriyasaeng et al. 1991).

The species has grown successfully in a wide range of soil and environmental conditions unsuitable for other species. This is very important since most available planting areas in Thailand are generally poor and degraded. The ability of species to avoid severe desiccation during drought periods is one of the important criteria in species selection.

In plantation forestry, it has become clear that successful introduction of an exotic species depends on species and provenance selection (Zobel and Talbert 1984). Plants from different origins often perform differently when planted together. Water relations in plants, as indicated by transpiration rate, leaf conductance or water potential, are known to differ among genotypes (Abrams 1988). Trees belonging to the same species but originating from different habitats can exhibit very different water balances (Davies et al. 1981). A study conducted by Blake and Filho (1988) revealed considerable genetic variability in water relations in *Eucalyptus* seedlings subjected to drought.

Studies of geographic variation in *A. auriculiformis* have been concentrated on early growth performances (Luangviriyasaeng et al. 1991; Awang et al. 1994; Minquan and Yutian 1994; Shukor et al. 1994). Geographic variation in morphological and anatomical characteristics of phyllodes was reported by Swatdipakdi (1992). An understanding of some physiological characteristics in relation to genetic variability would provide useful information for further improvement programs of this species. The present study reports the geographical variation studies in water relations of *A. auriculiformis* grown under dry conditions in Thailand.

Materials and Methods

The experimental site

The study was carried out on *A. auriculiformis* located at Lumpao Lumsai Research Station in Kanchanaburi Province (13°58′N, 99°18′E; 45 m altitude). The mean annual rainfall is 900–1000 mm, with a marked peak in September; the dry period occurs from mid-November to March. Mean daily temperature is 24–36°C. Soil is sandy and silty loam, pH 6–7 (Luangviriyasaeng et al. 1991).

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Provenance trials of *A. auriculiformis* were established in 1989, using a Randomised Complete Block design with six replications. The trials comprised 25 seedlots of Northern Territory, Northern Queensland and Papua New Guinea provenances. Each plot consisted of 4 × 4 trees planted at a spacing of 3 × 3 m.

Stomatal conductance

One seedlot from each provenance region of *A. auriculiformis* was randomly selected for stomatal conductance measurement. These were CSIRO seedlots 16151 (NT), 16485 (Qld) and 16107 (PNG). Four trees were selected from each provenance (each one from a different replicate plot). Five fully expanded phyllodes of each selected tree were sampled from the outermost canopy for the measurement. Stomatal conductance (g_s) was measured by using a steady-state diffusion porometer, Model AP3, Delta-T Devices, Cambridge, UK. Measurements were taken hourly (07.00–17.00) on selected sample days on different seasons: March 1996 (dry) and October 1996 (wet).

In order to determine the seasonal variation in stomatal conductance, a similar measurement was carried out monthly from January to December 1996 at 13.00–15.00. Two seedlots from each provenance region were selected, including seedlots 16151 (NT), 16156 (NT), 15697 (Qld), 16485 (Qld), 16107 (PNG) and 16108 (PNG). Soil samples for soil moisture determination were simultaneously taken at 20–30 cm depth near all selected trees. Soil moisture content was determined by the gravitational method.

Phyllode water potential

At the same time as stomatal conductance was measured, determinations of phyllode water potential were made from the same selected trees as for the stomatal conductance measurement. Phyllode water potential was measured with a pressure chamber, Model 3005, Soilmoisture Equipment Corp. Four fully developed phyllodes were detached from the top (6–8 m) and basal (2–3 m) parts of the canopies of the selected trees. Measurements of phyllode water potential were taken hourly (07.00–17.00) only in October 1996, and afternoon phyllode water potential measured at 13.00–15.00 was taken during both wet (August–October 1996) and dry (January–March 1997) seasons.

Tree phyllode area

Determinations of the tree phyllode area of the selected trees were made on both seasons: March (dry) and October (wet) 1996. Total phyllode area of individual trees was estimated by determining the leaf area on a subsample of the canopy using the 'one-third counting' technique.

Statistical analysis

The mean and standard error of the mean of each characteristic were calculated for each seedlot and each provenance. The significance of differences was analysed using the analysis of variance module in *Statistica* (V 5.0, StatSoft Inc, USA).

Results

Stomatal conductance (g_s)

Figure 1 shows the mean stomatal conductance in the three provenances of *A. auriculiformis* measured in dry (March) and wet (November) seasons. The stomatal conductance in the wet season was

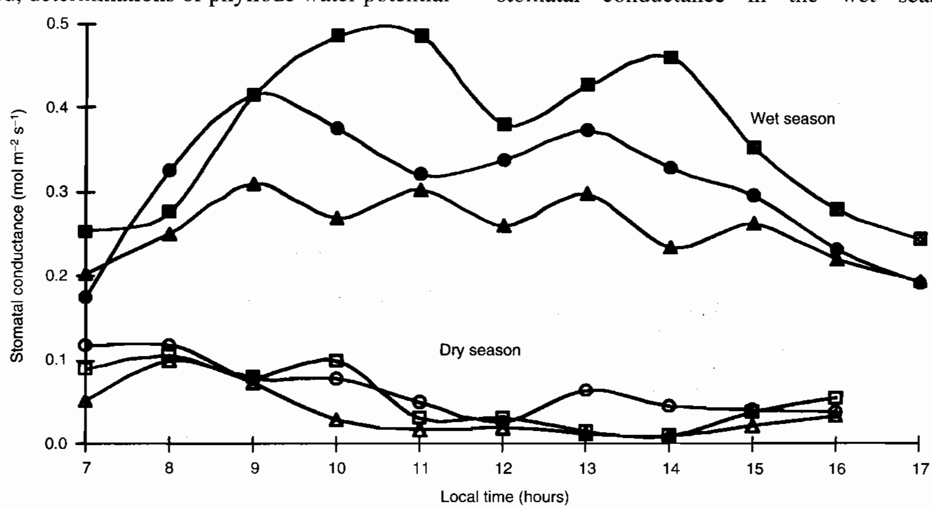

Figure 1. Diurnal changes in stomatal conductance of 7-year-old *Acacia auriculiformis* from Northern Territory (△), Queensland (□) and Papua New Guinea (○), measured in wet (closed symbols) and dry seasons (open symbols).

remarkably high compared with that in the dry season. Maximum stomatal conductance was observed at 08.00 in the dry season and 10.00 in the wet. Variations occurred throughout the day, but differences between provenances, either in dry or wet seasons, were not statistically significant. The maximum difference among provenances was observed at 10.00 and 14.00. In the wet season, Qld materials showed the highest stomatal conductance, while NT had the lowest values consistently throughout the day. In the dry season, NT still showed the lowest stomatal conductance while PNG had the highest value during most of the day. There was a limited diurnal change in stomatal conductance in the dry season, since stomata were completely closed, especially around midday (12.00–13.00).

There was a consistent clear pattern in the seasonal change of stomatal conductance in the three provenances of *A. auriculiformis*. Large differences in stomatal conductance were observed from month to month in all provenances ($p < 0.01$). The seasonal changes of stomatal conductance in relation to changes of soil moisture content are shown in Figure 2. The highest stomatal conductance occurred

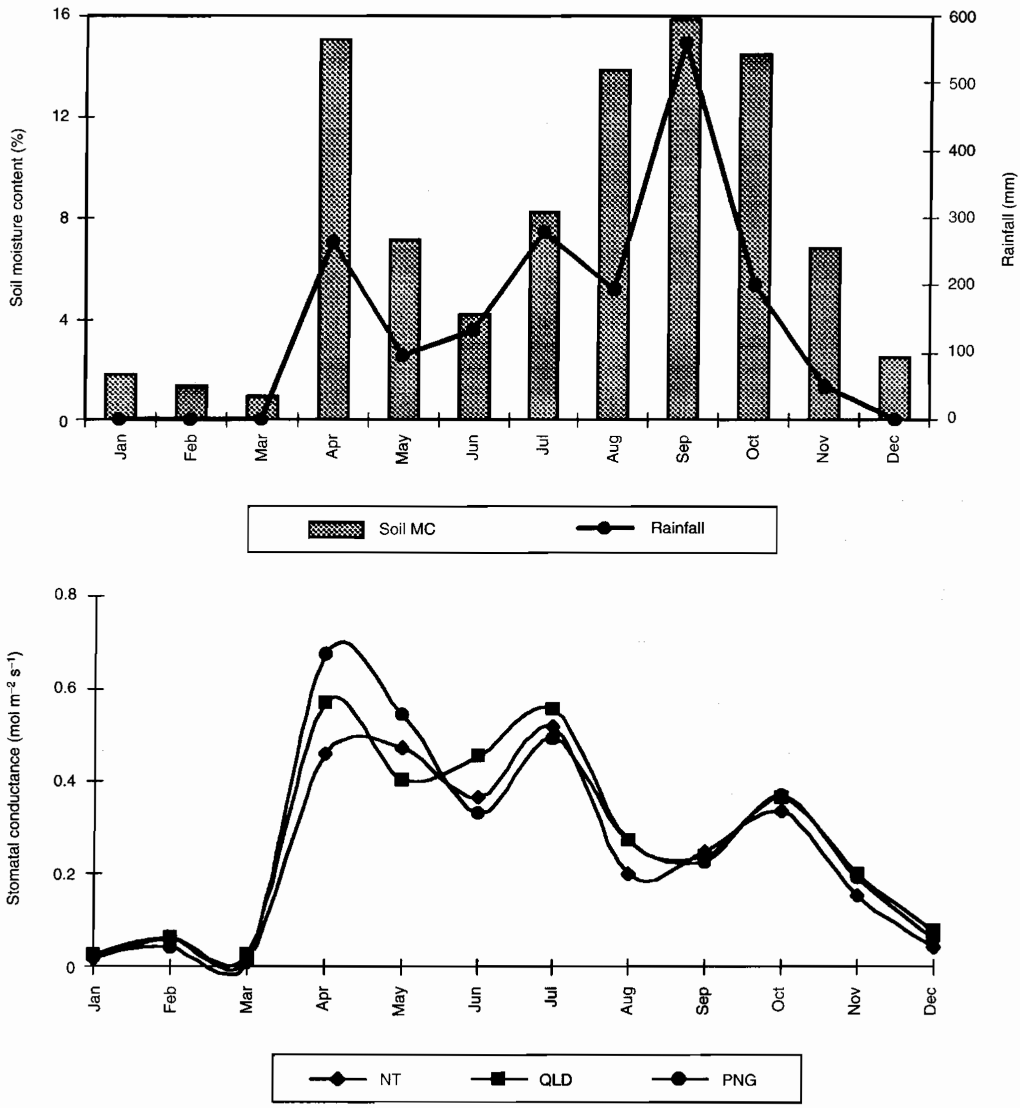

Figure 2. Monthly variation in soil moisture content, rainfall and stomatal conductance of *Acacia auriculiformis* from three provenances grown in Kanchanaburi, Thailand. Data were collected at 13.00–15.00 h.

in April when an exceptional heavy storm occurred, and the greatest difference among provenances was also observed then. Generally, the highest rainfall and soil moisture content was recorded in September, but stomatal conductance showed only moderate values during that period. Stomatal conductance seemed to respond well to the first rainfall with a sharp increase and then a decline for the rest of the regular rainy days. Stomata rarely opened during December–March. The lowest stomatal conductance occurred in March when the lowest soil moisture content was also recorded. The Qld provenance showed the highest and the NT provenance showed the lowest stomatal conductance in most of the months. However, the difference in stomatal conductance was not statistically confirmed.

Phyllode water potential

The mean phyllode water potential measured at the lower canopy levels was higher than that measured at the upper canopies for all provenances studied, and this was so at all times; however, the differences of <–0.4 MPa were not statistically significant. Phyllode water potential measured hourly during the day in October, which is the wet season, showed a clear diurnal pattern (Figure 3). The water potential was highest early in the morning, and it decreased during the day. The lowest water potential occurred during midday (12.00–13.00) when the maximum difference among provenances was observed (–0.4 MPa). However, the difference between provenances was not statistically significant over the day.

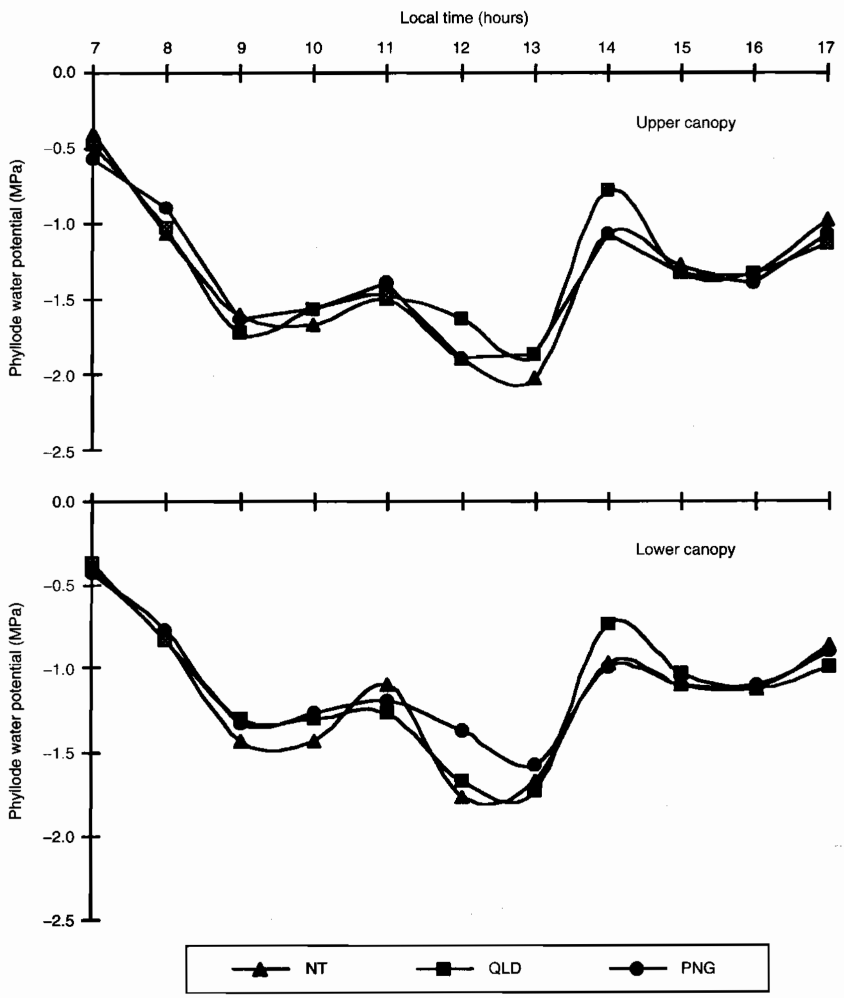

Figure 3. Diurnal phyllode water potential of *Acacia auriculiformis* from three provenances measured in October 1996 (wet season) at different canopy levels.

The afternoon phyllode water potential measured during dry (January–March) and wet (August–September) seasons were statistically different ($p < 0.01$). The results revealed remarkably low water potential during the dry season (Figure 4). The lowest water potential was found in PNG provenance measured in March (–3.95 MPa), when the lowest soil moisture content occurred, while Qld provenance showed the highest value (–3.71 MPa). However, the differences among provenances and seedlots were not statistically significant in both seasons.

Tree phyllode area

The total phyllode area of 7-year-old trees measured in the wet season were approximately 25–45% greater than the total phyllode area measured in the dry season. Large differences among provenances were found ($p < 0.01$). The PNG trees had the highest total phyllode area, while the Qld trees had the smallest area in the wet season and the NT trees were the smallest area in the dry season. The large area of phyllodes which remained on the trees would cause high water loss; however, it would also produce more photosynthate which may encourage tree growth directly.

Discussion

Species with extensive geographic ranges often exhibit genotypes that are adapted to local

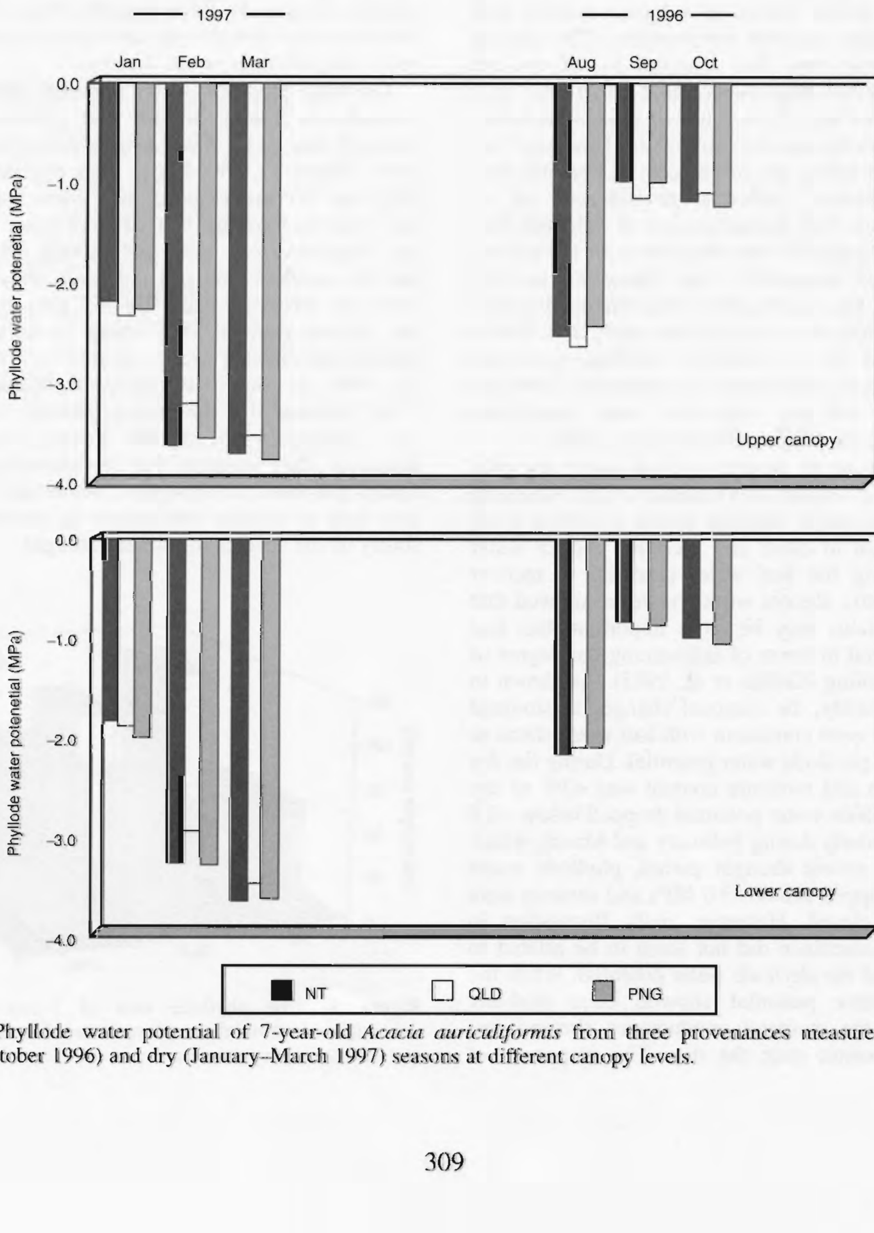

Figure 4. Phyllode water potential of 7-year-old *Acacia auriculiformis* from three provenances measured during wet (August–October 1996) and dry (January–March 1997) seasons at different canopy levels.

environmental conditions (Berry and Bjorkman 1980), and perform differently when planted together in a new environment. Environmental gradients including temperature, humidity and precipitation have been related to physiological differences among populations. *A. auriculiformis* occurs naturally from Irian Jaya (Indonesia) to Papua New Guinea and southwards to the Northern Territory and Queensland, Australia (Pinyopusarerk 1990). The environmental conditions between these natural regions differ considerably.

Our comparative study of *A. auriculiformis* water relations showed that differences among the three provenances were small. The NT provenance which originates from relatively dry conditions showed the lowest stomatal conductance, while the PNG provenance which occurs in a higher rainfall area showed higher stomatal conductance. The present result differed from that reported by Myers and Landsberg (1989) who showed that *Eucalyptus* from the dry habitat had a much higher transpiration rate than that from the moist environment. However Cole et al. (1994) found no differences in stomatal conductance between different provenances of *A. auriculiformis*. The diurnal course of stomatal conductance measured in the wet season in the present study showed remarkably high values for the Qld provenance. The magnitude of stomatal conductance of *A. auriculiformis* in the present study was double that reported for *A. mangium* seedlings measured under laboratory conditions (Atipanumpai 1989), but comparable with the values for young *Eucalyptus* stands in southern India (Roberts et al. 1992).

The response of stomata to leaf water potential has long been recognised (Raschke 1975). When the leaf water potential declines below a critical level, stomata begin to close and therefore reduce water loss, allowing the leaf water potential to recover (Ludlow 1980). Recent works however showed that soil water status may be more important than leaf water potential in terms of influencing the degree of stomatal opening (Gollan et al. 1985). As shown in the present study, the seasonal changes in stomatal conductance were consistent with soil water status as well as with phyllode water potential. During the dry season when soil moisture content was <3% of dry weight, phyllode water potential dropped below −2.0 MPa. Particularly during February and March, which is the most severe drought period, phyllode water potential dropped below −3.0 MPa and stomata were completely closed. However, daily fluctuation in stomatal conductance did not seem to be related to the change of the phyllode water potential. While the phyllode water potential showed clear mid-day depression, the stomatal conductance showed just slight fluctuation over the day. The responses of stomatal conductance to phyllode water potential of *A. auriculiformis* in the present study were not clear enough to suggest that water potential limited stomatal conductance. Whitehead (1980) noted that daily fluctuations in water potential are ecologically not severe enough to reduce leaf conductance unless a critical limit of water potential is reached.

The phyllode water potential found in the present study was much lower than those reported for temperate conifers, but was comparable with tropical species of *Eucalyptus* (Roberts et al. 1992) and *Casuarina* (Chumriang 1997). Atipanumpai (1989) pointed that when *A. mangium* showed signs of wilting, the phyllode water potential ranged from −2.3 to −2.9 MPa, which was similar to that of *A. auriculiformis* at the beginning of both the dry and the wet seasons (Figure 4). This suggests that *A. auriculiformis* is more drought tolerant than *A. mangium*, and better adapted to grow on dry sites.

The high phyllode water potential and stomatal conductance found in the Qld provenance was probably due to the small total phyllode area of the trees (Figure 5). The larger total phyllode area of PNG and NT provenances may cause higher water loss from the trees and caused more water stressed. It was surprisingly to note that though the Qld trees had the smallest total phyllode area, they still grew fastest in this trial, while the NT provenance show the poorest growth. Differences in height growth among provenances were reported by Puangchit et al. (1996). In contrast to our result, Blake and Filho (1988) showed that the most productive provenance of a *Eucalyptus* sp. had the lowest stomatal conductance. This suggests that the physiological processes involved are complex. Water-use efficiency may help to explain differences in growth and the ability of the species to tolerate drought.

Figure 5. Tree phyllode area of 7-year-old *Acacia auriculiformis* from three provenances determined at the end of wet and dry seasons.

Conclusions

A small provenance variation of stomatal conductance and phyllode water potential was found in *A. auriculiformis*, but it was statistically insignificant. Each provenance performed differently when measured both in the wet (growing) and dry periods.

Trees from Papua New Guinea and Queensland have the largest and smallest crown diameter, respectively. The PNG trees with largest crown diameter had the largest total phyllode area. Trees from the same provenance had different phyllode areas when measured in different seasons. Although not statistically significant, the following variations in stomatal conductance were noted: the Qld provenance was highest in the wet season; the NT provenance was low in both wet and dry seasons; and PNG provenances were highest in the dry season. Phyllode water potential of the Qld provenance was highest in the dry season; low phyllode water potential was observed in trees originating from NT and PNG provenances.

Despite the present study not confirming the genetic variation in water relations of *A. auriculiformis*, they do suggest the importance of selecting best adapted provenances for successful plantations.

Acknowledgment

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References

Abrams, M. 1988. Genetic variation in leaf morphology and plant and tissue water relations during drought in *Cercis canadensis* L. Forest Science, 34, 200–207.

Atipanumpai, L. 1989. *Acacia mangium*: Studies on the genetic variation in ecological and physiological characteristics of a fast-growing plantation tree species. Acta Forestalia Fennica, 206, 92.

Awang K., Shukor, N.A.A., Adjers, G., Bhumibhamon, S., Pan, F.J. and Venkateswarlu, P. 1994. Performance of *Acacia auriculiformis* provenances at 18 months on four sites. In: Awang, K. and Venkateswarly, P. ed., Compendium of Research on *Acacia auriculiformis* Carried Out under the MPTS Research Network in Asia, F/FRED Bangkok, Thailand.

Berry, J.A. and Bjorkman, O. 1980. Photosynthetic response and adaptation to temperature in higher plants. Annual Review of Plant Physiology, 31, 491–543.

Blake, T.J. and Filho, W. 1988. Drought tolerance, growth partitioning and vigour in eucalypt seedlings and rooted cuttings. Tree Physiology, 4, 325–335.

Chumriang, P. 1997. Variation in some physiological characteristics of *Casuarina equisetifolia* from different provenances. MS Seminar Paper, Department of Silviculture, Kasetsart University.

Cole, S.P., Woo, K.C., Eamus, D., Harwood, C.E. and Haines, M.W. 1994. Field measurements of net photosynthesis and related parameters in four provenances of *Acacia auriculiformis*. Australian Journal of Botany, 42, 457–470.

Davies, W.J., Wilson, J.A., Sharp, R.E. and Osonubi, O. 1981. Control of stomatal behaviour in water-stressed plants. In: Jarvis, P.G. and Mansfield, T.A., ed., Stomatal Physiology. Cambridge University Press, Cambridge, 163–185.

Gollan, T., Turner, N.C. and Schulze, E.D. 1985. The responses of stomata and leaf gas exchange to vapor pressure deficits and soil water content. III. In the sclerophyllous woody species *Nerium oleander*. Oecologia, 65, 356–362.

Luangviriyasaeng, V., Pinyopusarerk, K. and Williams, E.R. 1991. Results at 12 months of *Acacia auriculiformis* trials in Thailand. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35, 77–81.

Ludlow, M.M. 1980. Adaptive significance of stomatal responses to water stress. In: Turner, N.C. and Kramer, P.J., ed., Adaptation of Plants to Water and High Temperature Stress. John Wiley & Sons, New York, 155–172.

Minquan, Y. and Yutian, Z. 1994. Growth and survival at 18 months of an *Acacia auriculiformis* trial in Southern China. In: Awang, K. and Venkateswarly, P., ed., Compendium of Research on *Acacia auriculiformis* Carried Out under the MPTS Research Network in Asia, F/FRED Bangkok, Thailand.

Myers, B.J. and Landsberg, J.J. 1989. Water stress and seedling growth of two eucalypt species from contrasting habitats. Tree Physiology, 5, 207–218.

Pinyopusarerk, K. 1990. *Acacia auriculiformis*: An Annotated Bibliography. Winrock International Institute of Agricultural Development – ACIAR, 154 p.

Puangchit, L., Woo, K.C. and Montagu, K. 1996. Physiology of *Acacia auriculiformis*: Implications for genetic improvement. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI-IUFRO Conference, Caloundra, Queensland, Australia, 27 October–1 November, Queensland Forestry Research Institute, 384–385.

Raschke, K. 1975. Stomatal action. Annual Review of Plant Physiology, 35, 15–44.

Roberts, J.M., Rosier, P.T.W. and Murthy, K.V.S. 1992. Physiological studies in young *Eucalyptus* stands in southern India and their use in estimating forest transpiration. In: Calder, I.R., Hall, R.L. and Adlard, P.G. ed., Growth and Water Use of Forest Plantations. John Wiley & Sons, Chichester, 226–243.

Shukor, N.A.A., Awang, K., Venkateswarlu, P. and Senin, A.L. 1994. Three years performance of *Acacia auriculiformis* provenances at Serdang, Malaysia. In: Awang, K. and Venkateswarly, P., ed., Compendium of Research on *Acacia auriculiformis* Carried Out under the MPTS Research Network in Asia, F/FRED Bangkok, Thailand.

Swatdipakdi, R. 1992. Provenance variation in growth performances and some phyllode characteristics of *Acacia auriculiformis* A. Cunn. ex Benth. at Lad Krating Plantation, Chachoengsao. MS thesis, Kasetsart University, Bangkok, 108 p.

Whitehead, D. 1980. Assessment of water status in trees from measurements of stomatal conductance and water potential. New Zealand Journal of Forest Science, 10, 159–165.

Zobel, B.J. and Talbert, J.T. 1984. Applied Forest Tree Improvement. John Wiley & Sons, New York, 505 p.

Assimilation and Resource Allocation for Growth in *Acacia auriculiformis*

K.D. Montagu[1] and K.C. Woo[1]

Abstract

This study examines the physiological factors associated with the growth variation in eighteen seedlots of *Acacia auriculiformis*. 'Maximum net assimilation rate' (A_{max}) was determined 13 weeks after germination. Seedlings were then harvested and tree height, phyllode area and dry-weight of phyllodes, stems and roots were determined. In the fastest growing seedlot, height, phyllode area and total biomass were 78–137% greater than those in the slowest growing seedlot. A_{max} was 22.9–28.2 µmol m^{-2} s^{-1}, but this variation could not in itself account for the observed differences in growth between seedlots. Instead total phyllode area was found to account for more than 75% of the variation in total biomass. Changes in biomass partitioning within the plants could not account for differences in total phyllode area. Instead fast-growing seedlings were found to produce lower-cost phyllodes, i.e. phyllodes with a high 'specific leaf area' (SLA). As a result these plants were able to produce more foliage for a given amount of biomass. A high SLA was also associated with increased assimilation efficiency when expressed on a chlorophyll or dry-weight basis. As SLA can easily be measured, we propose that it be used as a selection parameter in *A. auriculiformis* breeding programs.

CONSIDERABLE variation in the growth of *Acacia auriculiformis* Cunn. ex Benth, both between and within the main provenances of Queensland (Qld), Northern Territory (NT), and Papua New Guinea (PNG), has been reported in a number of field trials (e.g. Awang et al. 1994). In such trials the tree height and dbh (diameter at breast height) of fastest growing provenances can be 25–40% greater than the slowest growing provenances. In the initial phase of domestication such variations in growth can be exploited to achieve a rapid improvement in tree performance. However, further advances in tree performance may require an understanding of the underlying physiological factors which permit rapid tree growth.

The importance of net assimilation rate and canopy characteristics for tree growth has been emphasised in a number of studies (Kramer and Kozlowski 1979; Fownes and Harrington 1990). Studies on acacia species indicate canopy size to be more important than maximum assimilation rate A_{max} (Atipanumpai 1989; Cole et al. 1994). For field-grown *A. auriculiformis* A_{max} was 21.4–26.2 µmol m^{-2} s^{-1}; however, these variations did not account for the variation in tree size (Cole et al. 1994). Similarly in a study on *A. mangium* seedlings, variations in A_{max} (5.9–7.7 µmol m^{-2} s^{-1}) were unrelated to seedling growth (Atipanumpai 1989). Instead, in both studies canopy size was suggested to be the most important parameter in achieving rapid tree growth. Increased canopy size can be achieved in a variety of ways including:

- increased partitioning of the plants biomass to foliage;
- retention of foliage for longer; and
- production of foliage using fewer resources (Poorter 1989).

The objectives of this study were to determine the major physiological parameters contributing to variations in growth of 18 seedlots of *A. auriculiformis* and assess their usefulness as selection parameters for growth. For this purpose, we examined A_{max} and canopy and foliage characteristics of the plants in addition to apportioning biomass between the phyllodes, stem and roots.

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Methods and Materials

We studied 18 seedlots of *A. auriculiformis*, 17 from the Australian Tree Seed Centre plus a local collection from Flora River, NT (131°35′S, 14°45′E). These represented six seedlots from the three main provenances of Qld and NT (Australia), and PNG. Details of seedlots used are provided in Table 1.

Table 1. Growth parameters and maximum net assimilation rate (A_{max}) of 13-week-old seedlings of *Acacia auriculiformis* from the provenances of Queensland (Qld), Northern Territory (NT), and Papua New Guinea (PNG). (Values are the means ± standard errors. Provenance means are shown in italics.)

CSIRO seedlot #	Height (cm)	Total biomass (g)	Phyllode area (cm^2)	A_{max} (μmol m^{-2} s^{-1})
Qld	*66.9 ± 2.7*	*28.4 ± 1.1*	*1675 ± 77*	*26.8 ± 0.7*
15483	54.0 ± 5.9	30.3 ± 3.1	2126 ± 232	27.8 ± 1.3
15985	84.6 ± 6.0	31.6 ± 1.8	1627 ± 137	27.3 ± 1.4
16142	59.3 ± 3.0	28.9 ± 2.6	1776 ± 135	27.1 ± 2.3
16145	72.7 ± 3.1	27.6 ± 2.5	1502 ± 177	27.5 ± 1.2
16484	64.3 ± 5.2	28.3 ± 1.9	1695 ± 101	22.9 ± 0.6
16485	66.9 ± 5.1	23.8 ± 3.6	1324 ± 123	28.2 ± 1.7
PNG	*71.7 ± 2.0*	*34.3 ± 1.2*	*2158 ± 81*	*26.0 ± 0.7*
16106	69.4 ± 5.7	34.5 ± 2.0	2171 ± 41	26.9 ± 0.3
16107	71.2 ± 3.2	38.2 ± 2.9	2204 ± 146	23.5 ± 2.4
16114	75.0 ± 6.4	35.4 ± 2.5	2448 ± 233	24.6 ± 1.4
16355	74.0 ± 2.7	34.7 ± 2.2	2111 ± 80	28.0 ± 1.8
16684	65.2 ± 7.0	27.5 ± 3.1	1903 ± 315	27.3 ± 1.2
19261	75.8 ± 4.7	35.6 ± 4.0	2111 ± 208	26.0 ± 2.4
NT	*58.3 ± 2.8*	*26.4 ± 1.4*	*1616 ± 97*	*24.6 ± 0.9*
1995*	56.9 ± 6.2	18.7 ± 3.4	1035 ± 88	26.7 ± 1.4
16147	47.6 ± 8.9	22.6 ± 5.6	1609 ± 377	23.4 ± 2.4
19149	67.0 ± 5.2	25.7 ± 2.7	1625 ± 74	27.0 ± 1.7
16152	53.1 ± 2.4	32.6 ± 1.3	2210 ± 150	24.3 ± 2.7
16154	52.5 ± 2.3	29.2 ± 1.5	1611 ± 101	22.3 ± 2.7
16155	73.0 ± 7.3	29.7 ± 1.6	1605 ± 132	23.7 ± 1.9
Lot $LSD_{0.05}$	11.6	5.1	331	5.0

* Local collection from Flora River, NT.

Seeds were pre-treated with boiling water and three seeds per pot sown into PVC pots (9 cm diameter × 100 cm height) containing 8.7 kg of potting mix (peat:sand:soil = 1:2:3) with 6 g of osmocote per kg). The experiment was designed as a randomised complete block with four blocks. After three weeks seedlings were thinned to one per pot and grown for three months in shadehouses (25% shade). Plants were watered daily for the first nine weeks, and twice daily thereafter.

Twelve weeks after germination, A_{max} rates were determined on two (the most recently expanded) phyllodes per plant using a *LI-COR LI-6200* portable gas exchange system (Licor Inc., USA). On the same phyllodes, chlorophyll content was determined non-destructively using a Minolta Corp. *SPAD-501*. One week later, seedling height was measured and plants were subsequently harvested. Total phyllode area was determined using a leaf area meter (Delta-T Devices Ltd, UK) and the dry-weight of phyllode, stems and roots was determined. The specific leaf area (SLA, cm^2 g^{-1}) of each plant was calculated by dividing the total phyllode area by the phyllode dry-weight. Data were analysed, with seedlots nested in provenances, using the analysis of variance module in *Statistica* (V 5.0, StatSoft, Inc., USA).

Results and Discussion

Seedling height was greatest in those seedlings from the PNG provenance, and least in seedlings from the NT provenance (Table 1). Similarly PNG seedlings also had the greatest phyllode area and total biomass. Differences between provenances were greater for phyllode area and total biomass than for height (Table 1). Significant variation between the six seedlots within each provenance was also observed (Table 1), a result in agreement with field trials reports (Awang et al. 1994). Below we examine the role of A_{max} and foliage characteristics in determining growth, as indicated by total biomass production, in *A. auriculiformis* seedlings.

Maximum assimilation rates were 22.9–28.2 μmol m^{-2} s^{-1} in *A. auriculiformis* seedlings (Table 1). These A_{max} rates, which are also observed in field-grown *A. auriculiformis*, are higher than rates of many other fast-growing tree species (Eamus and Cole 1997; Montagu and Woo unpublished data). In some tree species high A_{max} rates have been correlated with fast growth (Ceulemans and Impens 1983). However, in this study the variation in seedlings A_{max} did not account for variations in total biomass production under well-watered conditions, a result which is consistent with other studies on acacia (Atipanumpai 1989; Cole et al. 1994). Since A_{max} and biomass production are poorly related, we explored physiological factors which might be responsible for the growth differences observed between fast- and slow-growing seedlings.

Increases in plant phyllode area were found to account for more than 75% of the variation in seedling total biomass (Figure 1). This suggests that the amount of photosynthetic tissue was important in determining total biomass production. In seedlings the rapid development of phyllode area may occur either through greater partitioning of resources to leaf growth, or by the ability to produce leaves at a lower cost (Poorter 1989). Approximately 50% of the total biomass was allocated to phyllode production in *A. auriculiformis* seedlings (Table 2). The resource allocation to phyllodes, stems and roots within the plant was similar in all three provenances. These data suggest that the rapid development of phyllode area observed in the PNG provenance could not be attributed to differences in resource allocation. On the contrary, total phyllode area of *A. auriculiformis* seedlings was strongly correlated with SLA (Figure 2). It would appear that the rapid development of phyllode area in *A. auriculiformis* seedlings was achieved by producing phyllodes at a lower cost. Thus for a given allocation of biomass, the PNG seedlings were able to produce a larger phyllode area, compared with NT and Qld seedlings. Consequently, SLA would appear to be an important factor determining growth in *A. auriculiformis* seedlings. SLA has also been shown to be positively related to biomass production in *Eucalyptus globulus* (Pereria 1995).

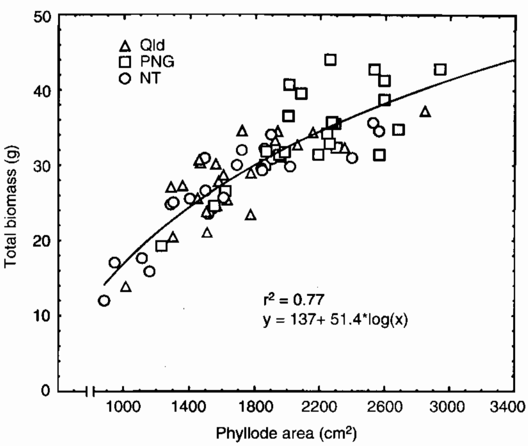

Figure 1. Relationship between phyllode area and total plant biomass (phyllodes, stems and roots) of *A. auriculiformis* seedlings. Six seedlots from each of the provenances of Queensland (Qld), Northern Territory (NT), and Papua New Guinea (PNG) were grown for 13 weeks under well-watered conditions.

Table 2. Biomass distribution in *A. auriculiformis* from Queensland (Qld), Northern Territory (NT), and Papua New Guinea (PNG) provenances. (Values are the means of six seedlots per provenance ± standard errors.)

Provenance	Biomass distribution		
	% phyllode	% stem	% roots
Qld	49.1 ± 0.7	26.4 ± 0.8	24.6 ± 0.5
PNG	47.9 ± 0.6	26.9 ± 0.6	25.2 ± 0.8
NT	51.5 ± 0.7	23.8 ± 0.7	24.7 ± 0.6
$LSD_{0.05}$	1.9	1.8	1.9

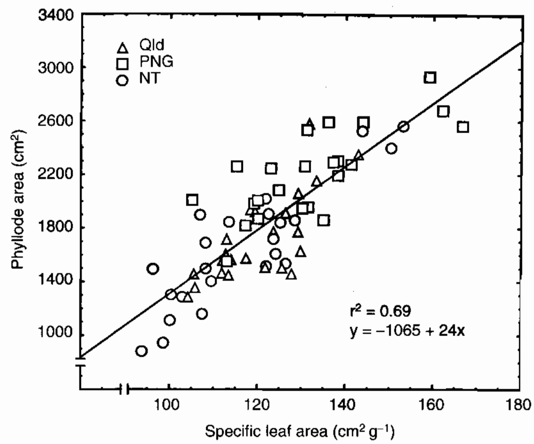

Figure 2. Relationship between specific leaf area and phyllode area of *A. auriculiformis* seedlings.

These studies highlight the importance of phyllode area in plant growth, but ultimately plant growth depends on photosynthesis. Measurements of photosynthesis are often expressed on a unit leaf area basis, as in this study. However, the amount of resources per unit phyllode area is not constant; fewer resources are present in phyllodes with greater SLA. Thus when assimilation is expressed on the basis of resource use, faster growing plants are observed to be more efficient at utilising the resources available in the phyllodes (Table 3). Consequently, it is important to relate assimilation measurements to the resources required to obtain those rates.

Table 3. Phyllode assimilation in *A. auriculiformis* from Queensland (Qld), Northern Territory (NT), and Papua New Guinea (PNG) provenances. (Values are the means of six seedlots per provenance ± standard error.)

Provenance	Assimilation		
	per unit leaf area (μmol m^{-2} s^{-1})	per unit chlorophyll (μmol m^{-2} s^{-1})	per unit dry-weight (nmol g^{-1} s^{-1})
Qld	26.8 ± 0.7	41.9 ± 1.4	329 ± 11
PNG	26.0 ± 0.7	43.5 ± 1.3	347 ± 13
NT	24.6 ± 0.9	36.7 ± 1.5	297 ± 11
$LSD_{0.05}$	2.0	3.6	27

Conclusion

SLA is an important parameter for the determination of growth of *A. auriculiformis* seedlings. A high SLA value was associated with a large total phyllode area, due to the lower cost of producing individual phyllodes. Also the phyllodes with high SLA values had higher A_{max} rates, when expressed on a chlorophyll or dry-weight basis indicating an increase in resource use efficiency, rather than on a leaf-area basis. Given the ease of measurement of SLA, we propose that it should be used as a selection parameter in *A. auriculiformis*, and perhaps other, acacia breeding programs.

Acknowledgments

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References

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

Awang, K., Venkateswarlu, P., Nor Aini, A.S., Adjers, G., Bhumibhamon, S., Kietvuttinon, B., Fuh-Juinn Pann, Pitpreecha, K. and Simsiri, A. 1994. Three year performance of international provenance trials of *Acacia auriculiformis*. Forest Ecology and Management, 70, 147–158.

Ceulemans, R. and Impens, I. 1983. Net CO_2 exchange rate and shoot growth of young *Populus* clones. Journal of Experimental Botany, 34, 866–870.

Cole, S.P., Woo, K.C., Eamus, D., Harwood, C.E. and Haines, M.W. 1994. Field measurements of net photosynthesis and related parameters in four provenances of *Acacia auriculiformis*. Australian Journal of Botany, 42, 457–470.

Eamus, D. and Cole, S. 1997. Diurnal and seasonal comparisons of assimilation, phyllode conductance and water potential of three *Acacia* and one *Eucalyptus* species in the wet-dry tropics of Australia. Australian Journal of Botany, 45, 275–290.

Fownes, J.H. and Harrington, R.A. 1990. Modelling growth and optimal rotation of tropical multipurpose trees using unit leaf rate and leaf area index. Journal of Applied Ecology, 27, 886–896.

Kramer, P.J. and Kozlowski, T.T. 1979. Physiology of Woody Plants. Academic Press, Orlando, Fl.

Pereria, J.S. 1995. Gas exchange and growth. In: Schulze, E.D. and Caldwell, M.M., ed., Ecophysiology of Photosynthesis. Springer-Verlag, Berlin, 146–181.

Poorter, H. 1989. Interspecific variation in relative growth rate: on ecological causes and physiological consequences. In: Lambers, H., Cambridge, M.L., Konings, H., Pons, T.L., ed., Causes and Consequences of Variations in Growth Rate and Productivity of Higher Plants. SPB Academic Publishers, 45–68.

The Growth of *Acacia auriculiformis* Provenances and Seed Orchard Progeny in Vietnam and Australia

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Abstract

The growth of *Acacia auriculiformis* provenances (first generation) and seed orchards (second generation) progeny was examined in trials in Vietnam and Australia. After three years, tree growth was 30–50% greater in the southern Vietnam site (Song May), compared with sites in central (Dong Ha) and northern Vietnam (Ba Vi). The South Coen provenance was the best seedlot; tree growth was 10% and 21% faster than progeny from the Melville Island (Australia) and Dong Nai (Vietnam) seed orchards, respectively. In Katherine, Australia tree height was 5.6 ± 0.3 and 5.4 ± 0.3 m for progeny from the Melville Island and Sakaerat (Thailand) seed orchards, respectively, after three years. Trials at Darwin, Australia, compared the growth of first and second generation open-pollinated Sakaerat seed orchard progeny from three Queensland provenances. The second generation progeny showed a 13–21% increase in growth compared with that of the first generation. The relative importance of tree selection compared with out-crossing vigour could not be determined in this trial. Current plantings of controlled intra- and inter-provenance crosses will address these questions and assist in the design of subsequent *A. auriculiformis* seed orchards.

ONE of many acacias introduced into southern Vietnam in the 1960s was *Acacia auriculiformis* Cunn. ex Benth. (Nghia and Kha (these Proceedings)). It proved adaptable and fast growing, resulting in its use as a reforestation species throughout the country. By 1992 it accounted for 4.5% (43 000 ha) of Vietnam's plantations (Science and Technology Department, Ministry of Forestry 1994). These plantings utilised seed from local seed stands which originated from the initial introduction.

The unknown genetic origin of the *A. auriculiformis* introduced to Vietnam prompted a systematic introduction of additional genotypes of *A. auriculiformis* and other acacia species during the 1980s as summarised by Nghia and Kha (these Proceedings). Following the planting of these trials a more extensive collection of *A. auriculiformis* seed was undertaken in 1987 by the Australian Tree Seed Centre (ATSC) of the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Multilocational international provenance trials were established in several Southeast Asian countries in 1989 with funding from the Forestry/Fuelwood Research and Development (F/FRED) Project and the Australian Centre for International Agricultural Research (ACIAR). However, Vietnam did not participate in these trials; consequently, significantly better provenances of *A. auriculiformis* may not yet be introduced into Vietnam.

Some earlier provenance/progeny trials of *A. auriculiformis* have been converted into seedling seed orchards in a number of countries including Thailand (Luangviriyasaeng et al. 1995) and Australia (Harwood et al. 1991). These seed orchards contain a range of provenances from the three main regions of provenances of Queensland (Qld) and Northern Territory (NT) in northern Australia, and Papua New Guinea (PNG). Depending on the composition of these seed orchards, a range of intra- and inter-provenance crosses may occur. However, nothing is known about the genetic gains that may result from these crosses. The second generation progeny from these seed orchards will give some indication of possible genetic gains from out-crossing within the species.

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This paper reports results from trials in Vietnam and Australia. In Vietnam the growth of *A. auriculiformis* local provenance and seed orchard progeny was compared. Trials in Australia examined in more detail the growth of seed orchard progeny and attempts to quantify the genetic gain in growth between first and second generation progeny

Materials and Methods

Vietnam

Sixteen seedlots of *A. auriculiformis* were grown in three sites in Vietnam at Song May (southern Vietnam: 10°57′N, 106°49′E), Dong Ha (central Vietnam: 17°10′N, 107°22′E) and Ba Vi (northern Vietnam: 21°06′N, 105°26′E). Details of *A. auriculiformis* provenances are provided in Table 1, and climatic details are summarised in Table 2. In addition to the 14 natural provenances, seedlots from a seedling seed orchard on Melville Island, Australia (Harwood et al. 1991) and a local seed orchard at Dong Nai (southern Vietnam) were included.

The three trials, planted in July–November 1994, consisted of 12–25 tree-plots arranged in a randomised complete block design with four blocks. Tree height and diameter at breast height (dbh) were measured in July 1997, approximately three years after planting. Foliage samples were taken from Ba Vi in August 1997, dried, ground and digested before the concentration of P, K, Ca, Mg, Mn, Fe, Zn, and Cu was determined by ICP emission spectroscopy. Tree growth data were analysed using *Datachain* and *Genstat*.

Table 2. Summary of climate and tree growth of 3-year-old *Acacia auriculiformis* in southern (Song May), central (Dong Ha) and northern (Ba Vi) Vietnam.

Site	Rainfall (mm)	Temperature (°C)		Height (m)	DBH (cm)
		Average minimum	Average maximum		
Song May	1642	23.2	32.4	7.4 ± 0.2	7.0 ± 0.2
Dong Ha	2376	22.0	29.1	4.9 ± 0.1	5.7 ± 0.2
Ba Vi	2189	20.3	26.9	5.6 ± 0.1	6.0 ± 0.1

Australia

In Australia two trials were planted to examine the performance of seed orchard progeny. In Katherine (Northern Territory, Australia; 14°30′S, 132°20′E), bulked seed from an open-pollinated seedling seed orchard at Sakaerat, Thailand (Luangviriyasaeng et al. 1995 — CSIRO seedlot 18719), Melville Island, Australia (Harwood et al 1991 — CSIRO seedlot 18856), and a local provenance from Boggy Creek, Queensland (CSIRO seedlot 17966) were planted in December 1994. The trial consisted of 15–33 tree plots arranged in three blocks in a split plot, completely randomised block design. The main plots were tree spacings of 3 × 3 m, 4 × 4 m and 4 × 5 m and subplots of seedlots were randomised within the main plots. The Katherine region has an annual rainfall of 972 mm and an extended dry season in which there are seven consecutive months with less than 40 mm of rainfall. Mean annual minimum and maximum temperatures are 20.3 and 34.2°C,

Table 1. Details of *Acacia auriculiformis* seedlots used in the Vietnam trials.

Local provenance	Seedlot	Region	Latitude (S)	Longitude (E)	# parents
South Coen	15697	Qld	14°07′	143°16′	9
Morehead River	18564	Qld	15°02′	143°40′	20
Lower Pasco River	18359	Qld	12°34′	143°10′	15
Oliver Creek	17961	Qld	12°15′	142°52′	9
Wenlock River	18247	Qld	13°05′	142°51′	30
Halroyed River	16644	Qld	14°16′	143°07′	10
Boggy Creek	17966	Qld	15°52′	144°53′	10
Rifle Creek	15688	Qld	16°40′	145°20′	7
Wondo Village	18018	PNG	8°54′	141°16′	120
Morehead	18090	PNG	8°43′	141°36′	10
Bensbach River	16684	PNG	8°55′	141°15′	15
Manton River	16148	NT	12°50′	131°07′	10
Goomadeer River	16154	NT	12°08′	133°41′	9
Mary River	16151	NT	13°36′	132°08′	8
Melville Island SO[1]	18601	na[2]	na	na	11
Dong Nai SO[1]	local	na	na	na	unknown

[1]SO = Seed Orchard
[2]na = not applicable

respectively. During the dry season trees were irrigated with overhead sprinklers. Tree height, dbh, dgl (diameter at ground level) and overall tree form was assessed when trees were 3 years old. Tree form was assessed using a 6-point scoring system (6 = excellent for site; 1 = poor for site) (Cotterill and Dean 1990). Data were analysed using the analysis of variance module in *Statistica* (V 5.0, StatSoft Inc., USA).

In Darwin (NT, Australia; 12°34′S, 131°08′E) first and second generation seedlots from the same three Qld provenances were planted in December 1995. These were bulked first generation seedlots from Wenlock River (CSIRO 16145), Coen River (CSIRO 16141), and Kings Plain (CSIRO 19253); and second generation seedlots from Sakaerat seed orchard (Luangviriyasaeng et al. 1995) from selected mother trees from Wenlock River (CSIRO 16145/1479), Coen River (CSIRO 16141/1479), and Kings Plain (CSIRO 16485/13299). Three tree plots were arranged in a randomised complete block design with six blocks. The Darwin region has an annual rainfall of 1659 mm and a dry season in which there are 5 consecutive months with less than 40 mm of rainfall. Mean annual minimum and maximum temperatures are 23.3 and 31.9°C, respectively. Tree height, dbh, dgl and tree form were assessed 12 months after planting. Data were analysed using the analysis of variance module in *Statistica*.

Results and Discussion

A. auriculiformis tree height was 30–50% greater in the southern Vietnam site of Song May, compared with the central or northern sites of Dong Ha and Ba Vi (Table 2). Higher rates of acacia growth in southern Vietnam have previously been reported (Nghia and Kha 1993). The increased growth would appear to be related to higher average temperatures, although nutrient deficiencies may have limited growth at Ba Vi as discussed below. At Song May both minimum and maximum temperatures were 1–5°C warmer than the other sites, whereas rainfall for all three sites exceeded 1600 mm per year (Table 2). Such information can be used for refining climate requirements for *A. auriculiformis* (Nghia 1995a) and thus assist in the process of site selection for further plantings of this species.

Seedlot variation was only observed at two of the sites, Song May and Dong Ha. At Ba Vi there was no seedlot variation (P = 0.40). Nutrient deficiencies may have been responsible for the lack of seedlot variation at Ba Vi. Foliar nutrient concentrations of Mg (0.08%), Ca (0.19%), and K (0.12%) were in the deficient range for *A. auriculiformis* (Boardman et al. 1997). At Song May the best performing seedlot was South Coen provenance (Table 3), a result in agreement with other studies (Nor Aini et al. 1994). In other trials the Coen River local provenance has been identified as one of the most promising provenances

Table 3. Tree growth of sixteen seedlots of 3-year-old *Acacia auriculiformis* grown in southern (Song May), central (Dong Ha) and northern (Ba Vi) Vietnam.

Seedlot	Height (m)			DBH (cm)		
	Song May	Dong Ha	Ba Vi	Song May	Dong Ha	Ba Vi
South Coen	8.3	5.2	5.4	7.8	6.3	5.9
Halroyed River	8.1	5.1	5.8	7.7	6.2	6.3
Wenlock River	8.0	4.8	5.6	7.7	5.6	6.2
Oliver Creek	8.0	5.3	5.8	7.5	6.2	6.1
Wondo Village	7.9	5.2	5.5	7.5	6.1	6.1
Lower Pasco River	7.8	5.5	5.7	7.1	6.5	6.1
Morehead	7.8	5.0	5.8	8.0	5.7	6.5
Goomadeer River	7.8	5.0	5.3	7.5	5.5	5.5
Melville Island SO	7.7	5.1	5.4	7.4	6.3	5.9
Morehead River	7.4	5.0	5.7	6.8	5.9	6.2
Mary River	7.2	4.5	5.4	6.5	3.9	5.8
Bensbach River	7.0	4.7	5.2	7.0	6.0	5.7
Dong Nai SO	6.8	4.9	5.0	6.0	5.1	5.1
Manton River	6.8	5.1	5.8	6.1	5.2	5.9
Boggy Creek	6.4	3.8	5.5	5.8	5.0	5.8
Rifle Creek	5.9	4.4	6.4	5.3	4.9	7.0
$LSD_{0.05}$	1.4	1.0	1.7	1.6	1.2	1.4

of *A. auriculiformis* (Nghia and Kha these Proceedings). By comparison Manton Dam (NT) performed poorly in the trials reported here, whereas in other trials in Vietnam its growth has been in the top five for this species.

Plantings of *A. auriculiformis* in Vietnam have utilised seed from local seed stands, such as from Dong Nai (Nghia 1995b). Such stands are of unknown genetic origin. Also inbreeding depression may have occurred in the population due to the small number of genotypes in the initial introduction. Consequently, substantial improvements in tree growth could be achieved by the introduction of new genotypes. This is demonstrated in the Vietnam trials. The best seedlot showed over 20% improvement in growth compared with Dong Nai seed orchard progeny (Table 3). Introduction of the new genotypes could significantly increase forest productivity in Vietnam, which currently is not very high (Nghia 1995b).

Provenance trials have been successful in identifying superior provenances. However, obtaining sufficient seed from local provenances to supply large scale plantings can be difficult, unreliable and expensive. Seed orchards have been established to overcome these difficulties. Composition of seed orchards varies considerably and testing of second generation progeny is required. In Vietnam the Melville Island seed orchard progeny were ranked 9, 5 and 13th (out of 16), at Song May, Dong Ha and Ba Vi respectively (Table 3). Averaged across the three sites this represents an 8–21% increase in tree height and dbh compared with progeny from the Dong Nai seed orchard. However, the Melville Island seed orchard progeny was consistently outgrown by the best local provenances (Table 3). The height and dbh of the South Coen seedlot was on average 11 and 9% greater, respectively, than Melville Island seed orchard progeny.

Table 4. Tree growth and form of *Acacia auriculiformis* progeny from seed orchards at Melville Island (Australia), Sakaerat (Thailand) and a Queensland local provenance. (Trees were grown at Katherine, Northern Territory, Australia and measured at 3 years old. Tree form was assessed on a scale of 1 (worst) to 6 (best).)

Seedlot	Ht (m)	DGL (cm)	DBH (cm)	Form
Boggy Creek, Qld	4.0 ± 0.4	8.9 ± 0.2	4.8 ± 0.2	3.6 ± 0.1
Sakaerat SO	5.4 ± 0.3	11.0 ± 0.6	5.8 ± 0.4	2.9 ± 0.1
Melville Is, SO	5.6 ± 0.3	11.4 ± 0.2	6.7 ± 0.7	2.6 ± 0.1
$LSD_{0.05}$	1.1	1.3	1.7	0.5

In Australia two trials further investigated the performance of seed orchard progeny. At the Katherine site the vigour of progeny from the two seed orchards was clearly superior to that of the Boggy Creek local provenance (Table 4). However, growth was considerably less compared with that in Vietnam after the same period (Tables 3 and 4). Furthermore, it should be noted that Boggy Creek performed poorly in the Vietnam trials, and therefore is not a good 'control' against which to assess the performance of second generation seed orchard progeny. The form of seed orchard progeny was poor, which contrasts with the good form of Sakaerat seed orchard progeny in Thailand.

The vigour of the progeny from the two seed orchards was similar (Table 4). However, the composition, and hence intra- and inter-provenance crosses possible, differed between the two seed orchards. The Melville Island seed orchard consists of trees from PNG origin only (Harwood et al. 1991). By contrast the Sakaerat seed orchard contains trees from the three major region provenances in addition to local Thailand selections (Luangviriyasaeng et al. 1995). The contrasting orchard compositions, and thus possible outcrosses, did not appear to affect tree vigour at the Katherine site.

In this paper, seed orchards progeny has been compared with a range of local provenances (Tables 3 and 4). In the Vietnam trials the best local provenances grew faster than either the Melville Island or Dong Nai seed orchard progeny. This would suggest that potential gains from out-crossing vigour and selection from within seed orchards are not large enough to compensate for the original inclusion of poor genotypes in the seed orchard.

In the second Australia trial reported here we measured the growth of first and second generation progeny from three superior Qld local provenances. The second generation seed orchard progeny showed a 13–21% increase in vigour compared with the first generation progeny (Table 5). These results demonstrate that vigour does increase in second generation progeny as expected. However, the moderate increase between generations serves to highlight the importance of initial genotype selection for the seed orchards. Growth differences between provenances of 25–40% are often reported in provenance trials of *A. auriculiformis* (e.g. Awang et al. 1994).

An increase in the vigour of seed orchard progeny may arise from:

- selection of plus-trees (from both initial genotype selection and within the seed orchard),
- removal of inbreeding depression, or
- hybrid vigour due to out-crossing within the seed orchard (Eldridge et al. 1994).

Table 5. Growth and form of *Acacia auriculiformis* local provenance (LP) or seed orchard (SO: Sakaerat, Thailand) progeny from three Queensland provenances. (Trees were grown in Darwin, Northern Territory, Australia and measured after 1 year. Form was assessed on a scale from 1 (worst), to 6 (best). LSDs are provided to compare differences between means of LP and SO progeny.)

Provenance	Ht (m)		DGL (cm)		DBH (cm)		Form	
	LP	SO	LP	SO	LP	SO	LP	SO
Coen River	2.28 ± 0.23	2.68 ± 0.18	4.87 ± 0.48	5.71 ± 0.43	1.85 ± 0.39	2.32 ± 0.34	3.61 ± 0.22	3.31 ± 0.24
Wenlock River	2.59 ± 0.22	2.71 ± 0.21	5.34 ± 0.30	5.90 ± 0.23	2.14 ± 0.39	2.25 ± 0.28	3.39 ± 0.23	3.56 ± 0.28
Kings Plain	2.13 ± 0.29	2.68 ± 0.30	4.26 ± 0.30	5.70 ± 0.62	1.32 ± 0.24	2.38 ± 0.60	3.34 ± 0.18	3.39 ± 0.35
Mean	2.3 ± 0.1	2.7 ± 01	4.8 ± 0.2	5.8 ± 0.3	1.8 ± 0.2	2.3 ± 0.2	3.5 ± 0.1	3.4 ± 0.2
$LSD_{0.05}$	0.3		0.4		0.3		ns	

In this trial we were unable to determine the relative importance of out-crossing compared to selection in increasing tree vigour. Current plantings of controlled intra- and inter-provenance crosses (Jiwarawat et al. 1996) by our group will provide information on the role of out-crossing in increasing *A. auriculiformis* vigour. This will assist in the design of subsequent seed orchards to maximise genetic gain. The improved seed produced will help realise the aim of increasing forest productivity in Vietnam and other countries where *A. auriculiformis* is planted.

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References

Awang, K., Venkateswarlu, P., Nor Aini, A.S., Adjers, G., Bhumibhamon, S., Kietvuttinon, B., Fuh-Juinn Pann, Pitpreecha, K. and Simsiri, A. 1994. Three-year performance of international provenance trials of *Acacia auriculiformis*. Forest Ecology and Management 70, 147–158.

Boardman, R., Lambert, M.J., Webb, M. and Cromer, R.N. 1997. Forest plantations. In: Reuter, D.J. and Robinson J.B., ed., Plant Analysis: an Interpretation Manual. CSIRO Publications, Melbourne, 2nd Ed., 507 p.

Cotterill, P.P. and Dean, C.A. 1990. Successful Tree Breeding with Index Selection. CSIRO Publications, Melbourne.

Eldridge, K., Davidson, J., Harwood, C. and van Wyk, G. 1994. *Eucalyptus* Domestication and Breeding. Clarendon Press, Oxford.

Harwood, C.E., Gororo, N., Haines, M.W. and Matheson, A.C. 1991. Seed orchards of *Acacia auriculiformis* at Melville Island, Northern Territory, Australia. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35, 87–91.

Jiwarawat, P., Luangviriyasaeng, V. and Woo, K.C. 1996. Hybrid seed of *Acacia auriculiformis*. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI-IUFRO Conference, Caloundra, Queensland, Australia, 27 October–11 November, Queensland Forestry Research Institute, Gympie, 234–237.

Luangviriyasaeng, V., Pinyopusarerk, K., Pitpreecha, K., Simsiri, A. and Kiatvuttinand, B. 1995. Early growth of *Acacia auriculiformis* progeny trial. Thai Journal of Forestry, 14, 81–93.

Nghia, N.H. 1995a. Climate requirements for some main plantation tree species in Vietnam. In: Booth, T.H., ed., Matching Trees and Sites. ACIAR Proceedings No. 63, 43–49.

Nghia, N.H. 1995b. Current methods and future needs for tree growth prediction in Vietnam. In: Booth, T.H., ed., Matching Trees and Sites. ACIAR Proceedings No. 63, 65–67.

Nghia, N.H. and Kha, L.D. 1993. Species and provenance trials of acacias. Scientific report, FSI, Hanoi, 41 p.

Nor Aini, A.S., Kamis Awang, Venkateswarlu, P. and Abd. Latib Senin 1994. Three-year performance of *Acacia auriculiformis* provenances at Serdang, Malaysia. Pertanika Journal of Agricultural Science, 17, 95–102.

Science and Technology Department, Ministry of Forestry. 1994. Planting Techniques of Some Tree Species. Agriculture Publishing House, Hanoi, Vietnam.

Morphology and Growth Performance of Natural Hybrids of *Acacia mangium* and *A. auriculiformis* in Thailand

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Abstract

This study examined the morphology and growth performance of putative natural hybrids of *Acacia auriculiformis* A. Cunn. ex Benth. and *A. mangium* Willd. growing at the ASEAN Forest Tree Seed Centre (AFTSC), and of their parental species growing at the AFTSC field station in Thailand. The hybrids, planted at three different sites, were 4.5, 6.5 and 9.5 years old. The two older groups were grown from seeds while the younger consisted of clones of selected hybrids. The morphological characteristics of the hybrids were found to be intermediate between *A. auriculiformis* and *A. mangium*. The mean phyllode length, width and length:width ratio of the hybrids were 16.0–20.4 cm, 3.5–4.1 cm and 4.7–4.8, respectively. Large variations in growth were observed between the three groups of hybrids and their parental species. The hybrids grew faster than the parental species and the hybrid clones outperformed the hybrid seedlings.

REFORESTATION programs in Thailand have used *Acacia auriculiformis* A. Cunn. ex Benth. and *A. mangium* Willd. extensively during the last two decades. The former, first introduced into Thailand from Australia as an ornamental tree in 1935 (Pinyopusarerk 1987), has been widely planted despite its poor form. *A. mangium* has better form but possesses less favourable traits such as large branches and fluted stem. It seems to grow well only in favourable sites with deep soil and good drainage and an annual rainfall greater than 1300 mm (Bhumibhamon 1992). Both species were reported to have outstanding adaptability to acid-sandy soil (Yantasath et al. 1992).

The first occurrence of a natural hybrid between *A. auriculiformis* and *A. mangium* was recorded in Sabah and later confirmed by the Queensland Herbarium in 1978 (Pinso and Nasi 1992). Natural hybrids of these two species have since been reported in both natural and plantation populations (Sim 1987; Skelton 1987). Many natural hybrids showed more rapid growth than their parents (Pinso and Nasi 1992), and their potential for plantation forestry and reforestation programs is finally being recognised. But the biological processes underpinning heterosis remained to be determined.

This study examines the morphology and growth performance of these putative natural hybrids and clones growing at the ASEAN Forest Tree Seed Centre (AFTSC) at Muak Lek, Saraburi, Thailand and of the parental species growing at a different site at the AFTSC field station.

Materials and Methods

Three plots of putative natural hybrids/clones of *A. mangium* × *A. auriculiformis* growing at AFTSC (latitude 14°38′N, longitude 101°13′E; mean annual rainfall 1227 mm) are used in this study (Kijkar 1992). They were established originally as observation plots with no experimental design. The trees in Plot A (planted 1987) and Plot B (planted 1990) are putative F_1 hybrids selected from seedlings derived from open-pollinated seeds, while those in plot C (planted 1992) are putative clones derived from selected F_1 hybrids. They were planted at 1×1 m spacing whereas the parental species were planted at 2×4 m.

Tree height and diameter at breast height (DBH) were measured in February 1997. Phyllode samples

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were collected randomly from each tree in July 1997, and their length and width and number of main veins determined. The characteristics of the flowers of these trees were also recorded. Analysis of variance and F-test were applied for plot mean data.

Results and Discussion

Morphological characteristics

The putative natural hybrids have intermediate stem and crown form between *A. auriculiformis* and *A. mangium* (Kijkar 1992). They have smaller and lighter branches than those of *A. mangium*. The bark of the mature hybrid trees is brownish-white and smoother than those of the parental species. The creamy to whitish flowers resemble those of *A. mangium* and are arranged in a straight or slightly curved rachis.

The phyllode morphology of seedlings of these hybrids is also intermediate between those of the parental species. There are three main veins on the phyllode of *A. auriculiformis* and four on *A. mangium*. In contrast, the phyllodes of their hybrids have 3 or 4 main veins (Kijkar 1992; Kha 1996). The number of the main veins on the phyllodes of mature hybrids examined in this study was also 3 or 4 (Table 1). However, most of the phyllodes of hybrid trees examined — 62, 85 and 94% from Plots A, B and C respectively — had four main veins.

Large variations in phyllode length and width were observed for all trees (Table 1). Generally, the phyllodes of *A. mangium* are large and wide, while those of *A. auriculiformis* are long and narrow. Phyllodes of hybrids tend to be wider than those of *A. auriculiformis*, but narrower than those of *A. mangium*. The length:width ratio of the phyllode of the natural hybrids was intermediate between their parental species, and has been used as an indicator of hybrid status (Gan and Sim 1992; Kijkar 1992; Kha 1996). Table 1 indicates that the values determined for mature hybrid trees in this study are also intermediate between those of the parental species growing in Thailand. Interestingly, the absolute values of phyllode length:width ratio reported for both hybrids and their parental species in Vietnam (Kha 1996) are lower than those obtained in Thailand. These differences may be due to variations in environment and tree age.

Growth performances

The growth performance of putative F_1 hybrids and clones in Thailand is summarised in Table 2. Because the parental species in Thailand are not grown under the same conditions of spacing etc., it is not possible to analyse the growth data in the present study on a statistical basis. Nonetheless, the observations presented in this study indicate that both the hybrid seedlings and clones showed higher growth rate compared with the pure species planted at the field station. On the average, the mean annual increment (MAI) values were 1.5–2.5 times those obtained for the pure species. The MAI of height and DBH of the F_1 hybrids/clones were 23–148% and 2–94% greater than those of the two parental species, respectively. The highest growth rate for height and DBH were determined in the 4.5-year-old F_1 clones (Plot C).

Natural hybrids of *A. mangium* and *A. auriculiformis* planted on a common site in Vietnam also showed superior growth rate compared to their parent species (Kha 1996). The MAI values for height and DBH of the hybrids were 21–49% and 30–66% of the parental species (Kha 1996; Table 2). These data, included in Table 2 for comparative purposes, are comparable with those reported in the present study. The MAI values determined for the 4.5-year-old clones (Plot C) in Thailand are almost identical to the highest values obtained in the Song May (Vietnam) study, even though the planting distance used in the present study is considerably less than the 3 × 3 m spacing commonly used in acacia trials. The data in Table 2 indicate that, compared with their parental species, the hybrids were superior in growth

Table 1. Phyllode length, phyllode width and phyllode length:width ratio of F_1 hybrid trees planted at AFTSC, Thailand. (Means and standard deviations are given in parenthesis; n = 20, 39 and 55 for Plots A, B and C, respectively.)

Species	Length (cm)	Width (cm)	Length:width ratio	Main veins
Thailand				
F_1 hybrids (Plot A)	12.2–22.3 (17.6 ± 2.8)	2.6–5.5 (3.9 ± 0.8)	3.4–7.6 (4.7 ± 1.0)	3–4
F_1 hybrids (Plot B)	12.1–20.1 (16.0 ± 2.6)	2.2–4.7 (3.5 ± 0.7)	3.7–5.6 (4.7 ± 0.4)	3–4
F_1 hybrid clones (Plot C)	15.8–26.4 (20.4 ± 2.8)	3.3–5.1 (4.1 ± 0.5)	3.8–5.4 (4.8 ± (0.4)	3–4
F_1 hybrids[1]	15.0–20.0	4.0–6.0	2.5–5.0	3–4
A. auriculiformis[1]	15.5–28.0	2.5–3.0	5.0–11.2	3
A. mangium[1]	12.0–25.0	6.0–8.0	1.5–4.2	4

[1] Data from Kijkar (1992)

Table 2. Mean growth of F_1 hybrids in Thailand and Vietnam, compared with *A. auriculiformis* and *A. mangium*. (Standard deviations are in parenthesis; n = 20, 39 and 55 for plot A, B and C, respectively.)

Species	Age (yrs)	Spacing (m)	Growth: Height (m)	Growth: DBH (cm)	MAI: Height (m/yr)	MAI: (DBH (cm/yr)
Thailand — AFTSC						
F_1 hybrids (Plot A)	9.5	1 × 1	19.84 (1.57)	18.19 (3.25)	2.09 (0.17)	1.91 (0.34)
F_1 hybrids (Plot B)	6.5	1 × 1	12.97 (3.16)	13.03 (4.18)	2.00 (0.49)	2.00 (0.64)
F_1 hybrid clones (Plot C)	4.5	1 × 1	17.31 (2.51)	13.90 (3.98)	3.85 (0.56)	3.09 (0.88)
AFTSC field station[1]						
A. auriculiformis	9.0	2 × 4	14.61	14.31	1.62	1.59
A. mangium	9.0	2 × 4	13.96	16.95	1.52	1.88
Vietnam[2] — Ba Vi						
F_1 hybrids	4.5	—	9.7	12.4	2.16	2.76
A. mangium	4.5	—	8.0	9.6	1.78	2.13
Vietnam — Song May						
F_1 hybrids	3.0	—	10.90	9.30	3.63	3.10
A. auriculiformis	3.0	—	7.30	5.60	2.43	1.87
A. mangium	3.0	—	8.00	6.20	2.67	2.07

[1] Data from the report of AFTSC field station (unpublished)
[2] Data from Kha (1996)

performance at all the ages examined. The results are similar to earlier studies by Darus and Ghani (1989), Yantasath et al. (1992) and Kha (1996).

The hybrid trees at AFTSC used for this study were planted at a spacing of 1 × 1 m compared with 2 × 4 m for the parental species. Close spacing is expected to have a negative impact on tree growth, especially diameter, and the values reported for these hybrids in Table 2 may underestimate their potential growth. Nonetheless, the hybrids had superior growth to the parental species (Table 2).

Clonal planting of natural acacia hybrids has already begun in Vietnam, and is expected to take place in other countries around the region as soon as clones of selected hybrids become available. Programs for their genetic improvement by controlled pollination have been established in many national and private institutions. The availability of selection markers for plus trees would greatly accelerate such development, but there is little research on the biological factors underpinning rapid growth in acacia hybrids. Our research on *A. auriculiformis* has identified many useful physiological processes linked to superior growth performance (Montagu and Woo these Proceedings; Puangchit et al. these Proceedings). It is reasonable to suggest that these physiological parameters are likely to be involved in the fast-growing acacia hybrids described in the present study. If this is the case, then their application for plus tree selection would greatly facilitate the development and utilisation of acacia hybrids in plantation forestry and agroforestry in the region.

Acknowledgment

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References

Bhumibhamon, S. 1992. Potential for growing acacias in Thailand. In: Awang, K. and Taylor, D.A., ed., Tropical Acacias in East Asia and the Pacific. Proceedings of the First Meeting of the Consultative Group for Research and Development of Acacias (COGREDA), June 1–3, Phuket, Thailand, 15–17.

Darus, A.H. and Ghani, R. 1989. A note on acacia hybrids in a forest plantation in Peninsular Malaysia. Journal of Tropical Forest Science, 2 (2), 170–171.

Gan, E. and Sim, B.L. 1992. Nursery identification of hybrid seedlings in open pollinated seedlots. In: Carron, L.T. and Aken, K.M, ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37, 76–87.

Kha, L.D. 1996. Studies on natural hybrids of *Acacia mangium* and *A. auriculiformis*. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI-IUFRO Conference, Caloundra, Queensland, Australia, 27 October–1 November, 328–332.

Kijkar, S. 1992. Handbook: Vegetative propagation of *Acacia mangium* × *Acacia auriculiformis*. ASEAN-Canada Forest Tree Seed Centre, Saraburi, Thailand, 19 p.

Pinso, C. and Nasi, R. 1992. The potential use of *Acacia mangium* × *Acacia auriculiformis* hybrid in Sabah. In: Carron, L.T. and Aken, K.M, ed., Breeding Technologies for Tropical Acacias. ACIAR Proceedings No. 37, 17–21.

Pinyopusarerk, K. 1987. Improving *Acacia auriculiformis* through selection and breeding in Thailand. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. ACIAR Proceedings No. 16, 147–148.

Sim, B.L. 1987. Research on *Acacia mangium* in Sabah: A review. In: Turnbull, J.W., ed., Australian Acacias in Developing Countries. 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. ACIAR Proceedings No. 16, 38–44.

Yantasath, K., Buranasilpin, P., Supatanakul, W., Tanpanich, S., Chantrasiri, S., Patanawibul, S. and Jitanawasan, S. 1992. Research on acacias and their potential. In: Awang, K. and Taylor, D.A., ed., Tropical Acacias in East Asia and the Pacific. Proceedings of the First Meeting of the Consultative Group for Research and Development of Acacias (COGREDA), June 1–3, Phuket, Thailand, 50–58.

Silviculture of *Acacia mangium* in Papua New Guinea

W. Yelu[1]

Abstract

Acacia mangium, although native to Papua New Guinea as well as Australia and Irian Jaya, has not traditionally been of interest for use in silviculture in PNG. This paper discusses the reasons for recent interest in greater utilisation of the species, reviews developments arising from trials of *A. mangium* on selected sites throughout PNG, and records the results of testing different techniques for seed collection, germination, nursery culture and plantation establishment. Recommendations regarding research priorities and future program activities are also listed.

THE fast-growing leguminous tree species *Acacia mangium* is native to Australia, Irian Jaya and Papua New Guinea (PNG). In PNG it is located in the Western Province, and is distributed between Digul and Fly rivers on a low plateau (30–90 m altitude), known as the Oriomo Plateau (Figure 1). The soils are silt to clay-loam overlaying clay of pH 4.5 and the average annual rainfall is 2000 mm. The tree grows on edges of bushes and swamps, thus creating woodlots or forest. A few isolated specimens grow on savannah areas, and are usually of poor form associated with *Melaleuca* and *Tristania* spp.

Studies into establishment techniques only started recently after private companies and the Forest Authority started to go into reforesting this species. As a result, very little has been done. For the earlier trials and small plantings the seedlings were raised using experience from Sabah and Australia.

It has many uses, as stated by Eddowes (1977). In PNG it is used locally for fuel wood, shade and building material, and commercially for woodchip for pulp and paper. Although the species is indigenous to PNG, the development of silvicultural techniques began with the seed collection in 1980. From 1981 pretreatment, storage and nursery techniques were investigated, which led to standardisation of techniques. The areas in the nursery not investigated were use of fertilisers, inoculation with mycorrhiza and production of planting stock by vegetative propagation. This report summarises current practices and future research programs.

Reforestation in PNG

German settlers and missionaries planted small areas of teak (*Tectona grandis*) for a few years after 1911 in the Madang and Rabaul areas (Skelton 1981). In 1950 large scale reforestation began in Bulolo (120 km southwest of Lae), Morobe Province with two major species, *Araucaria cunninghamii* (hoop pine) and *A. hunsteinii* (klinki pine). From 1950 to 1995, 60 000 hectares had been established throughout the country, using major species like the two mentioned above plus *Eucalyptus deglupta*, *E. grandis*, *E. robusta*, *Pinus patula*, *Terminalia brassii*, *Ochroma lagopus* and *A. mangium*.

The reforestation of *Acacia mangium* began in 1989 with small-scale plantings in Madang, Kimbe and Rabaul. This was because it had not been considered a priority species by the PNG Forest Authority. The initial interest was in seed collection, which began in 1980 due to its excellent performance in Sabah, Malaysia. From this collection, a species trial of *A. mangium*, *A. auriculiformis* and *Eucalyptus deglupta* was established in 1982. In 1983 another seed collection was made and this resulted in the establishment of an acacia species trial of *A. mangium*, *A. auriculiformis*, *A. aulacocarpa* and *A. crassicarpa* in 1986.

Results from the first trial in 1985 (Table 1) and second trial in 1987 (Table 2) indicated *A. mangium* growing faster than *A. auriculiformis*, *A. crassicarpa*, *A. aulacocarpa* and *E. deglupta*. This

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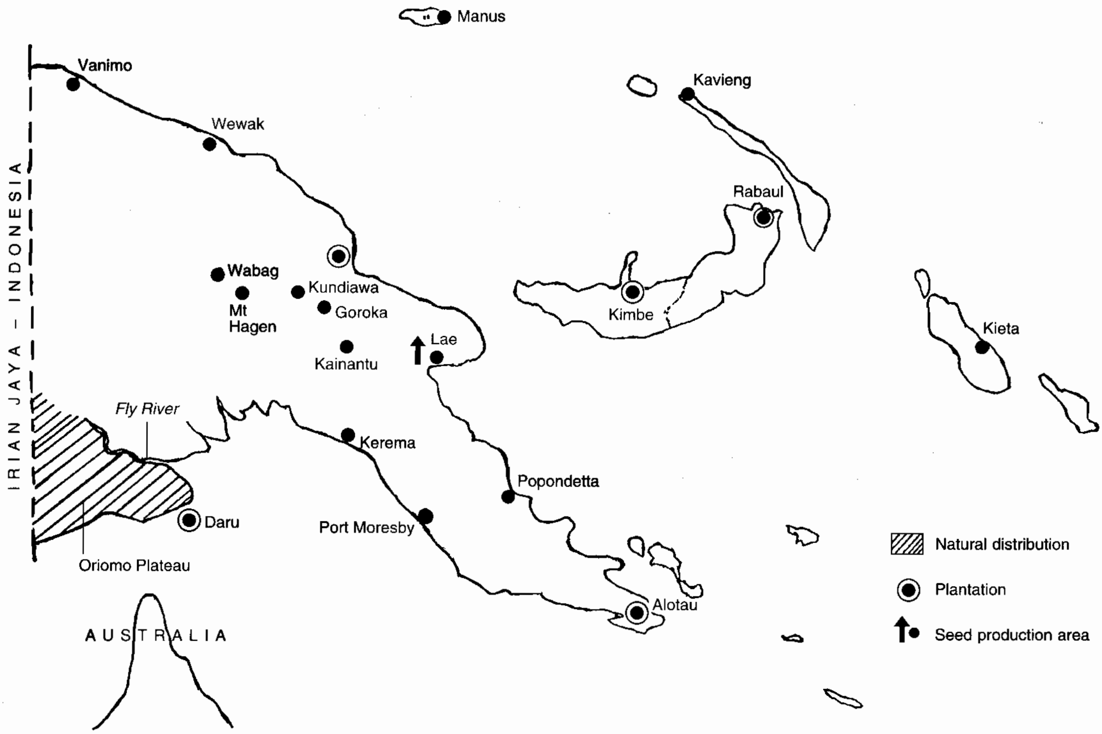

Figure 1. Papua New Guinea, showing distribution of *A. mangium* in natural and plantation forests.

attracted large timber companies like JANT (Japan New Guinea Timber) in Madang, Open Bay Timber in Rabaul and Stettin Bay Lumber in Kimbe to attempt large-scale planting of this species. To date JANT has a planting target of 1200 ha/annum, Stettin Bay Lumber 100–200 ha/annum; Open Bay Timber, with no planting target, planted 24.2 ha between 1988 and 1992 (Yandekao 1997).

Table 1. Height at 2.5 years of *A. mangium* in species/provenance trials (spacing 3 × 3 m) (after Skelton and Howcroft 1987).

Species/Provenance	Height (m), by type of site		
	Well drained	Poorly drained	Grass-land
A. mangium – Balamuk (PNG)	12.4	10.6	2.2
A. mangium – Toko (PNG)	12.2	10.1	2.5
A. mangium – Iokwa (PNG)	11.0	10.4	2.4
A. mangium – Oriomo (PNG)	11.0	10.3	3.2
A. mangium – Claudie River (Aust)	10.9	9.6	2.2
A. mangium – Daintree (Aust)	9.3	9.5	0.7
A. mangium – Walsh's Pyramid (Aust)	8.0	6.3	1.1
A. mangium – Abergowrie (Aust)	11.2	9.7	1.4
A. auriculiformis – (PNG)	9.7	8.3	1.3
E. deglupta – (PNG)	10.1	6.8	1.2

Table 2. Growth characteristics at 12 months of acacia species trials on a well drained site (3 × 3 m spacing).

Species	Characteristic	
	Height (m)	Diameter (cm)
A. mangium (PNG)	4.8	7.4
A. auriculiformis (PNG)	3.4	5.6
A. crassicarpa (PNG)	2.8	4.3
A. aulacocarpa (PNG)	2.5	4.2

The Forest Authority also started planting this species in 1989 on a small scale in Madang, Open Bay and Kimbe without specific annual targets. In 1990–91 Wasab in Madang and Ulabo in the Milne Bay Province were included. It is now planned that large-scale planting of this species in Madang, Rabaul and Kimbe will commence with 250 ha/annum.

Interest has also developed among the local people because of its fast growth and good fuelwood. This has resulted in people planting woodlots either to be used for fuelwood or sold to the company. In Madang landowners plant 1–5 ha woodlots, and to date 800 ha have been established. At maturity they sell to the JANT Company at K5.00 per m^3. The company encourages the landowners by providing free seedlings, free transport to planting site, and also cultural advice (Cholai 1997). To date the total area has increased, but the actual figure has not been calculated. *A. mangium* is 15–16% of the 60 000 ha total.

Silviculture Techniques

Seed collection, extraction and storage

Seed collection

Acacia mangium usually seeds annually; flowering occurs March–April and fruiting May–July. Seeds are ready to be collected in August and September. Large seed collections are made from Western Province from selected seed trees in the natural forest. Small quantities (2–3 kg/annum) are collected from the seed production areas (<1 ha) in Bulolo. The local people, with advice from CSIRO and the PNG NTSC teams, collect seeds from natural stands. These teams then buy the seeds from the local people at K80.00 per kg. Staff and labourers from the NTSC in Bulolo collect the seeds from the seed production area in Bulolo.

Seed drying and extraction

Green pods are spread on polythene sheets and air-dried. When pods are dry, seeds are removed either manually or with a threshing machine. The debris is separated from the seeds using sieve sizes of 3.36–4.0 mm. The larger fragments are retained on the sieve while the seed and dust passes through. The 2.83 mm and 0.35 mm sieves are then used to separate the seeds from the dust.

Seed storage

White plastic bags (60 × 40 cm) are placed in the 20-litre black plastic screw-top containers. The clean seed is poured into the bags in the containers and stored in an airconditioned room at 25°C. Small quantities in 1-litre plastic containers are stored either in the domestic fridge (22ºC) or in the air-conditioned room. Seeds have kept well in the air-conditioning for 5 years, but some viability is lost following repeated opening of stored seed. Trials indicated that fresh seeds before storage were 90–100% viable. Viability from years1 to 5 dropped to 65–70%, 55–60%, 50–55%, 45–50% and 40–45% (Yelu 1993).

Seed sale

The only body licensed to sell seeds locally and overseas is the National Tree Seed Centre in Bulolo. There are no fixed markets for sale of seeds locally and abroad. The main local markets are Gogol Reforestation Company, Stettin Bay Lumber and Open Bay Timbers. Demand is low and in some instances operations stopped, for example when the earlier plantings produced trees of poor form that were easily uprooted by wind (Yandekao 1997).

There are no fixed overseas markets, but seeds are sold on request. They are sold either fresh (80–90% viability) or from storage at 1-year-old (>70%). The price is K1000.00 per kilogram.

Nursery Practices

Pretreatment and sowing

Seeds are placed in a small round flywire container, which is then soaked in boiling water at 100ºC for 20–30 seconds. The seeds are stirred so that they are treated thoroughly, then removed after 20–30 seconds and soaked in cold water for 24 hours. The water is poured off and once the seeds have dried, they are dusted with *Thiuram* and broadcast-sown in germination trays. They are spread evenly in the trays to avoid the problem of damping off.

Tubing

This operation is done under full shade. The seedlings are transplanted when they are 5 cm tall and have a pair of leaflets. A pencil-size sharp stick is used to lift and soften the soil before pulling it out. A hole is made in the centre of the soil in the tube and the seedling planted. After tubing, seedlings are left in full shade (corrugated iron roof) for 5 days. After this period they are moved to the wire beds under temporary 70% shade (sarlon cover); in the bush, material such as coconut leaves and leucaena sticks providing 80–90% shade has also been successful. The seedlings stay under temporary shade for 4 weeks. After that the shade is removed and seedlings left in open beds to harden until they attain plant-out size of 25 cm height and 4–5 mm root collar diameter.

Watering and fertilising

Tank water is used for watering seeds and seedlings in germination trays and river or creek water is commonly used for seedlings in the nursery beds. A sprinkler system is used in large nurseries, while rubber hoses are used in small nurseries. Fertilisers are not commonly used in the nursery because not much research has been carried out in this area. The JANT Company in Madang is currently using NPK at 1–2 granules per seedling, and this has led to colour change from yellow to the normal dark green. SBLC and Open Bay have not used fertiliser.

A rate trial carried out in the nursery using diammonium phosphate (DAP) and NPK (12:12:17) indicated rate of 0.75 g per seedling to be the best rate, producing seedlings ready for plant-out in 2.5–3 months (Yelu 1995). Growers were advised of the results.

Culling and dispatch

No standard criteria for selection are used. Individual judgement is made to select healthy, tall, straight, thick-stemmed seedlings for planting. Thin, tall, crooked seedlings (1–10% of seedlings) are discarded.

For dispatch the seedlings are lifted in polypots and placed in a 30 × 30 cm square metal box for transportation to the planting site.

Potting mixtures

Two types are commonly used:

a) mixtures of two parts of fine river sand to four parts of black forest loam;
b) pure forest loam.

Establishment and maintenance

Site selection

The plantations are currently grown on an ex-forest hill, a slope up to 22°, on ex-forest flat, on grassland hills up to 20° slope and grassland flat and wet sites. Studies are now been carried out to identify the best site for this species.

Site preparation

On ex-forest and wet sites, the procedure involves clear felling, burning, picketing and planting. Sometimes burning is not necessary, especially in the second rotation plantations. Grassland sites are burnt, followed by picketing and planting. However because of slow growth and low survival (45–55%) on grassland and wet sites, studies are now planned on how to improve these sites. The plan for the grassland site is to plough before planting or encourage gardening on large scale to remove compacted roots of *Imperata cylindrica* grass. Results from growth plots indicated good growth on disturbed sites (height 12 m and dbh 14.0 cm) compared to undisturbed (no gardening) sites (height 9.5 m and dbh 8.5 cm) (Yelu 1995). The plan for the wet site is to raise the soil by building a mound 30 cm high and 15 cm radius to avoid conditions too wet for the seedlings.

Planting

Wet sites are planted immediately as long as the soil is moist. There is no need to wait for the rainy season because it will get too wet. Plantings on ex-forest and grassland sites starts at the beginning of rainy season. In Rabaul, Kimbe, Madang and Alotau high rainfall enables year-round plantings. In Kimbe the annual rainfall is 3848 mm, Madang 2500 mm, Rabaul 2600 mm and Alotau 2700 mm. Main plantings correspond with high rainfall periods from January to April and October to December.

Spacing

Appropriate spacing for this species is not yet identified in PNG. The first trial established in 1993 in Bulolo (700 m altitude) was abandoned because of cattle damage and high mortality in dry weather. The second trial was established in March 1997 in Madang (65 m altitude). Spacings tested are 2 × 2 m, 2.5 × 2.5 m, 3 × 3 m, 3.5 × 3.5 m, 4 × 4 m, 4.5 × 4.5 m and 5 × 5 m. Final results should be known at 36 months.

To date, without the results from proper spacing trials, past trials were planted at 3 × 3 m spacing. For the seed production areas, spacings of 7 × 7 and 8 × 8 m have been used and are still in use, so that trees produce wide crowns and hence increase seed production.

Plantings of the Reforestation Division of the Forest Authority have also used 3 × 3 m spacing and are continuing to use it, while private companies have chosen their own plantation spacings. JANT uses 4 × 4 and 3.5 × 3.5 m, Open Bay Timbers uses 4 × 4 m and Stettin Bay Lumber 4 × 4 m.

Tending

Manual tending with grass knives and bush knives is commonly used. Contract labourers, who are cheaper than permanent employees, undertake most of the work. These contract labourers are mostly unemployed landowners.

In the first year, four tendings are carried out. First is a line tending (0.5–1 m wide) 2 months after planting. This is done to avoid too much exposure of newly planted seedlings to dry weather. The second, third and fourth are clear tending done at 3-month intervals.

In the second year, three clear tendings at 3-month intervals are carried out on ex-forest and grassland disturbed sites. This is because at age 2 years there is crown closure, which suppresses and kills undergrowth. On the grassland sites because of the slow growth of trees there is no crown closure so a line (1 m wide) tending is carried out at three-month intervals during the third year. In the fourth year tending is only necessary where trees are below or at the same height as the grass. On the wet site, ring tending continues in the third and fourth years.

Pruning and thinning

Pruning and thinning are not currently practised in the plantations. This is because:

- no trials have been carried out to identify appropriate techniques;
- current plantations are for pulp and paper, and pruning and thinning are not necessary at this stage;
- current spacings of 3 × 3 , 3.5 × 3.5 and 4 × 4 m have resulted in self pruning of trees, indicating that pruning is not necessary at such spacings.

Fertilisation

Fertiliser is not currently applied to plantations because very little work has been done on fertiliser use. Thus it is difficult to recommend the type of fertiliser and the rate required by this species. A trial carried out on different sites in the Gogol Valley, Madang Province using NPK (12:12:17) showed good results on grassland sites, with 300 g/tree the best rate. Trees reached a height of 9.4 m and dbh 10.5 cm compared to control with height 6.5 m and dbh of 7.1 cm at age 2.5 years (Yelu 1995b). On the ex-forest sites, there was a little difference between the untreated and treated plots, indicating that here fertilisation is not necessary.

Growth and yield

The growth of *A. mangium* varies from site to site and between spacing. On ex-forest hill and flat with soil types ranging from loam to clay loam overlaying clay soil, growth is fast compared to grassland and wet sites. Very poor growth was recorded on the grassland clay soils (Table 3).

Table 3. Growth and yield of *A. mangium* on different sites at age 3.5 years (4 × 4 m spacing).

Site	Characteristic		
	Height (m)	Dbh (cm)	Yield (m^3/ha)
Ex-forest; hill, 15–20° slope; loam to clay-loam soil, pH 5.5	15.5	15.3	155.3
Ex-forest; hill, 10–15°; loam to clay-loam, pH 5.3	14.7	15.6	153.8
Ex-forest; flat; loam to clay-loam, pH 5.2	15.8	16.3	159.6
Disturbed grassland; hill, 15–20°; loam to clay-loam, pH 4.8	10.5	11.0	41.4
Undisturbed grassland; hill, 15–20° slope; loam to clay-loam, pH 4.8	9.3	9.1	25.4
Grassland; hill, 5–10° slope; clay, pH 4.2	6.2	8.5	14.3
Wet; clay-loam to clay	9.6	10.4	17.7

Spacing also has an effect on tree growth. In the seed production areas trees spaced 7 × 7 and 8 × 8 m were growing faster than those at 4 × 4 and 3 × 3 m on ex-forest sites. But the form of trees is better in the closer spacing. In the wide spacing heavy branching starts 2 m above the ground, while in the closer spacing the clear bole is over 8 m and heavy branching occurs at the crown.

Pests and diseases

Nursery

There have been no serious pest and disease problems in the nursery. However, defoliation by *Eurema hecabe* has been recorded on *A. mangium* seedlings in some nurseries. Other minor defoliators which attack seedlings from time to time are grasshoppers.

The control for *Eurema hecabe* uses *Bacillus thuringiensis*. Up to 10 g is mixed in 20 litres of water and then sprayed on the seedlings (Kosi pers. comm. 1997).

The common disease is damping-off caused by major pathogens such as *Rhizoctonia* spp. *Fusarium* spp. and *Curvularia* spp. (Mukiu 1992). Thiuram has been successful in control. Other methods of control used are soil sterilisation, wider plant spacing and less water to seedlings.

Plantations

No serious pest problems up to date have been encountered. However, some studies indicated that *A. mangium* has root and heart rot problems (Mukiu pers. comm. 1997). Further studies are continuing to identify the sites where these problems mainly occur, when they start and when they get worse in order to institute control measures. Other pests identified on the plantations are termites, namely *Microcerotermes* and *Nasusitermes* spp. Studies are currently under way to control this problem. Preliminary findings attribute infestations to non-removal of tree stumps after logging and prior to new plantings (Kosi pers. comm. 1997).

Research Priorities and Future Programs

From the review of current silviculture practices, it seems that most research has concentrated on the establishment of a seed production area, *Acacia* species trials, *A. mangium* provenance trials and nursery techniques. Very little work has been carried out on plantation establishment techniques and tree breeding, due to lower priority placed on it by Department of Forests and timber companies, and lack of trained personnel. Only in the last few years have some timber companies started large-scale planting of *A. mangium* after they had been shown that this species grows faster than *Eucalyptus deglupta* on the same sites. Since *A. mangium* is now attracting attention from large timber companies for planting programs and also from local people for woodlot plantings, PNGFRI's research program includes the subjects listed below.

Nursery techniques

(a) Shorten nursery period through use of fertilisers
(b) Produce planting stock by vegetative procedures
(c) Inoculate trials with rhizobia

Plantations

Develop appropriate techniques for: (a) spacing trials on different sites; (b) thinning; (c) fertilisation; (d) growth and yield; (e) tending; (f) pruning.

Tree improvement

(a) Select plus trees
(b) Establish clonal and seedling seed orchards
(c) Progeny test

Fuelwood projects

The density of *A. mangium* and its calorific value (4800–4900 kcal/kg) makes the wood good for fuel (National Research Council 1983). In Lae, where Niugini Table Birds and Ramu Sugar buy fuelwood from villages and logging companies for their boilers, the potential for this species is excellent. Villages can plant woodlots that can be thinned and sold to these companies.

Alternative crops

From some studies carried out in Madang, heartrot was found in both *A. mangium* and *A. auriculiformis*. It is recommended that studies into an alternative crop be undertaken if the disease gets serious in the future. This will start with the establishment of a spacing trial in 1998.

Termites, rootrot and heartrot

Carry out studies on different sites and on different age groups of *A. mangium* to see where trees are being most affected and at what age.

References

Bakath, D. 1996. Reforestation in Papua New Guinea. AFPNG First Biennnial Conference, 21–25 October 1996, Lae, PNG.

Cholai, T. 1997. Economics of village woodlots. PNGFRI-HRD Forest Research Seminar, 27 September 1997, Lae, PNG.

Eddowes, P.J. 1997. Commercial timbers of Papua New Guinea. Forest Products Research Centre, Office of Forests, Hohola, PNG.

Mukiu, J. 1992. Preliminary report on some tree diseases in Papua New Guinea. Forest Research Note, Forest Research Institute, Lae, PNG.

National Research Council 1983. Mangium and other Fast-growing Acacias in the Humid Tropics. National Academy Press, Washington D.C.

Skelton, D.J. 1981. Reforestation in Papua New Guinea. Office of Forests–CSIRO Pulp and Paper Seminar, 8–10 June 1981, Port Moresby, PNG.

Skelton, D.J. and Howcroft, N. 1987. Seed production and silvicultural trials of acacias in Papua New Guinea. Proceedings of an international workshop held at the Forestry and Training Centre, 4–7 August 1986, Gympie, Australia. ACIAR Proceedings No. 16, 188–190.

Yandekao, F. 1997. Information on *Acacia mangium* in Open Bay. Open Bay Timber Co, Rabaul, East New Britain province, PNG.

Yelu, W. 1993. Nursery techniques for *Acacia mangium* in Papua New Guinea. Proceedings of JICA-FRI Forest Research Project seminar, 1–3 September 1993.

— 1995a. Effect of fertiliser on the growth of *A. mangium* and *E. deglupta* on three different sites. Forest Research Note, Forest Research Institute, Lae, PNG.

— 1995b. Effect of site on the growth of *A. mangium* on six different sites in the Gogol Valley, Madang. Forest Research Note, Forest Research Institute, Lae, PNG.

Progress in Silviculture, Improvement and Market Prospects for Tropical Acacias in Southern China

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Abstract

Research and development on tropical acacia have advanced rapidly in the past 20 years. Tree improvement as the first step has made great progress. Species have been selected and genetic variation between provenances/families of the main species has been identified. Superior provenances, families and clones are playing an important role in large-scale plantation. Intensive tree farming has been quickly accepted in southern China based on early results of silvicultural experiments including spacing, species mixtures, fertilising, and nutrient cycling. The wood is now being used for many different products.

TROPICAL acacias are now extensively planted in the Asian region. They will survive and grow rapidly in a wide range of environments with low soil nutrients (Turnbull 1991). Especially on acidic, infertile hilly sites in southern China, they grow much better than many native species and have many advantages. Timber production is being developed on a large scale, based on systematic research on tropical acacia. In this paper, achievements of the past 20 years in silviculture, improvement and market prospects for tropical acacia in China are discussed.

Plantations

A tropical acacia, *A. auriculiformis*, was introduced into China in the 1960s (Yang et al. 1996). After that, *A. mangium* was introduced to Guangdong and Guangxi provinces in 1979. Following their successful introduction, these two species were put into broad-scale production. Now, there are about 200 000 ha of such plantations in southern China, mainly in Hainan Island, and Guangdong, Guangxi and Yunnan provinces. More than 20 000 ha of *A. mangium*, *A. crassicarpa* and *A. auriculiformis* plantations are being established each year.

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Research on nutrient cycling of *A. mangium* plantations has been carried out (Xu et al. 1994). This showed that nitrogen fixation was significant (Table 1). For example, the amount of nitrogen taken up by a tree reached 154 kg/ha in 6 months, which is much higher than for non-nitrogen-fixing species (about 100 kg/ha). At the same time, 102 kg/ha of nitrogen was returned to the soil, which is the equivalent of 250 kg urea applied to the ground. The cycling rates of N, Ca, Mg, Zn, Mn, Cu and B were very high, but this was not the case for P and K. This means that site fertility can be well maintained under acacia plantations when P and K are added to the site, and soil nitrogen content can be significantly increased after an acacia plantation.

Tree farming practices are changing from extensive to intensive. Addition of 250 g P, 150 g N and 100 g K for each tree in the first two years is an accepted practice. Pulpwood volume production at 6 years, is much greater, with a spacing 2.5 × 3 m (i.e. 1333 trees/ha) compared with 2500, 1666, or 1111 trees/ha. Mixed species plantations can yield 19–62% more volume than a pure plantation of either acacia or eucalypts (Yang Zengjiang et al. 1995). Instead of mixed plantations, the rotation of acacia and eucalypt is an alternative which is easier to manage. The current rotation length for acacia plantations is usually 6–7 years, but this may be extended in the future to meet demands for large-sized timber, and to obtain the best economic return.

Table 1. Nutrient cycle of *A. mangium* plantation during 24–30 months.

Factor	Element								
	N	O	J	Ca	Ng	Zn	Mn	Cu	B
Uptake (kg/ha)	153.8	5.04	55.4	36.4	20.5	0.28	7.04	0.24	0.14
Remaining in trees (kg/ha)	51.7	3.57	37.9	9.4	6.6	0.10	2.14	0.10	0
Returned to soil (kg/ha)	102.1	1.47	12.1	27.0	13.9	0.18	4.9	0.14	0.14
Cycle rate[1]	0.66	0.29	0.21	0.74	0.68	0.64	0.70	0.82	1.00

[1] cycle rate = return/uptake

Tree Improvement

Twenty-one species of tropical acacias (179 provenances and 469 families) have been tested in southern China. The total area of trials in the past 8 years was some 130 ha, and *Acacia mangium*, *A. auriculiformis*, *A. crassicarpa*, and *A. aulacocarpa* have been tested intensively. Great progress on tree improvement has been made with the support of the Australian Centre for International Agricultural Research (ACIAR) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

A number of species for different purposes have been selected. *A. mangium*, *A. crassicarpa* and *A. auriculiformis* are already in production for timber on a large scale. *A. concurrens*, *A. leptocarpa*, *A. colei*, *A. holosericea*, *A. ampliceps* and *A. brassii* have been identified as having the potential to play an important role in water and soil conservation in the near future (Yang Minquan et al. 1995). Other ornamental trees such as *A. dunnii*, *A. podalyriifolia*, *A. neriifolia*, *A. cincinnata* and *A. flavescens* show great potential for use in gardens.

Genetic variation in growth and stem form for four tropical acacias has been shown. The best provenances of *A. mangium* are from Abergowie (Qld), Claudie River (Qld) and Oriomo (PNG). The provenances from Indonesia grew very slowly (Pan and Lu 1988). The seedlots of *A. auriculiformis* from the east of 143° E such as Morehead River (Qld), Coen River (Qld), Mt Molloy Creek (Qld) and Iokwa (PNG) were much better than those from the west of 143° E (Yang et al. 1996). The best provenances *of A. crassicarpa* were all from the east of 141°45′E in PNG (Pan and You 1994). The other species were less satisfactory. For *A. aulacocarpa*, Oriomo (PNG) was the only provenance showing fast growth and good stem form.

A good system of tropical acacia propagation has been established. On the basis of species/provenance trials and progeny tests, 40 ha of seed production area have been established in Guangdong province and Hainan Island. They include a clonal seed orchard, a hybrid seed orchard, and a 1-generation and a 1.5-generation seedling seed orchard. Annual seed production is 690 kg, which is expected to increase to >1000 kg per year after 1999. Tissue culture and cutting propagation are playing an increasingly greater part in forestry. Tissue culture and cutting experiments had survival rates >65%, and >85% of the cultured plantlets were successfully transferred to the field. Several research institutes are now working on large-scale vegetative propagation of three tropical acacias.

Market Prospects

Innovation in timber utilisation

Before the 1980s, acacia wood was only used for firewood and charcoal as there were quite limited acacia plantations and the logs were usually crooked and branched. With the support of ACIAR (Projects Nos. 8457 and 8848), acacia timber has significantly improved since 1990. Many straight logs were used for plywood, floor boards and furniture while it was considered to be a good material for fibreboard; but now, higher economic returns are gained when trees are used for both ornament and scaffolding. In order to satisfy wide demands and to use acacia wood more efficiently, cabinet-making and industrial uses are being developed in China.

Timber markets

Acacia timber is in short supply (Table 2). Production from plantations is currently about 8.9 million cubic metres, of which 2.3 comes from young growth, 3.7 from later growth, and 2.9 from mature forest. The volume from mature forest will increase to 5.5 after 3 years, and 7.0 after 6 years; but aggregate demand is at least 12 million cubic metres. This disparity between demand and supply will decrease only slightly in the future, so increasing the resource continues to need attention.

Table 2. Acacia timber: supply and demand in China ($m^3 \times 10\ 000$).

Year	Supply, by plantation age (showing current ha × 000)			
	1–3 yrs (80)	4-6 yrs (70)	>7 yrs (50)	Demand
Current	230	365	290	>1200
>3 years	270	465	550	>1800
>6 years	297	594	700	>2000

Financial appraisal of timber production

The costs and benefits of acacia timber production in China are changing over time. During the 1980s it was quite cheap to plant, manage and harvest plantations, and the price of timber was only US$8/$m^3$ (Table 3). When the improved timber was used in applications such as fibreboard and plywood, the price quickly increased, to the point where it reached US$45/$m^3$ in 1993–95. Now (1996-97) the price is about US$55/$m^3$, and the internal rate of return (IRR) of plantations is 29.4%, which is much higher than the discounting rate (12%) (Zhou et al. 1994). The IRR rose quickly from 6.8 to 29.4%, indicating that favourable returns on investment in acacia timber production can be realised.

Table 3. Acacia timber: costs and benefits of production in China.

Factor	Time			
	1980s	1990–92	1993–95	1996–97
Cost (US$/ha)	200	1300	1380	1500
Vol. (m^3/ha, 7 yo)	45	60	75	85
Price (US$/$m^3$)	8	35	45	55
Yield (US$/ha)	360	2100	3375	4675
Benefit (US$/ha)	22.9	114.3	275.0	453.6
Benefit (US$/$m^3$)	3.6	13.3	26.6	37.4
IRR (%)	6.8	21.2	27.5	29.4

Social Benefits of Plantations

Acacias, good nitrogen-fixing and multipurpose species, are welcomed in China. They play an important part in sustainable development of forestry and society. The main contributions are to:

- afforest barren land quickly;
- transform low productive land on large scale; and
- improve poor, acidic hilly sites and their environment.

Acacias, especially *A. mangium* and *A. crassicarpa*, have been important species in large-scale industrial plantations in southern China. The Chinese Government, and agencies such as the World Bank and the Bank of China, are supporting their establishment, and many foreign companies are investing in acacia plantations also.

References

Pan Zhigang, Lu Pengxin et al. 1988. Early report of provenance trial of five acacias in 5 years. Forestry Research, 1, 553–559.

Pan Zhigang and You Yingtian 1994. Introduction and provenance trial of *A. crassicarpa*. Forestry Research, 7, 498–505.

Turnbull, J.W., ed. 1991. Advances in Tropical Acacia Research. ACIAR proceedings No. 35, Canberra.

Xu Daping, Yang Minquan and Zeng Yutian 1994. Study on the above-ground net productivity and nutrient cycling of the plantation of young *A. mangium*. Forestry Science and Technology of Guangdong Province, 4, 11–16.

Yang Minquan, Zhang Fangqiu, Cheng Chuangqi and Lin Xin 1996. Study on provenances of *A. auriculiformis* over its natural distribution. Forest Research, 9 (4), 359–367.

Yang Minquan, Zhang Fangqiu, Xie Huazheng, Lin Kang Luan and Luo Wen Xian 1995. Study on selection of acacia species/provenances in water and soil serious erosion area. Forestry Research, 8 (5), 489–496.

Yang Zengjiang, Zhen Haishui and Weng Qiji 1995. Effects of eucalyptus and acacia mixed plantation on the growth and soil fertility. Forestry Science and Technology of Guangdong Province, 11 (2), 10–16.

Zhou Zaizhi, Xu Huangcan, Yin Guangtian and Zong Bishan 1994. A financial appraisal of three commercial rattan plantations. Rattan Research, 168–176.

Social and Technical Considerations in Establishing Large-scale *Acacia* Plantations on Grassland and Bushland in West Kalimantan, Indonesia

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Abstract

Possibilities of establishing large-scale pulp plantations using tropical acacias are being tested in a humid tropical climate on heavily degraded *Imperata* grasslands and abandoned shifting cultivation areas in West Kalimantan, Indonesia. The ultimate aim is to establish a plantation of about 100 000 ha to feed a pulp mill. A gross area of 300 000 ha has been allocated for the purpose. There are 60 000 people living within these boundaries. The plantations are established in close cooperation with the local population through land-use agreements and a carefully designed benefit system. The benefit system aims to ensure balanced social development, sufficient land availability and, finally, development of a productive plantation. Currently, the established plantation area covers 8600 ha, which consists of 86% *Acacia mangium*, 6% *A. crassicarpa*, 3% indigenous species (over 80 species), 3% rubber (*Hevea brasiliensis*) and 2% *Eucalyptus pellita*. Intensive site preparation and NPK fertilisation are standard. The initial growth of the plantations has mostly met expectations. However, occasional problems with pests, diseases and nutritional disorders have been recorded during the first two years of practical plantation activities. Long-term availability of sufficient land-area for continuous growth of plantations on a socially sustainable basis will determine the technical success of the project.

TROPICAL acacias have shown great potential in rehabilitating degraded lands in Southeast Asia (e.g. Turnbull 1987, 1991). In Indonesia, tropical acacias have been the highest ranking species in several trials on grasslands dominated by *Imperata cylindrica* (Turvey 1996; Vuokko 1996); their remarkable growth potential gained by provenance selection has been recognised (Otsamo et al. 1996). In addition to vigorous growth, tropical acacias have favourable wood qualities for pulp production, and some of them could also be considered for mechanical products (Laurila 1995).

Several timber estate companies in Indonesia have prepared plans and initiated activities for large-scale acacia plantations, mostly based on *Acacia mangium*. Establishing plantations on freshly cut rainforest sites is, however, increasingly considered an environmentally harmful, unsustainable and unacceptable practice (e.g. Kerski 1995). Therefore, when planning the new acacia pulp plantation program described in this paper, the areas were selected so that no primary forest would be affected. Similarly, the future pulpmill would accept only plantation wood, and no timber from natural forests.

A joint-venture company consisting of Enso Group from Finland and two Indonesian companies, PT Inhutani III and PT Gudang Garam, was established in June 1996. The aim of the venture is to establish in West Kalimantan a plantation resource which could feed a modern pulpmill. A net plantation area of about 100 000 ha will be needed, and a gross area of 300 000 ha has been allocated for the purpose by the government.

The project area is located in the districts of Sanggau and Sintang in West Kalimantan, Indonesia between 0°00′–0°40′S and 110°30′–111°30′E at an altitude of 50–100 metres. The average annual rainfall is 3518 mm, but it varies significantly between years and localities. The soils are mainly deeply

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weathered heavy soils with low levels of organic matter. The pH (H_2O) is 4.5–5.3, and the available nutrient levels are low. In general terms, soils are poorer than in similar vegetation in South Kalimantan, where several promising results growing tropical acacias on degraded lands have been reported (Otsamo et al. 1996; Turvey 1996; Vuokko 1996).

The main principle in determining the project area was that no primary forest, productive logged-over forest or high secondary forest, would be cleared for acacia plantations. The allocated gross area consists of:

- grassland, 12%;
- bushland or young secondary forest, 64%;
- active swidden areas, 5%; and
- forest gardens, riverine forests, rubber gardens and village areas, 19%.

Land Availability and the Social Context

The whole area was thoroughly mapped before planting, using a new video-image technique (Hippi and Rissanen 1996). Vegetation classification maps were prepared, and positions of rivers, existing roads and villages were determined from video images. Simultaneously a detailed socio-economic survey was carried out in the villages within the area. According to the latest government statistics, the average population density in the area is 18 persons/km^2. Government figures predict annual population increases of 1.5%. The average family size is 5.2 persons. There are 190 village sites within the proposed gross plantation area, with an estimated total population of 50 000 (Potess 1996).

Proposed lands for the pulp plantation have been long been used for swidden agriculture by local communities. Tenure over these lands remains with the local people, although the government claims ownership and has allocated them for plantation forestry. Although extensive portions of land have been degraded to alang-alang grasslands, local farmers still include them within their swidden cycles and use them to plant rubber tree crops with local 'jungle rubber'. Development of the pulp plantation will undoubtedly modify some of the prevalent local agricultural patterns and community lifestyles. However, the degrading farming conditions will soon force farmers to move from the present swidden agricultural system. To support local people with the needed land-use change, and advance pulp plantation goals at the same time, the integrated approach for land development has been adopted.

After the suitable areas for plantation development have been selected by using the video images, villages in that area are approached and the principles of the plantation project explained. This starts a negotiation process, which results finally in signing the land-use agreement. This means that the company and the community agree that certain, carefully determined areas can be used for plantations, and the company provides a package of long-term benefits for the community. Instead of paying actual rent for the land, the community is provided with improved infrastructure and work opportunities and a 10% share of the plantation. Also the company plants 10% of the plantation area with local species selected by the farmers, and 5% of the area with improved rubber trees. Support in developing agricultural practices as well as institutional strengthening are included in the program (Figure 1).

Initially there was great variation between the villages in their reactions to the proposed program. Some areas were ready to join the program, because they thought that any opportunity from outside would be better than the existing situation. Others refused either because they did not understand the idea of planting acacias for pulp, or because their earlier experiences disposed them to not trust plantation companies. However, many of those who were reluctant at first have joined the program on their own initiative after becoming familiar with the activities in the neighbouring villages. Currently land-use agreements cover 15 000 hectares in 50 villages, and the land acquisition process with the related community development components is proceeding without major difficulties. The main threat for land availability is the competition with other plantation developments, mainly oil-palm. This problem is mainly caused by poor provincial land-use planning.

Plantation Development

Although the joint venture was officially established in 1996, the first species and provenance trials had been established earlier in 1993 by Enso and Inhutani III. Pilot plantations were added in to the program in 1994–95, and the land acquisition model was tested. These early trials showed the good potential of *Acacia mangium* and *A. crassicarpa* (Figure 2). Demanding species like *Paraserianthes falcataria* and *Gmelina arborea* totally failed. More recent tests have demonstrated the potential of *A. aulacocarpa*, and *Eucalyptus pellita* has so far performed well on some sites. Intensified plantation establishment in various parts of the area was initiated only in late 1996. By late 1997 the plantation area was 8600 ha, consisting of 86% *Acacia mangium*, 6% *A. crassicarpa*, 3% indigenous species, 3% rubber (*Hevea brasiliensis*), and 2% *Eucalyptus pellita*.

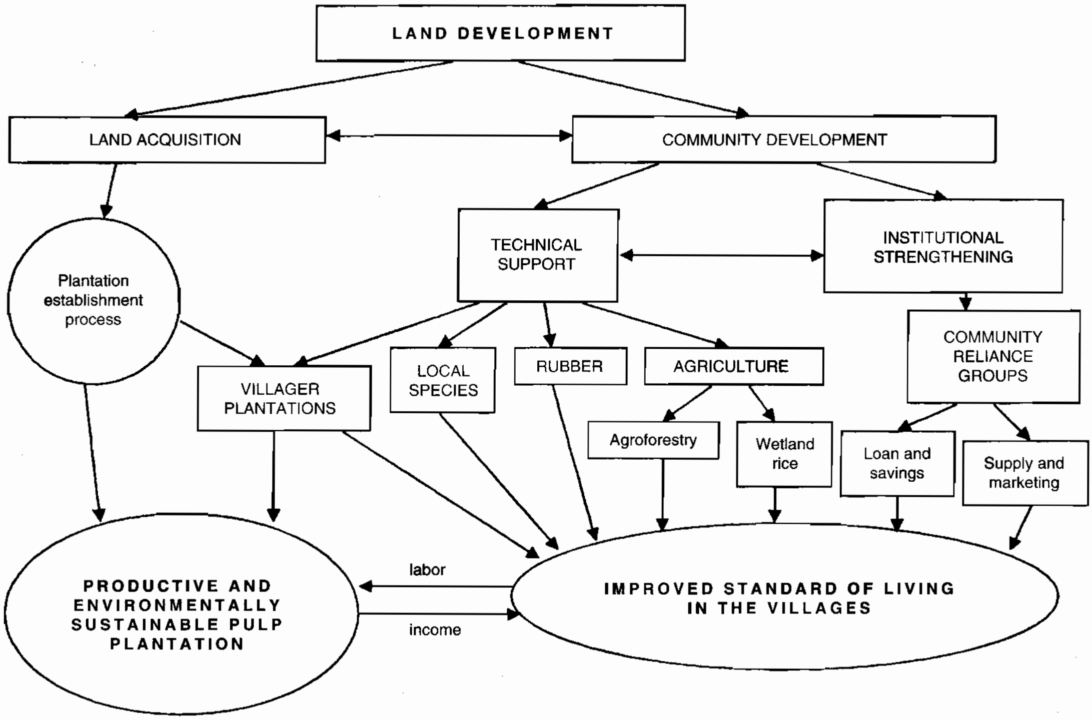

Figure 1. Land acquisition model at PT Finnantara Intiga, West Kalimantan.

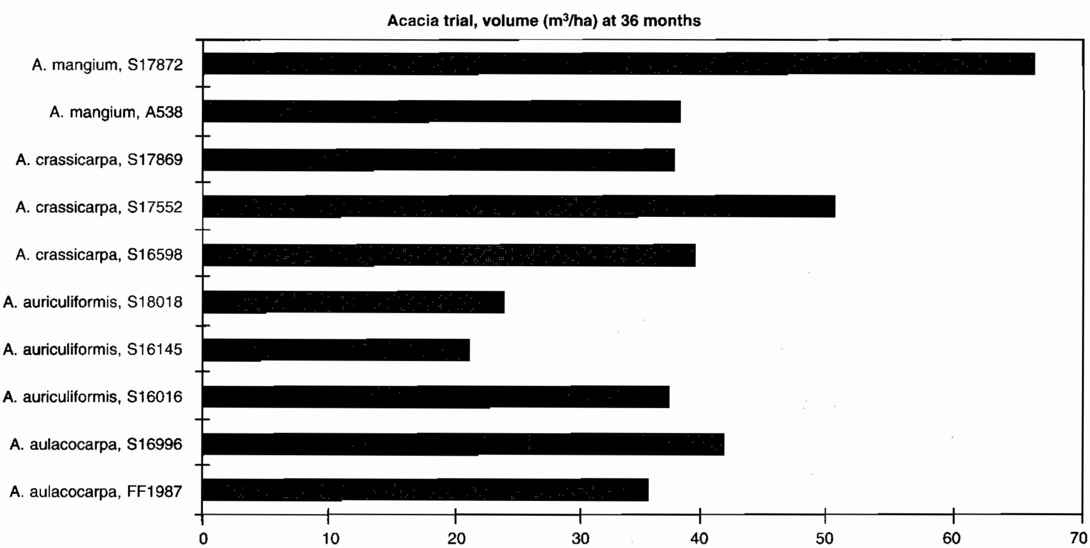

Figure 2. Results of comparison trial 3 years after planting in Sape, West Kalimantan, Indonesia.

Seeds of Papua New Guinea, Irian Jaya or Queensland acacias and eucalypts were purchased from Australian suppliers (CSIRO, Queensland Forest Service, Future Forests); also seed has been bought from plantations in South Kalimantan, and recently from South Sumatra. So far these seed purchases have included large quantities of more than 20 different mangium provenances or landraces and about ten provenances of both *A. crassicarpa* and *A. aulacocarpa*; however, *A. auriculiformis* is represented by only a few provenances. These seed introductions are assumed to give a good, broad genetic basis for own-seed collections and long-term tree improvement. A similar approach has been applied by some other pulp projects (Arisman and Havmoller 1994; Wong 1993). However, PT Finnantara Intiga's purchases may have been more extensive than would otherwise have been expected because no local seed sources were available. Collections in its own plantations were initiated in 1997, and by the year 2000 the company will become self-sufficient in seed supply. As an example, a projection of seed sources in seedling production of *Acacia mangium* is shown in Figure 3. The total annual mangium planting of 8000–9000 ha will require some 10 million seedlings, although vegetative propagation of superior individuals should reduce the total seed need in the future.

Seedling production is carried out in one central nursery, and three temporary nurseries. All nurseries use the pot-tray system, processed peat being the main part of the substrate mixture. Nursery procedures follow the guidelines recommended for *Acacia mangium* (Ådjers and Srivastava 1993).

On grassland sites preparation is intensive, generally one or two ploughings and one harrowing. This method was effective in grasslands in South Kalimantan (Otsamo et al. 1995), but it is only possible on fairly flat areas. Cultivated slopes are prone to erosion and steep slopes are inaccessible for tractors, and to date full manual planting is used on such slopes. The most appropriate site preparation methods for bushland areas have also not yet been developed; fire cannot be used, so disc ploughing is most often applied. However, due to the sharp stumps, rubber-wheeled tractors can operate only after the land has been cleared by bulldozers; but such clearing is expensive, and there is a risk of removing some of the fertile topsoil. A bulldozer-driven Savannah plough was found to be too bulky, and a rubber-wheeled forwarder too slow for economical operation.

As the soils are poor, fertilisers have given remarkable growth increments. NPK fertilisers are applied one month after planting, at the rate of 100 g per seedling into small holes surrounding the seedling. At 1–2 years an additional fertiliser application has proved necessary and efficient (Figure 4). For acacias this fertilisation is a PK broadcast application, and for eucalypts it is NPK; in each case the application of the main elements is 50–60 kg/ha. However, as likely boron deficiency has been found during this year's long dry seasons, boron (5 kg/ha) will be applied as a separate fertiliser (*Fertibor*) or by using a PK/NPK fertiliser including various trace elements (*Kemira* slow-release forest fertilisers).

Weeding of plantations is carried out manually. However, chemical weeding is tested and may be included in some tending regimes later. The spacing 4 × 2 m would allow the use of mechanical weeding between rows, but it is rarely practised. Singling is carried out at 4–6 months from planting. The early growth of fertilised plantations has been satisfactory or good. However, all plantations are still young and

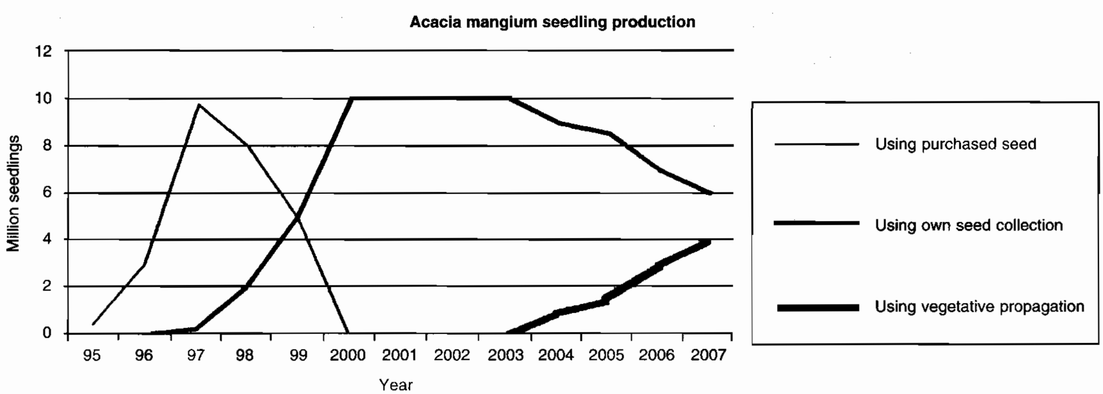

Figure 3. Projected *Acacia mangium* seedling production at PT Finnantara Intiga, West Kalimantan.

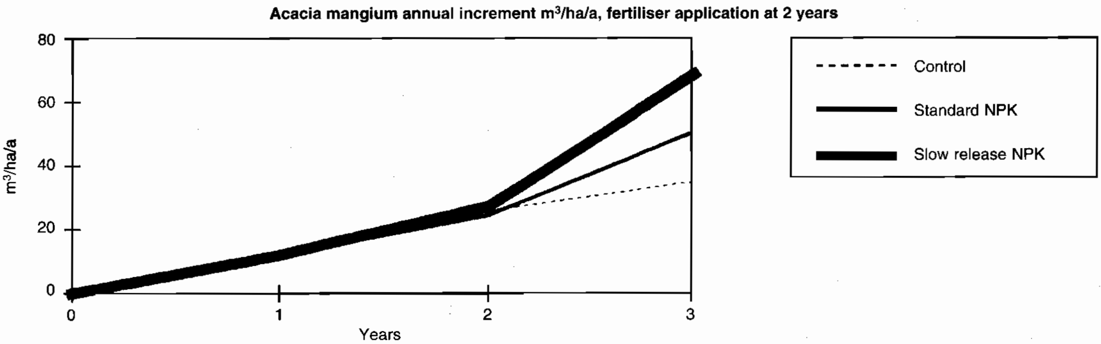

Figure 4. Annual increment in *Acacia mangium* fertilising trial.

more reliable growth estimates are needed before final decisions on the pulpmill are taken.

At least two different leaf-eating larvae have occasionally caused heavy defoliation in young (about one year old) plantations. These attacks do not kill the trees, but adversely affect growth rate and tree form. Insect problems in the few older plantations have been minimal. In a disease several potentially fatal diseases were found to be present in species and provenance trials survey (Hadi and Nuhamara 1996). Most of the plantations have been healthy to date. However, trees which have been attacked by larvae have also got black leaf rust, and occasionally, pink disease has been found in *A. mangium* and *A. crassicarpa* stands. However, the present long dry season has increased the environmental stress of trees and has weakened especially young (i.e. 1–2-year-old) plantations, and heavy shoot die-back has been observed in many areas; detailed studies on the disease are underway. Although winds in Kalimantan are moderate, wind damage of *A. mangium* and *A. crassicarpa* such as broken tops and fallen trees is not uncommon, and may later increase the health risks of plantations. Early observations on *E. pellita* indicate that pest and disease problems are fewer.

Research and Development Priorities

Research and development of the company is divided into four sectors:

- tree improvement,
- soils and plant nutrition,
- silviculture, and
- pest and diseases management.

In addition, growth and yield of the plantations is monitored by the Mapping and Inventory Section, and environmental and socioeconomic issues are studied by the Land Development section. Pulping properties are studied separately by Enso's Research Centre in Finland. Pulping studies have included several laboratory assessments as well as factory-scale production runs. For factory tests, 25 000 m^3 of acacia wood from South Kalimantan was delivered to Enso's Kemijarvi pulpmill in 1996.

Urgent research and development topics in tree improvement deal with the development of own seed stands and seed orchards. These are expected to provide seed with better adaptation and resistance, and later genetic material with higher growth potential. Old mangium provenance trials and several high-performing plantations have been heavily thinned for seed production. For seed orchard development, older stands and trials have been screened for candidate plus-trees, and air-layering and cutting propagation techniques have been tested. In future tree breeding the improvement of wood properties will be given much attention. Acacia hybrids are considered to have high potential and several mixed plantations have been established to be used for hybrid development. Alternative species are also sought, and ideally such species should be suitable for pulping with mangium without adversely affecting pulp quality.

The soil and nutrition studies concentrate at present on fertilisation regimes. Special attention is paid on balanced nutrition, thus avoiding any nutritional disorders. In the long run one of the main issues is the maintenance of soil productivity over successive rotations by appropriate site preparation, fertilisation and harvesting.

Site preparation methods for slopes and bush areas need to be developed. Seedling production will be rearranged and refinement of the production systems requires detailed studies. Seedling quality problems are most evident with *A. crassicarpa* as seedlings often seem to lack apical dominance during the first months after planting.

The pest and disease problems identified warrant increased efforts in pest and disease monitoring and management. As plantations get older, it is possible that decays affecting total volume or pulp yield will become more common. Such problems would bring a heavy costs burden in increased volume in harvesting and wood transportation.

Conclusions and Future Prospects

Long-term availability of sufficient land for the continuous growth of plantations on a socially sustainable basis will determine the success of the project.

Currently the project is running technically smoothly. The social framework is not causing any major problems. On the contrary, land availability at the village level has been improved as the project activities and the acacia trees have become more widely known. Farmers seem be eager to join the program, and on the other hand there is a growing interest in establishing private acacia plantations. Scattered and badly managed private plantations are, however, not encouraged, since they may result in failures that would surely be harmful for the image of the company and discourage the use of acacias.

On a provincial level, land use pressures from the agricultural sector, especially oil-palm companies, may have negative effects on the availability of suitable additional planting areas for large-scale acacia plantations.

The economic feasibility of the project depends largely on future growth rates and wood quality. The growth rates should allow a 6–8 year rotation, and a final harvest of about 200 m^3/ha of commercial wood. Presently such growth rates seem possible. However, there are some potential threats, too. Main biological threats are pests and diseases, and potential decrease in soil fertility over successive rotations. Changes in the local or regional climate are also potential risks. If the climate becomes drier, adapted acacias may still be available; but fire would then become a much bigger problem than today, and rivers would be less useful for transportation.

References

Ådjers, G. and Srivastava, P.B.L. 1993. Nursery practices. In: Awang, K. and Taylor, D., ed., *Acacia mangium*, Growing and Utilisation. MPTS Monograph Series No. 3, Bangkok, Thailand, Winrock International and FAO, 75–99.

Arisman, H. and Havmoller, P. 1994. Seed supply strategy for a pulpwood plantation project in Southern Sumatra. In: Drysdale, R.M., John, S.E.T. and Yapa, A.C., ed., Proceedings: International Symposium on Genetic Conservation and Production of Tropical Forest Tree Seed. ASEAN-Canada Forest Tree Centre Project, Muak-Lek, Saraburi, Thailand.

Hadi, S. and Nuhamara, S.T. 1996. Diseases of species and provenances of acacias in West and South Kalimantan, Indonesia. In: Old, K.M., Lee, S.S. and Sharma, J.K., ed., Diseases of Tropical Acacias. Proceedings of an International Workshop held at Subanjeriji, South Sumatra, 28 April–3 May, CIFOR Special Publication, Bogor.

Hippi, I. and Rissanen, H. 1996. Modern technology in forest management planning: Ensofris and Ensovideo. In: Otsamo, A., Kuusipalo, J. and Jaskari, H., ed., Reforestation: Meeting the Future Industrial Wood Demand. Proceedings of the workshop held in Jakarta, 30 April–1 May, Reforestation and Tropical Forest management Project (ATA-267), Ministry of Forestry of Indonesia, Enso Forest Development Oy Ltd and FINNIDA, 42–54.

Kerski, A. 1995. Pulp, paper and power. How an industry reshapes its social environment. The Ecologist, 25 (4), 142–149.

Laurila, R. 1995. Wood properties and utilisation potential of eight fast-growing tropical plantation tree species. Journal of Tropical Forest Products, 1 (2), 209–221.

Otsamo, A., Adjers, G., Hadi, T.S., Kuusipalo, J., Tuomela, K. and Vuokko, R. 1995. Effect of site preparation and initial fertilisation on the establishment and growth of four plantation tree species used in reforestation of *Imperata cylindrica* (L.) Beauv. dominated grasslands. Forest Ecology and Management, 73, 271–277.

Otsamo, A., Nikles, D.G. and Vuokko, R. 1996. Species and provenance variation of candidate acacias for afforestation of *Imperata cylindrica* grasslands in South Kalimantan, Indonesia. In: Dieters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry, Proceedings of QFRI-IUFRO Conference, Caloundra, Queensland, Australia. 27 October–1 November, Queensland Forestry Research Institute, Gympie.

Potess, F. 1996. Integrated HTI-system. A paper presented in the workshop, Finnish Forestry and the Forests of the World, Helsinki, October 1996, Enso Forest Development Ltd, Imatra, Finland.

Turnbull, J.W., ed., 1987. Australian Acacias in Developing Countries. Proceedings of an international workshop held at the Forestry Training Centre, Gympie, Queensland, Australia, 4–7 August. ACIAR Proceedings No. 16, 196 p.

Turnbull, J.W., ed., 1991. Advances in Tropical Acacia Research. Proceedings of an international workshop held in Bangkok, Thailand, 11–15 February. ACIAR Proceedings No. 35, 234 p.

Turvey, N.D. 1996. Growth at age 30 months of *Acacia* and *Eucalyptus* species planted in *Imperata* grasslands in Kalimantan Selatan, Indonesia. Forest Ecology and Management, 82, 185–195.

Vuokko, R. 1996. Species selection for the afforestation of *Imperata cylindrica* (L.) Beauv. grasslands in Indonesia. PhD thesis, Department of Crop Science, Horticulture and Forestry, Faculty of Agriculture, National University of Ireland.

Wong, C.Y. 1993. Acacias in industrial development: experience in Sumatra. In: Awang, K. and Taylor, D.A., ed., Acacias for Rural, Industrial and Environmental Development. Proceedings of the second meeting of the Consultative Group of Research and Development of Acacias (COGREDA), Udorn Thani, Thailand, February 15–18, Bangkok, Thailand. Winrock International and FAO.

Morphological Variation in *Acacia tumida* and Implications for its Utilisation

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Abstract

Acacia tumida has a wide natural distribution in north west Australia over a wide range of sites and environmental conditions. The species exhibits considerable geographically-based morphological variation. It ranges from a low, spreading shrub in desert areas to small tree form in wetter environments, and there is geographic variation in phyllode size, shape and colour. Eighteen seedlots from across the natural distribution were tested in a provenance trial at Kununurra, Western Australia, to assess the extent to which morphological variation was genetically controlled. Based on growth habit and phyllode size and shape, three variants were recognised: a tree form (Variant 1); a multistemmed shrub form (Variant 2); and a narrow phyllode form (Variant 3). The variants are described and a botanical key for their identification presented. A summary of climate and soil data for the natural occurrences of the variants is given, and their significance in relation to domestication programs briefly discussed.

THE HOT tropical dry zone of north-west Australia supports *Acacia tumida* F. Muell. ex Benth. This species is endemic to the area, where it occurs over a wide range of sites and environmental conditions. Natural occurrences exhibit considerable morphological variation which appears to be geographically based. Under desert conditions with a mean annual rainfall of 300 mm, it occurs as a low, multistemmed shrub with small phyllodes. In wetter areas with a 800 mm rainfall, it occurs as a single-stemmed small tree with large phyllodes and reaches a maximum height of about 15 m. Its variability has been noted by Thomson (1992) who suggested that it probably includes at least two taxa, and by Maslin and McDonald (1996) who suggested that four variants probably warrant taxonomic recognition. Kenneally et al. (1996) also refer to an uncommon, prostrate form of *A. tumida* occurring on coastal cliffs north of Broome in Western Australia.

A number of tropical dry-zone *Acacia* species, distinguished on subtle morphological differences, have been recognised in recent taxonomic revisions (McDonald et al. 1996). Many of these newly recognised species have performed quite differently from one another when trialed together in domestication programs. Similar taxonomic differences, if found among the populations currently described as *A. tumida*, would be of value in planning domestication programs involving this species.

In recent years *A. tumida* has performed well in developing countries that have trialed Australian species of *Acacia* for multipurpose use on difficult sites. In tropical dry west Africa, the shrub form showed promise as a source of fuelwood, edible seeds, as a windbreak, and for erosion control (Turnbull 1986; Thomson 1992). In coastal south-east Vietnam the tree form grew well on infertile sands with a mean annual rainfall of 700 mm (Harwood et al., these Proceedings). However, no comprehensive provenance trials of the species had been undertaken.

To help understand geographically-based variation in the species, a provenance trial representing a range of populations of *A. tumida* was established near Kununurra, Western Australia. Its main aim was to assess the extent to which morphological differences was genetically based, by growing a range of provenances in a common environment.

Materials and Methods

Observations on the stature and form of adult plants in the 18 natural provenances tested in the trial, and

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the soils on which they occur, were made by Australian Tree Seed Centre (ATSC) collecting teams (McDonald and Morse 1994). Table 1 shows the seedlots trialed, the number of families comprising each bulk seedlot, and the approximate mean annual rainfall for each site (ABS 1992). Figure 1 shows the geographic origins of the seedlots, which sample most of known geographic range of the species, rainfall isohyets for the region and the location of the trial site. The Kununurra trial site (15°47′S, 128°44′E, altitude 46 m) receives a mean annual rainfall of 813 mm which is strongly seasonal, falling mostly in December–March. Monthly mean maximum temperatures are 30–39°C, and monthly mean minima 15–26°C. The soil at the site is a slightly acidic, red sandy loam (pH 5.5–6.5). Natural stands of *A. tumida* are common on this soil type in the area.

The trial was established during the wet season in January–February 1994. Thirteen of the provenances were tested in a randomised complete block design comprising 3 complete replicates of 13 plots, with a plot size of 12 trees (2 rows of 6). Spacing between plants was 4 × 4 m. Five provenances had poor survival during the nursery stage and had insufficient numbers for inclusion in the replicated trial, so smaller numbers of seedlings from these provenances were planted in the external buffer rows around the trial. Each plant received 100 g of triple superphosphate fertiliser at planting, applied in two slots 50 cm either side of the planting position.

In July 1996, 2.5 years after planting, height and crown diameters of the 13 provenances in the replicated trial were measured and observations were made on the morphology of all 18 provenances. Most plants were either in bud, or flowering or producing pods at the time of assessment. Plot means for height and crown width were subjected to analysis of variance using the statistical package Genstat 5.3 (Payne et al. 1987).

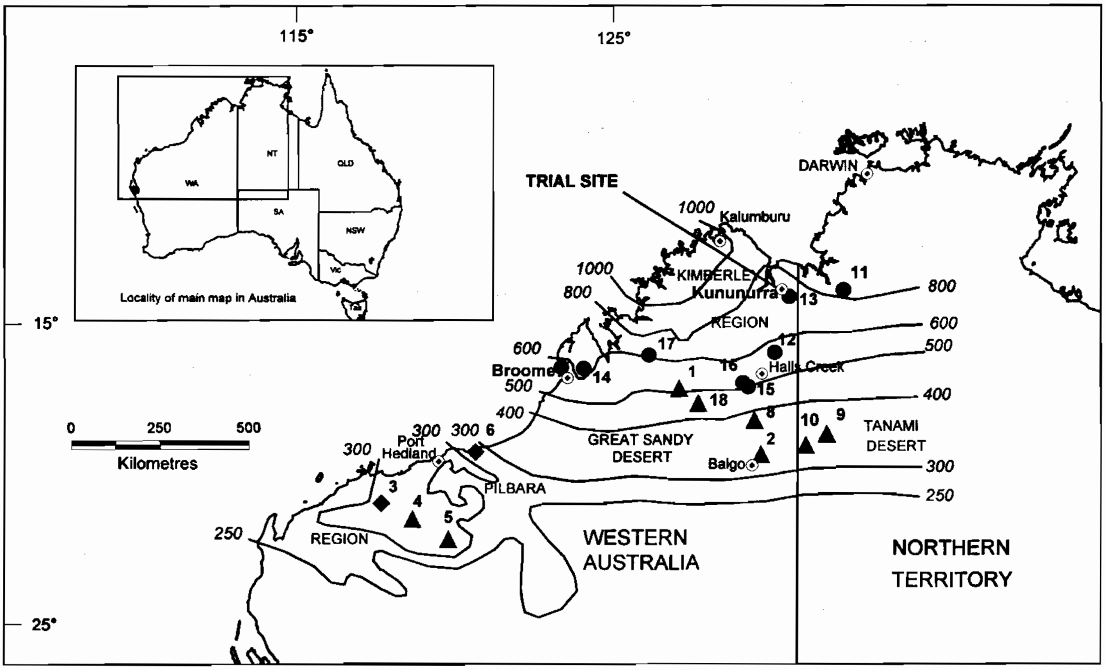
Results

Three morphological variants of *A. tumida* were evident in the trial. They were distinguished on habit and phyllode differences, and are referred to here as Variants 1, 2 and 3. Table 2 shows the 18 seedlots assigned to their respective variant number, the mean height and crown width, phyllode dimensions and pruinosity status. There were highly significant ($P < 0.001$) differences in height and crown-width among the 13 seedlots tested in the replicated trial. Provenances of Variant 1 all had significantly greater heights than those of Variant 2. The distinctive characteristics of the variants evident in the trial and in their natural occurrences are given below, and a draft botanical key to the variants is provided in Figure 2.

Table 1. *Acacia tumida* seedlots represented in the Seeds of Australian Trees (SAT) provenance trial at Kununurra, Western Australia. (The seedlot number, provenance name, the number of seed trees bulked to comprise the seedlot, the geographic coordinates, and the approximate mean annual rainfall at each site were derived from 1992 ABS records.)

No.	Seedlot	Provenance	No. of trees	Lat. (°S)	Long. (°E)	Mean annual rainfall (mm)
1	14661	Fitzroy River	20	18°19′	125°37′	500
2	15745	Balgo	32	20°09′	127°57′	300
3	16765	Portland River[1]	55	21°30′	117°09′	300
4	16768	Hooley[1]	20	21°56′	118°02′	350
5	16775	Dingo Creek	50	22°30′	119°03′	300
6	16808	Pardoo	46	20°05′	119°49′	300
7	17159	N Broome[1]	10	17°44′	122°15′	600
8	18220	Carranya	10	19°12′	127°46′	350
9	18221	Talbot Well	10	19°35′	129°50′	300
10	18222	Tanami	10	19°54′	129°14′	300
11	18224	Sandy Creek	10	15°36′	130°18′	800
12	18226	Bungle Bungle	6	17°20′	128°20′	600
13	18545	Kununurra	10	15°47′	128°45′	800
14	18653	E Broome	8	17°46′	122°53′	600
15	18790	Rockhole Creek[1]	10	18°17′	127°35′	500
16	18802	Moola Bulla	15	18°11′	127°26′	500
17	18810	Windjana[1]	5	17°24′	124°45′	800
18	18928	Christmas Creek	10	18°44′	126°10′	400

[1] Seedlots not included in replicated trial but planted in perimeter rows



Legend

Variant 1 (●)
11 18224 Sandy Creek
12 18226 Bungle Bungle
13 18545 Kununurra
14 18653 E Broome
15 18790 Rockhole Creek
16 18802 Moola Bulla
17 18810 Windjana
7 17159 N Broome

Variant 2 (▲)
1 14661 Fitzroy River
2 15745 Balgo
5 16775 Dingo Creek
4 16768 Hooley
8 18220 Carranya
9 18221 Talbot Well
10 18222 Tanami
18 18928 Christmas Creek

Variant 3 (◆)
3 16765 Portland River
6 16808 Pardoo

Figure 1. The geographic origin of *Acacia tumida* seedlots used in the provenance trial at Kununurra and rainfall isohyets for the region (ABS 1992). The location of the trial site at Kununurra is also shown.

1 Adult phyllodes less than 12 cm long, usually dimidiate[1]; multistemmed shrub from ground level, 1–3 m tall; producing basal coppice regrowth following fire .... **Variant 2**
1: Adult phyllodes mostly greater than 12 cm long, usually falcate[2]; single-stemmed trees or arborescent shrubs 3–15 m tall; non-coppicing following fire .... Go to 2 (below)
    2 Adult phyllodes 1–2.5 cm wide, 10–15 cm long; phyllodes and branchlets lightly pruinose[3] .... **Variant 3**
    2: Adult phyllodes normally 3–6 cm wide, 9–19 cm long; phyllodes, branchlets and stems moderately to strongly pruinose (or sometimes non-pruinose) .... **Variant 1**

[1]**Dimidiate:** divided into halves (Harris and Harris 1994) used to refer to the shape or symmetry of a phyllode when it has a straight lower margin and a curved upper margin imparting a half-circular appearance.

[2]**Falcate:** curved phyllodes, broadest at the middle, tapered at both ends (Maslin and McDonald 1996).

[3]**Pruinose:** with a white coating (waxy or powdery bloom) on the surface (Maslin and McDonald 1996). Pruinose forms of *A. tumida* have blue- or grey-green phyllodes, whitish branchlets, stems and upper branches. Non-pruinose forms have green to glossy green phyllodes, yellowish branchlets and greyish stems and upper branches.

Figure 2. Key to the provisional variants of *Acacia tumida*.

Variant 1 (tree form)

Distinctive characteristics in the trial

The habit of Variant 1 was mostly single-stemmed trees (provenance range for mean height was 3.36–4.59 m), with crown width less than plant height. Adult phyllodes were falcate, 9–19 cm long and 3–6 cm wide. Pruinose individuals were most common. These had phyllodes, branchlets and upper branches of the crown ranging from moderately to strongly pruinose. Both pruinose and non-pruinose plants were present in the Bungle Bungle provenance. Phyllode length and width varied considerably between provenances.

Characteristics of natural populations

Variant 1 normally occurs as a single-stemmed tree, 5–15 m tall, primarily in open woodlands. Adult phyllode dimensions and pruinosity status match those evident in the trial. The tallest plants occur in the Kununurra region where 15 m trees with clear boles up to 60% of tree height are found. It is fire-sensitive and does not produce coppice regrowth following damage by fire. Its natural occurrence is primarily in the southern Kimberley region and adjacent Northern Territory. The region of occurrence receives a mean annual rainfall of 500–800 mm, mostly falling during the wet season December–March with seven consecutive months receiving less than 40 mm per month. There are outlying northern populations (e.g. Kalumburu) which receive mean annual rainfall of around 1000 mm. Soil types include acidic red, sandy loams and sandy alluvia with a pH 5.5–6.5.

Variant 2 (coppicing shrub form)

Distinctive characteristics in the trial

All plants were spreading shrubs, multistemmed from ground level (provenance range for height mean 1.29–2.73 m), and crown width greater than plant height. Adult phyllodes were commonly dimidiate, 6–12 cm long and 2.5–3.5 cm wide. Plants from nearly all provenances were lightly to moderately pruinose; however the Christmas Creek provenance yielded both pruinose and non-pruinose individuals. Variant 2 was phenologically more advanced in flowering than Variants 1 and 3 as it had

Table 2. Seedlots of *Acacia tumida* grown in the provenance trial at Kununurra showing mean height, crown width, adult phyllode size, pruinosity status, and variant type.

No.	Seedlot	Provenance	Mean height (m)	Mean crown width (m)	Pruinosity
Variant No. 1 (Adult phyllode length × width = 9–19 × 3–6 cm)					
7	17159	N Broome	nd[1]	nd[1]	moderate
11	18224	Sandy Creek	3.93	3.12	strong
12	18226	Bungle Bungle	3.36	2.99	mod. or nil
13	18545	Kununurra	4.59	3.43	strong
14	18653	E Broome	3.72	2.82	strong
15	18790	Rockhole Creek	nd[1]	nd[1]	moderate
16	18802	Moola Bulla	4.20	2.98	moderate
17	18810	Windjana	nd[1]	nd[1]	moderate
Variant No. 2 (Adult phyllode length × width = 6–12 × 2–3.5 cm)					
1	14661	Fitzroy River	2.71[2]	2.53	strong
2	15745	Balgo	1.56[2]	2.59	light
4	16768	Hooley	nd[1,2]	nd[1]	moderate
5	16775	Dingo Creek	2.73[2]	3.05	moderate
8	18220	Carranya	1.81[2]	2.61	light
9	18221	Talbot Well	1.52[2]	2.54	light
10	18222	Tanami	1.53[2]	2.14	moderate
18	18928	Christmas Creek	1.29[2]	2.52	mod. or nil
Variant No. 3 (Adult phyllode length × width = 10–15 × 1–2.5 cm)					
3	16765	Portland River	nd[1]	nd[1]	light
6	16808	Pardoo	3.04	3.32	light
Significance of differences between provenances			$P < 0.001$	$P < 0.001$	
Standard error of difference of means			0.31	0.37	

[1] Provenances marked 'nd' for height and crown width were not planted in the replicated trial, but were included in the perimeter rows
[2] multistemmed at ground level

Table 3. ATSC seedlots of *Acacia tumida* provisionally reassigned as Variant 1, 2 or 3. (Summaries of growth habit, natural climate and soil texture/pH range of the three variants are shown.)

	ATSC seedlots	Habit	Climate[1]	Soil texture and pH
Variant 1	14661, 17046, 17047, 17159, 17166, 17170, 17181, 17500, 18005, 18225, 18226, 18545, 18653, 18668, 18741, 18790, 18797, 18802, 18810, 18818, 18819, 18823, 18827, 19015, 19016, 19021, 19026, 19036	Tree 5–15 m tall, fire-sensitive	Rainfall: 500–800 mm per year; temp. range: min. 11–16°C max. 33–40°C	Sand, sandy loam; pH 5.0–6.5
Variant 2	11496, 11514, 11522, 14673, 14675, 15739, 15745, 16768, 16775, 16797, 16806, 17035, 18220, 18221, 18222, 18223, 18646, 18816, 18928, 19032, 19087, 19181, 19197	Low shrub, multistemmed from ground level, 1–2 tall, produces basal coppice regrowth following fire	Rainfall: 300–400 mm per year; temp. range: min. 6–13°C max. 38–40°C	Mainly deep aeolian sands; pH 5.5–7.5
Variant 3	11505, 16761, 16765, 16808, 17964, 19518, 19524	Arborescent shrub, 2–5 m tall, fire-sensitive	Rainfall: 300 mm per year; temp. range: min. 12–14°C max. 36–37°C	Sand or clay loam or gravelly clay; pH 6.5–9.0

[1] Rainfall estimated from ABS (1992). Temperature range: min. = mean daily minimum for the coolest month; max. = mean maximum range for the hottest month (ranges estimated from regional station records provided by Bureau of Meteorology 1988).

already produced mature pods while the others were still at the bud or open-flower stage.

Characteristics of natural populations

Variant 2 occurs as a shrub, multistemmed from ground level with low, spreading branches, and produces coppice regrowth from ground level following damage by fire. Mature plants are typically 1–3 m tall, and crown width is greater than height. Phyllode dimensions and pruinosity match those observed in the trial. Some natural populations such as Christmas Creek and those near Broome have both pruinose and non-pruinose forms represented. It occurs in the Tanami Desert and Great Sandy Desert regions extending south to the Pilbara region and north-west to the Broome region. It is often associated with tussock-forming spinifex (*Triodia* spp.) grasslands. Regions of natural occurrence receive mean annual rainfall of 300–400 mm falling mostly in December–February, with nine consecutive months receiving less than 40 mm per month. It grows on red sands or red sandy loams which are slightly acidic (pH 5.5–6.5) and often derived from wind-formed (aeolian) dune systems.

Variant 3 (narrow phyllode Pilbara form)

Distinctive characteristics in the trial

A low-branching, upright shrub with crown width about equal to plant height. Adult phyllodes were falcate, lightly pruinose, 10–15 cm long and consistently relatively narrow 1.0–2.5 cm wide. Branchlets and upper crown branches are also lightly pruinose.

Characteristics of natural populations

Variant 3 occurs as a multistemmed shrub to 5 m tall with upright branches and a very short bole. Adult phyllode dimensions and pruinosity status match those evident in the trial. It is fire-sensitive and does not coppice following fire. It is known from riparian habitats in coastal and subcoastal areas of the Pilbara region. The region receives a mean annual rainfall of around 300 mm most of which falls during January–March with nine months of the year receiving less than 25 mm per month. Variant 3 grows on alkaline red-brown clay loam (pH 8.0–9.0), or red sand (pH 6.0–7.0) derived from alluvium. Field studies are required to further assess its ecology and the extent of its distribution.

Juvenile, intermediate and adult phyllodes

Juvenile, intermediate seedling and sapling phyllodes attain greater dimensions than adult phyllodes, particularly in Variant 1. The change to smaller adult phyllodes occurs at about two years of age. All three variants have juvenile phyllodes covered in dense, erect hairs. Intermediate and adult phyllodes produced after to age 6–12 months are smooth and hairless.

Inflorescences, pods and seeds

Inflorescence and pod characters assessed from plants in the trial did not appear to differ significantly between variants. However, examination of ATSC seedlots revealed a trend for Variant 2 to have larger seeds (7–9 mm long, 5–6 mm wide) than Variants 1 and 3 (5–7 mm long, 4–5 mm wide). Further study of inflorescence and pod/seed characteristics is required to assess whether significant differences exist between variants.

Discussion

Differences in habit and phyllode types evident in natural populations were maintained in the provenance trial, indicating that they are largely under genetic control rather than being induced by the different natural environments. The morphological differences between variants are based primarily on habit and phyllode length and width; phyllode venation, inflorescence and pod characteristics are similar. The variants are therefore likely to warrant formal taxonomic recognition at infraspecific level rather than species level. Field studies of natural populations are required to further assess the taxonomy of the variants, particularly in the Pilbara region where Variants 2 and 3 are both represented.

Pruinosity within the variants appears to have little taxonomic significance. Variants 1 and 2 are commonly pruinose, although progeny of pruinose parents from Christmas Creek and Bungle Bungle provenances produced both pruinose and non-pruinose forms in the trial. There was evidence to suggest that pruinosity may also be environmentally induced. Plants of Variant 2 from their natural habitat (e.g. Balgo and Talbot Well) are strongly pruinose (McDonald and Morse 1994), in marked contrast to plants grown at the trial site which were lightly pruinose.

The biological species concept is fundamental to the domestication process, but a botanical name can often become accepted and viewed as a static entity regardless of the extent of the initial research undertaken. Contemporary taxonomic revisions confirm 'good' existing taxa and have practical relevance in the recognition of new taxa. This study has enabled the ATSC to provisionally reassign *A. tumida* seedlots to Variants 1, 2 or 3 in advance of formal taxonomic treatment. Domestication programs involving *A. tumida* can now benefit by focusing on the variant best suited to their target environment and end-use, thus making more effective use of available resources.

Acknowledgments

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References

ABS 1992. Western Australian Year Book No. 29. Australian Bureau of Statistics, Western Australian Office, Australian Government Publishing Service, 3–2.

Bureau of Meteorology 1988. Climatic Averages Australia. Australian Government Printing Service, Canberra, 532 p.

Harris, J.G. and Harris, M.W. 1994. Plant Identification Terminology. An Illustrated Glossary. Spring Lake Publishing, Spring Lake, Utah, 197 p.

Kenneally, K.F., Edinger, D.C. and Willing, T. 1996. Broome and Beyond: Plants and People of the Dampier Peninsula, Kimberley, Western Australia. Department of Conservation and Land Management, Como, Western Australia, 256 p.

Maslin, B.R. and McDonald, M.W. 1996. A Key to Useful Australian Acacias for the Seasonally Dry Tropics. CSIRO, Canberra, 80 p.

McDonald, M.W., Maslin, B.R. and Harwood, C.E. 1996. Taxonomic studies of tropical dry zone *Acacia* species facilitate their domestication. In: Deiters, M.J., Matheson, A.C., Nikles, D.G., Harwood, C.E. and Walker, S.M., ed., Tree Improvement for Sustainable Tropical Forestry. Proceedings of QFRI-IUFRO Conference, Caloundra, Queensland, Australia, 27 October–1 November, Queensland Forestry Research Institute, Gympie, 96–98.

McDonald, M.W. and Morse, G.J. 1994. Seed Collections of Dry-zone Acacias in the Kimberly Region and the Tanami Desert, 1993. Unpublished report, Australian Tree Seed Centre, Canberra, 41 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. and White, R.P. 1987. Genstat 5 Reference Manual. Clarendon, Oxford, 749 p.

Thomson, L.A.J. 1992. Australia's subtropical dry-zone *Acacia* species with human food potential. In: House A.P.N. and Harwood C.E., ed., Australian Dry-zone *Acacias* for Human Food. CSIRO, Canberra, 3–36.

Turnbull, J.W., ed., 1986. Multipurpose Australian Trees and Shrubs: Lesser-known Species for Fuelwood and Agroforestry. ACIAR Monograph No. 1, Australian Centre for International Agricultural Research, Canberra, 316 p.

Use of Acacias for Wood-Cement Composites

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Abstract

Composites of cement and wood-wool are widely used for building construction in many developing countries. They are simple to manufacture and can utilise relatively small diameter pulp logs and logging residues. Wood from the extensive acacia plantations in South East Asia may be suitable for the manufacture of wood-wool cement composites, but to date there have been relatively few studies that have examined their feasibility. In this paper the use of acacias in wood-cement composites is reviewed, and preliminary findings on the compatibility of some commonly planted tropical and temperate acacias with cement are presented. These results are compared with those using coniferous wood species of very high and very low compatibility with cement, and with an important tropical eucalypt species. Heartwood samples from the tropical acacias were less compatible with cement than those of the temperate acacia species in that they greatly inhibited cement setting. The sapwood samples of the tropical acacias were generally compatible with cement, whereas those of the temperate species were not. Acacia heartwood (and sapwood of some species) probably contains soluble compounds which chemically inhibit the setting of cement. To overcome these effects, pre-soaking of wood-wool (to remove inhibitory compounds) and/or the use of cement hardening accelerators are often required to manufacture wood-wool cement panels from acacias. Other possible means of improving the compatibility of acacia wood with cement are: selecting and growing acacias which contain less heartwood, and whose wood is more compatible with cement; using younger trees which contain less heartwood; and using a cement substitute (rice-hull ash) which may be less susceptible to the inhibitory compounds present in acacia heartwood.

AUSTRALIAN acacias are widely planted throughout Southeast Asia, because of their ability to colonise and grow rapidly on low-nutrient and weed-infested sites, and to produce large volumes of wood, mainly for use as pulp and fuelwood (Gunn and Midgley 1991).

Wood-wool cement composite panels are widely used in many developing countries as a low cost building material. They can be fabricated locally using pulp-quality wood and logging residues, cement and water. The panels are resistant to termites, decay, water and fire, and they have good machining, nailing, and sound-proofing characteristics. Acacia plantation wood could potentially be used by wood-wool cement panel industries, but to date there have been few studies of the compatibility of acacia wood with cement and of the manufacture of wood-wool cement panels from acacias.

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A range of low molecular weight chemical compounds in wood constrain the use of many wood species for wood-cement composites. Such compounds include soluble carbohydrates, sugars and extractives which may be leached from the wood in the alkaline environment of cement, inhibiting the cement-setting process and resulting in boards of inferior strength and durability (Biblis and Lo 1968). Methods of ameliorating the effects of these extraneous components on cement include:

- extraction of wood to remove inhibitory compounds;
- storage or ponding of wood allowing micro-organisms to metabolise sugars;
- the use of rapid-hardening cements or cement-hardening accelerators such as calcium chloride and aluminium sulfate; and
- adding rice-hull ash or fly ash to the cement to make it less susceptible to the inhibitory effects of soluble wood components.

This paper reviews the suitability of acacias for wood-cement composites and presents some preliminary results on the compatibility of a range of important tropical and temperate acacias with cement. These results are compared with:

- two wood species known for their high compatibility with cement (*Picea abies* (L.) Karst. and *Pinus radiata* D. Don.);
- one species known for its extreme incompatibility (*Larix europea* D.C.); and
- an important plantation eucalypt species, *Eucalyptus pellita* F. Muell.

Possible ways of ameliorating the inhibitory effects of acacia wood on cement-setting are discussed.

Literature Review

Wood-cement products using acacia wood

Sudin and Ibrahim (1990) found that cement-bonded particle boards could be made to Malaysian standard (MS 934, 1986) using four-year-old *Acacia mangium* Willd. at a wood:cement ratio of 1:3 without chemical additives. Board properties could be improved by adding 2% aluminium sulfate and reducing the wood:cement ratio to 1:2.5. Cement-bonded particle boards with satisfactory mechanical properties were made using various sized flakes of *Acacia mearnsii* de Wild. and Portland cement, apparently without the use of accelerators (Teixeira and Pereira 1987).

Flawes and Chittenden (1967) found that *A. mearnsii* could be used to make commercial quality wood-wool cement boards, providing that the wood-wool was soaked in a 1% calcium chloride solution before mixing with cement. Calcium chloride and other mineral salts, if added to the wood, cause rapid setting of cement around wood surfaces before water-soluble components can migrate from the wood and inhibit cement setting (Pazner 1978). A 3% solution was recommended to obtain boards with reduced surface friability. Sulastiningsih et al. (1990) found that it was necessary to soak *A. mangium* wood-wool in cold water for 24 hours before making wood-wool cement boards. The addition of calcium chloride and calcium hydroxide further improved board properties.

Based on the pulling force required to remove test sticks set in cement in a laboratory study, Rahim and Ong (1983) rated *A. mangium* as unsuitable for use in wood-cement composites. Its bonding strength was only moderately improved by preliminary soaking with aluminium sulfate or calcium chloride.

Extractives in acacia wood and their effects on Portland cement

Yasin and Qureshi (1989) suggested that the amount of hot-water-soluble extractives in wood species is a good indicator of their compatibility with cement. This suggestion was based on the finding that the strength of wood-cement particle boards was inversely proportional to the extractive content of the wood used. Boards made from *Acacia nilotica* (L.) Delile, with an extractive content of 7.8%, had only moderate strength, whereas *Populus alba* L. with the lowest extractive content (2.4%) produced the strongest boards.

Other studies suggest that in the case of acacias, the level of extractives may not be indicative of the cement-inhibiting characteristics of the wood. The amount and chemical nature of extractives varies greatly between species, and no one single compound can account for variation in wood-cement compatibility; Hachmi and Moslemi (1989) found that *A. mearnsii* was highly incompatible with cement, even though its wood was relatively low in hot-water-soluble extractives. Thus its extractive content was only 7.8% compared with other equally incompatible species, *Quercus suber* L. and *Stipa tenacessima* L. which had higher extractive contents (>12%). This suggests that the chemical composition of extractives plays a major role in influencing the compatibility of wood with cement; Hachmi and Moslemi found that extractive content itself could explain only 50% of the variation observed in wood-cement compatibility. They identified a threshold level of extractives (7%) above and below which woods were classified as either 'incompatible' or 'compatible' with cement, respectively.

Tachi et al. (1989) found that *A. mangium* had a similar hot-water-extractive content to three other species: *Albizia falcataria* (L.) Fosberg, *Eucalyptus deglupta* Bl. and *Gmelina arborea* L. However, it inhibited cement hydration significantly. They subsequently isolated and identified two teracacidin-type flavonoids which had a similar effect. They suggested that other highly inhibitory compounds were also likely to be present in the heartwood of *A. mangium*.

Materials and Methods

Wood flour was prepared for 11 wood species:

- tropical acacias *A. auriculiformis* Cunn. ex Benth., *A. aulacocarpa* Cunn. ex Benth., *A. crassicarpa* Cunn. ex Benth., and *A. mangium* (six-year-old Papua New Guinea/Irian Jaya Provenance grown at Atherton District, Queensland, Australia);

- temperate acacias *A. dealbata* Link, *A. melanoxylon* R.Br., *A. mearnsii*;
- *Eucalyptus pellita* (six-year-old Papua New Guinea/South West Provenance grown at Atherton District, Queensland, Australia); and
- the coniferous species *Picea abies*, *Larix europea*, and *Pinus radiata* (38-year-old Monterey Provenance grown at Pierces Creek, Australian Capital Territory, Australia).

Wood blocks were reduced to matchstick-sized pieces using a hatchet, and coarsely ground in a 'Junior' laboratory mill to particles approximately 1 mm in diameter. These were then further ground in a Wiley mill to 20–40 mesh size. Heartwood and sapwood flour was prepared separately for all acacias and *E. pellita*, but no sapwood was available for *A. dealbata*. In the coniferous species, the heartwood and sapwood could not be differentiated. Wood flour was stored in open jars in a conditioning room at 20 ± 1°C and 65 ± 5% relative humidity for at least one week until ready for use. Just before use, a separate sample was taken for each flour to determine its equilibrium moisture content.

Two 15 g (oven dry basis) samples of wood flour from the heartwood and sapwood of each species (except *A. dealbata*) were used. Each sample was placed in a sealable *Dalgrip* polythene bag and evenly mixed with 200 g of fresh, dry, Portland cement (Blue Circle Southern brand, batch 199/97). Distilled water (90.5 ml) at 20°C was then added to the wood and cement, and the slurry was hand-kneaded for 2–3 minutes until evenly mixed. Two control samples containing only cement and 80 ml of water were similarly prepared. The amounts of cement, wood-flour and water used in the experiment accord with the recommendations of Weatherwax and Tarkow (1964).

Immediately after mixing a sample, the tip of a temperature thermocouple (Type J) was taped to the bag and enclosed within the body of the cement mix by folding and then securing the bag and contents around it. The bag was then placed in a polystyrene cup and sealed within a large thermos flask (Figure 1). A cement hydration temperature measuring apparatus capable of measuring the heat of hydration of six wood-cement mixtures over a 23-hour period recorded temperatures at 15-minute intervals. The curves were smoothed by progressive averaging and plotting of every three readings. All experiments were undertaken in a conditioning room at 20 ± 1°C and 65 ± 5% humidity. The ratio of area under each hydration curve from 0–23 hours to that of the cement control, the C_A factor, was used to assess the compatibility of the different wood species with cement (Hachmi et al. 1990).

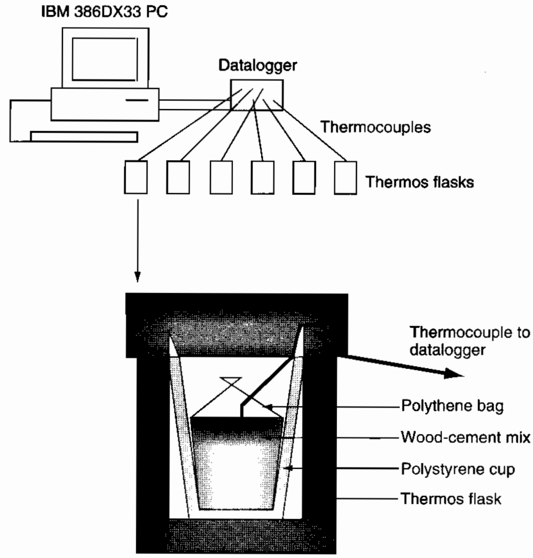

Figure 1. Schematic diagram of cement hydration temperature measurement apparatus.

Results and Discussion

The effects on cement hydration of both compatible woods (*A. mangium* sapwood and *P. abies*) and incompatible woods (*A. mangium* heartwood and *L. europea*) are shown in Figure 2. Cement containing wood-flour from inhibitory wood species showed only a slight initial temperature rise within the first two hours, with no further exothermic reaction over the test period of 23 hours. Compatible wood types did not prevent cement hydration, although the maximum hydration temperature ($T_{max.}$) compared with pure cement was reduced and the time taken to reach $T_{max.}$ was greater than that for pure cement. Both $T_{max.}$ itself and the time to reach $T_{max.}$ influence the cement hydration curve shape and hence the C_A factor compatibility index (Hachmi et al. 1990).

Compatibility indices (i.e. C_A factors) of *E. pellita*, of the acacia species sapwood and heartwood (separately), and of the coniferous species sapwood and heartwood (combined) are shown in Table 1. Hachmi and Moslemi (1989) divided wood species into three compatibility groupings across the range of C_A factor values:

- incompatible (<28%),
- moderately compatible (28–68%), and
- compatible (>68%).

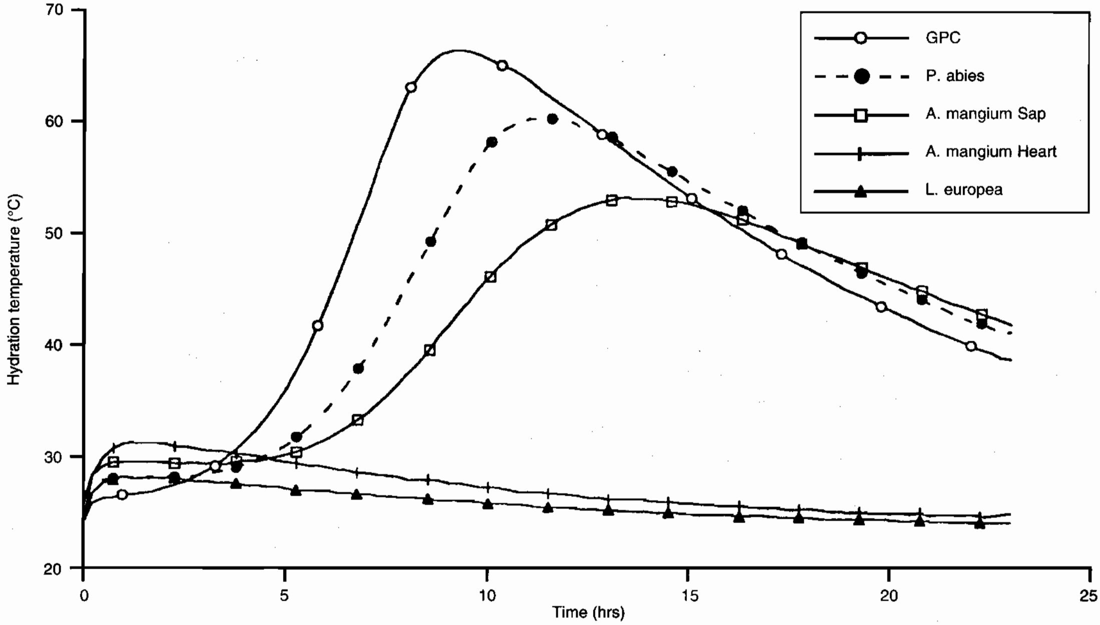

Figure 2. Typical cement hydration curves for compatible (*A. mangium* sapwood and *P. abies*) and incompatible (*A. mangium* heartwood and *L. europea*) woods compared with pure cement (GPC).

Using this classification, the sapwood of all the tropical acacias (except *A. aulacocarpa*) and that of *E. pellita* could be classed as compatible (Table 1). The sapwood of *A. crassicarpa* had the highest compatibility index (CA_A = 81.9%) whereas *A. aulacocarpa* sapwood was only moderately compatible (C_A = 66.4%). The sapwood samples of the temperate acacias (*A. melanoxylon* and *A. mearnsii*) were incompatible (C_A = 23.6% and 21.4% respectively).

The heartwood samples of the tropical acacias were incompatible with C_A factors ranging from 21.1% for *A. aulacocarpa* to 27.7% for *A. auriculiformis* (Table 1). The heartwood of the temperate species (*A. dealbata*, *A. melanoxylon* and *A. mearnsii*) and that of *E. pellita* was moderately compatible with C_A values only slightly above 28%. The heartwood of *A. dealbata* had the highest compatibility (C_A = 38.3%) of all the acacia heartwood specimens tested.

The results for the sapwood of the tropical acacias were promising relating them to the wood species of high compatibility (*P. abies* and *P. radiata*) and low compatibility (*L. europea*). They indicate a relatively high compatibility with cement, not markedly lower than that of *P. abies* or *P. radiata*, particularly in the cases of *A. crassicarpa* and *A. mangium*. The results for the heartwood of the tropical acacias and the sapwood of the temperate species were notable in that they showed the wood to be almost as incompatible with cement as *Larix* sp. which are among the most incompatible wood species ever tested (Hofstrand et al. 1984). (It has not been determined whether the inhibitory extractive compounds in the heartwood of tropical acacias tested here are the same as those identified in *A. mangium* by Tachi et al. (1989).)

Table 1. C_A factors for sapwood and heartwood of acacia species, *E. pellita*, and coniferous wood species.

Wood species	Sap C_A factor (%)		Heart C_A factor (%)
A. aulacocarpa	66.4		21.1
A. auriculiformis	72.9		27.7
A. crassicarpa	81.9		21.8
A. dealbata	—		38.3
A. mangium	80.8		23.9
A. mearnsii	21.4		29.4
A. melanoxylon	23.6		30.1
E. pellita	71.2		28.4
P. radiata		91.2	
P. abies		91.4	
L. europea		18.3	
GPC control		100.0	

The results for the tropical acacias suggest that the proportion of heartwood and sapwood used to manufacture wood-cement composites will greatly affect the setting, curing and properties of panels. Most previous research has found that acacia wood requires either soaking (Sulastiningsih et al. 1990), a high cement:wood ratio (Sudin and Ibrahim 1990), or cement-hardening accelerators (Flawes and Chittenden 1967) for successful use in wood-cement composites. All of these measures add extra cost to panel production, so other more cost-effective methods of improving the compatibility of acacia wood with cement are required.

Identifying and selecting acacia species and trees which contain less heartwood at a given age, or which develop heartwood at a later age, may be one method of increasing the suitability of acacia wood for the manufacture of wood-cement composites. Bhumibhamon et al. (1992) found significant heartwood variation among provenances and families of five-year-old *A. mangium* trees. Families from Oriomo River, Papua New Guinea, had the least heartwood while those from Captain Billy, Queensland, had the most. Further investigations will aim to confirm such findings, and examine whether families of *A. mangium* which form less heartwood at a given age, or possess few inhibitory extractives, are more compatible with cement and therefore better suited to the manufacture of wood-cement composites. Other options may include the manufacture of wood-cement composites from younger trees which contain less heartwood, and the use of alternative inorganic binders, such as rice-hull ash, which may be less susceptible to the inhibitory compounds in acacia heartwood.

Conclusion

The sapwood samples of the tropical acacia species *A. mangium*, *A. crassicarpa*, *A. aulacocarpa* and *A. auriculiformis*, and that of *Eucalyptus pellita*, were either 'compatible' or 'moderately compatible' with cement; sapwoods of the temperate species *A. melanoxylon* and *A. mearnsii* were incompatible. The heartwood samples of all the acacias and of *E. pellita* were generally incompatible with cement; however, the heartwood of the temperate acacia species, especially *A. dealbata*, was less inhibitory than that of the tropical species.

Future work will focus on ways of overcoming the incompatibility of tropical acacia wood with cement. Soaking and/or the use of accelerators are currently required in the manufacture of wood-cement panels from acacias, and methods for reducing or eliminating the need for such treatments deserve investigation. Such alternatives include selection of acacias which contain less heartwood and whose wood is more compatible with cement, and the use of cement-rice hull ash mixtures as more effective binders.

Acknowledgment

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References

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

Biblis, E.J. and Lo, C.F. 1968. Sugars and other wood extractives: Effect on the setting of southern pine-cement mixtures. Forest Products Journal, 18 (8), 28–34.

Flawes, L.J. and Chittenden, A.E. 1967. The amount and type of chemical treatment required to produce wood-wool cement building slabs from wattle timber. TPI Report, Tropical Products Research Institute, London, No. L11, 4 p.

Gunn, B.V. and Midgley, S.J. 1991. Exploring and accessing the genetic resources of four selected tropical acacias. In: Turnbull, J.W., ed. Advances in Tropical Acacia Research. ACIAR Proceedings No. 35, 57–63.

Hachmi, M. and Moslemi, A.A. 1989. Correlation between wood cement compatibility and wood extractives. Forest Products Journal, 39 (6), 55–58.

Hachmi, M., Moslemi, A.A. and Campbell, A.G. 1990. A new technique to classify the compatibility of wood with cement. Wood Science and Technology, 24 (4), 345–354.

Hofstrand, A.D., Moslemi, A.A. and Garcia, J.F. 1984. Curing characteristics of wood particles from nine northern Rocky Mountain species mixed with Portland cement. Forest Products Journal, 34 (2), 57–61.

Pazner, L. 1978. Novel development in non-restricted bonding of lignocellulosics by mineral binders. In: 8th World Forestry Congress, 16–18 October, Jakarta, Vol. VI-A, 545–553.

Rahim, S. and Ong, C.L. 1983. The effect of mineralising fluids on the compatibility of selected timber species with Portland cement. Malaysian Forester, 46 (2), 244–252.

Sudin, R. and Ibrahim, W.A. 1990. Cement bonded particle board from *Acacia mangium*: a preliminary study. Journal of Tropical Forest Science, 2 (4), 267–273.

Sulastiningsih, I.M., Memed, R. and Sutigno, P. 1990. Properties of wood wool boards made from 6 timber species. Jurnal Penelitian Hasil Hutan, 7 (2), 43–47.

Tachi, M., Nagadomi, W., Tange, J., Yasuda, S. and Terashima, N. 1988. Manufacture of wood-cement boards. II Cement-bonded particle boards from Malaysian fast-growing trees. Mokuzai Gakkaishi, 34 (9), 761–764.

Tachi, M., Tange, J., Nagadomi, W., Suzuki, Y., Terashima, N. and Yasuda, S. 1989. Manufacture of wood-cement boards. IV Cement-hardening inhibitory components of the Malaysian fast-growing tree, *Acacia mangium*. Mokuzai Gakkaishi, 35 (8), 731–735.

Teixeira, D.E. and Pereira, H. dos S. 1987. Alternative technology for the production of wood-cement boards. Brasil Florestal, 19, 49–55.

Weatherwax, R.C. and Tarkow, H. 1964. Effect of wood on setting of Portland cement. Forest Products Journal, 14 (12), 567–570.

Yasin, S.M. and Qureshi, T.A. 1989. Quantity of water solubles in some hardwood species (a basis for their relative suitability in wood cement board). Pakistan Journal of Forestry, 39 (2), 103–110.

The Effect of Wood:Cement Ratio and Accelerators on the Properties of Wood-wool Cement Board Made from *Acacia mangium*

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Abstract

Wood-wool cement boards (WWCBs) were produced using *Acacia mangium* and ordinary Portland cement as binder. The effects on WWCB strength properties of three wood:cement ratios and three types of cement-setting accelerators were examined. The accelerators were aluminium sulfate [$Al_2(SO_4)_3$], calcium chloride ($CaCl_2$), and sodium silicate (Na_2SiO_3). $Al_2(SO_4)_3$ was the most effective; $CaCl_2$ imparted better properties at higher wood:cement ratios; and Na_2SiO_3 did not significantly improve the strength of boards. The mechanical properties and thickness-swelling of boards increased at higher wood:cement ratios. The practical implications of these findings for the production of WWCB from *A. mangium* are discussed.

INCREASINGLY, 'wood-wool cement boards' (WWCBs) are being used as a construction material. They are light, they insulate well, and they resist water, termites, fungi and fire. Such properties and their low cost make them ideal and cost-effective in the construction of low-cost shelters in many developing countries.

However, there are problems that can arise during the manufacture of WWCB if the wood and cement are not compatible. Wood contains low molecular weight carbohydrates and extractives which interfere with the normal hydration and setting of cement. The dissolution of these wood components, when wood is in contact with cement paste, inhibits normal cement hydration (Sanderman et al. 1960; Biblis and Lo 1968). This results in poor wood-cement bonds, a particular problem with *Acacia mangium* Willd., even using ordinary Portland cement with $CaCl_2$ as binder.

The use of magnesium, iron, and aluminium salts as accelerators with *A. mangium* resulted in boards with comparable strength properties to that of *Chamaecyparis obtusa* Endl., a species which has been shown to be suitable for wood-cement composites (Tachi et al. 1988). Related work showed that the inhibitory index of *A. mangium* was high compared with other Malaysian fast-growing trees; they speculated that this was due to the presence of high amounts of condensed tannins in its heartwood, since the hot water and alkaline extractives of *A. mangium* were lower than that of other species examined in their study. Similarly, Rahim and Wan Asma (1989) reported that *A. mangium* had a low sugar content of 0.54%, but was within the range of 0.5–0.6% necessary to inhibit cement-setting. Further work by Tachi et al. (1989) found that two flavonoid components of *A. mangium* heartwood strongly inhibited cement-hardening. The major inhibitory compound teracacidin had a strong effect despite the presence of $CaCl_2$ as cement-setting accelerator.

Recently, heartwood of a range of acacia species has been shown to be incompatible with ordinary Portland cement (Semple and Evans 1997). Wood species that are less suitable for wood-cement composites generally require treatment prior to board manufacture. Several approaches have been developed to improve wood-cement compatibility. One effective technique is to soak the shredded wood (also known as 'wood-wool' or 'excelsior') in water

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to remove low molecular weight water-soluble components that hinder the normal setting of cement. A study conducted by Cabangon (1997) showed that the modulus of rupture (MOR) of WWCB manufactured from *Gmelina arborea* was increased by 2.66 times when excelsior was soaked in water beforehand. Another technique is to use cement-setting accelerators. The use of $CaCl_2$ accelerator with pines reduced the unfavourable effects of water-soluble substances on cement boards. However, the use of hot-water extraction proved more effective than the use of $CaCl_2$ (Liu and Moslemi 1985). Eusebio and Generalla (1984) studied the effect of various cement-setting accelerators on the properties of wood-cement boards manufactured from some Philippine wood species. They showed that the efficacy of different accelerators is species dependent.

Soaking the shredded wood in tap water for 12–24 hours and the use of small amounts of mineral additives are normally practised to improve wood-cement compatibility in making WWCB in the Philippines. Since *A. mangium* without pre-treatment is unsuitable for the manufacture of wood-cement composites, this study examined pre-treatments designed to improve its compatibility with Portland cement. Specifically, this study aimed to determine, for the manufacture of WWCB from *A. mangium*, the:

- optimum wood:cement ratio; and
- most suitable cement-setting accelerator.

Materials and Methods

Plantation-grown *Acacia mangium* Willd. from the Philippines was used in this study. WWCBs 300 × 300 × 12 mm having a target density of 0.65 g/cm^3 were produced. Ordinary Portland cement Type 1 was used as the binding agent, while technical grade calcium chloride ($CaCl_2$), aluminium sulfate [$Al_2(SO_4)_3$] and sodium silicate (Na_2SiO_3) were used as cement-setting accelerators. The water:cement ratio was 1.0, and the amount of cement-setting accelerator was 3% based on cement weight. Three wood:cement ratios were used: 1.0, 0.8, and 0.6.

Acacia mangium logs were cross-cut into 40 cm long billets and then debarked using a sharp bolo (knife). The debarked billets were fed into a vertical-type shredding machine to produce 0.4 × 4.0 mm wood-wool. The shredded material was soaked in tap water for two days to leach out cold water soluble extractives; water was replaced every 24 hours. The soaked wood-wool was air-dried for about two days or until an equilibrium moisture content of about 18% was attained. Wood-wool, water containing accelerator, and cement were mixed manually until all wood-wool was thoroughly coated with cement. The proportion of materials used was based on the pre-determined board density, wood:cement ratio, water:cement ratio and percentage of accelerator. The cement-coated wood-wool was formed into mats which were pressed for 24 hours at 3000 psi using a hydraulic press; wooden stoppers corresponding to the desired board thickness (12 mm) were used. The formed boards were allowed to cure in a dry, covered area for 28 days.

The mechanical and physical properties of the boards were then determined. The boards were tested in a *Zhimadzu* universal testing machine. Boards were soaked in a water bath prior to thickness swelling and water absorption tests. MOR, thickness-swelling, and water-absorption tests were performed in accord with the Philippine Standards for particleboard (PHILSA 106, 1975). Nail-head pull-through test (NHPT) was conducted using 5 × 10 cm WWCB samples attached to the loading head of the testing machine with the cross-head pulling at the rate of 5 mm/min. The 38 mm common wire nail was embedded slowly and allowed to penetrate through the horizontal board until the head of the nail touched the top surface of the board.

Results and Discussion

The average MOR of *A. mangium* wood-wool cement boards manufactured at different wood: cement ratios and containing different accelerators are shown in Figure 1. Boards with the highest wood:cement ratio, and for the manufacture which $Al_2(SO_4)_3$ accelerator had been used, had the highest MOR. Generally, bending strength of the boards increased with an increase in wood:cement ratio. According to previous reports, an increase in wood:cement ratio causes a reduction in board strength properties (Lee et al. 1987), except in those properties which are dependent on tensile strength of wood such as MOR in bending (Moslemi and Pfister 1987); the results of this study agree with those of Moslemi and Pfister. The effect of wood:cement ratio on MOR is due to the ability of wood, when present at higher levels, to resist the load applied during the bending test. This indicates that the tensile strength of wood can improve MOR when the amount of cement is just sufficient to develop wood-cement bonds. Furthermore, since cement represents approximately 20% of the total production cost, increasing the wood:cement ratios would lower board production costs.

Clearly, the MOR of the WWCBs was affected by the different cement-setting accelerators. The highest MOR was attained using $Al_2(SO_4)_3$. Na_2SiO_3 was ineffective as an accelerator, but $CaCl_2$ was as effective as $Al_2(SO_4)_3$, except at a wood:cement ratio of

0.6. The results accord with those of Zhengtian and Moslemi (1985). The finding that $Al_2(SO_4)_3$ is a suitable accelerator for *A. mangium* has important practical implications since it is cheaper than either $CaCl_2$ or Na_2SiO_3.

Many reports on the mechanical properties of inorganic bonded composites have examined bending, flexural, and tensile strength, elastic modulus, maximum bending moment and bending rigidity. Few reports have examined nail-head-pull-through strength. In this study, NHPT strength was examined because nail-holding capacity of WWCBs is important when used as ceiling or wall sheathing where nails are used as to fasten WWCB to wood frame members. Results of the average NHPT values of the boards are shown in Figure 2. At wood:cement ratios of 0.6 and 1.0, boards containing $Al_2(SO_4)_3$ had the highest NHPT strength, while the lowest values were obtained in boards containing Na_2SiO_3. The difference between boards containing $CaCl_2$ and $Al_2(SO_4)_3$ at a wood:cement ratio of 0.8 is insignificant. As in the findings for MOR in the study, $Al_2(SO_4)_3$ appears to be the cement-setting accelerator which most improves NHPT strength even at high wood:cement ratios. The decrease in NHPT for boards containing $CaCl_2$ at a wood:cement ratio of 1.0 can suggest that higher amounts of $CaCl_2$ may be required to increase NHPT when cement and wood contents are equal. Clearly, Na_2SiO_3 is not a suitable cement-setting accelerator for improving the NHPT strength of WWCBs manufactured from *A. mangium*.

The results of thickness-swelling tests of the *A. mangium* boards is presented in Figure 3. The least swelling was observed for boards manufactured using a wood:cement ratio of 0.6 and containing $Al_2(SO_4)_3$. Clearly, thickness-swelling of the boards was affected significantly by the wood:cement ratio: the higher the ratio, the greater the swelling. The presence of more cement in boards, i.e., low wood: cement ratio, probably imparted greater stability to the boards. More cement would coat the wood-wool to a greater extent, providing greater dimensional stability and restraint from swelling; conversely, lower cement contents can allow greater swelling because wood-wool is inadequately coated. The type of accelerator also affected the thickness-swelling of the boards. Again, the use $Al_2(SO_4)_3$ imparted greater stability, possibly because it improved bonding between wood and cement to a greater extent than the other accelerators. Boards containing Na_2SiO_3 showed relatively high thickness-swelling.

The average water-absorption values of the boards are shown in Figure 4. It did not vary significantly with the type of accelerator. However, an increase in the wood:cement ratio resulted in greater water absorption. Wood easily absorbs water and larger values can be attributed to the greater quantity of wood in boards with high wood:cement ratios.

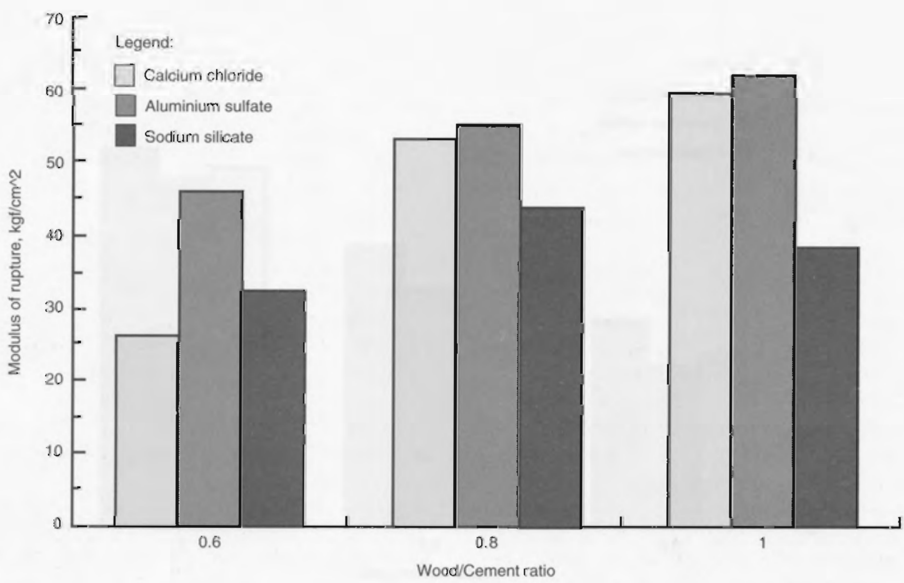

Figure 1. Effect of wood/cement ratio and accelerators on the MOR of WWCBs manufactured from *A. mangium*.

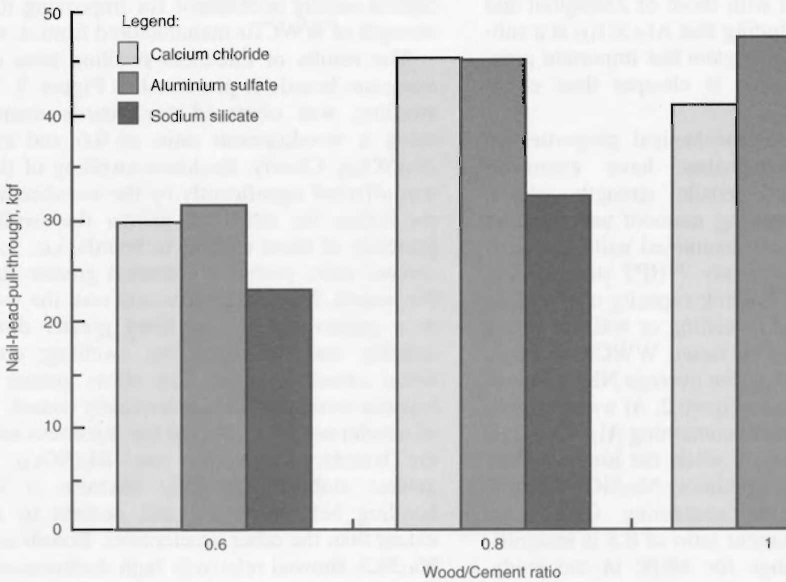

Figure 2. Effect of wood/cement ratio and accelerators on the NHPT of WWCBs manufactured from *A. mangium.*

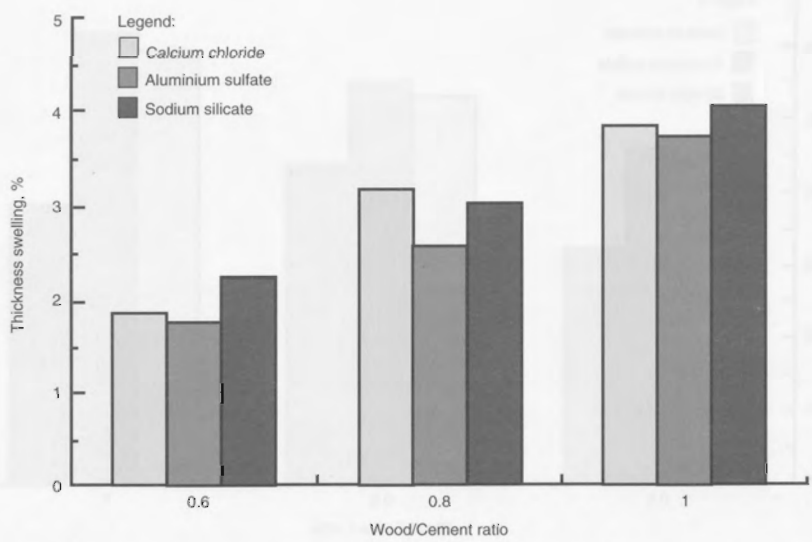

Figure 3. Effect of wood/cement ratio and accelerators on the thickness swelling of WWCBs manufactured from *A. mangium.*

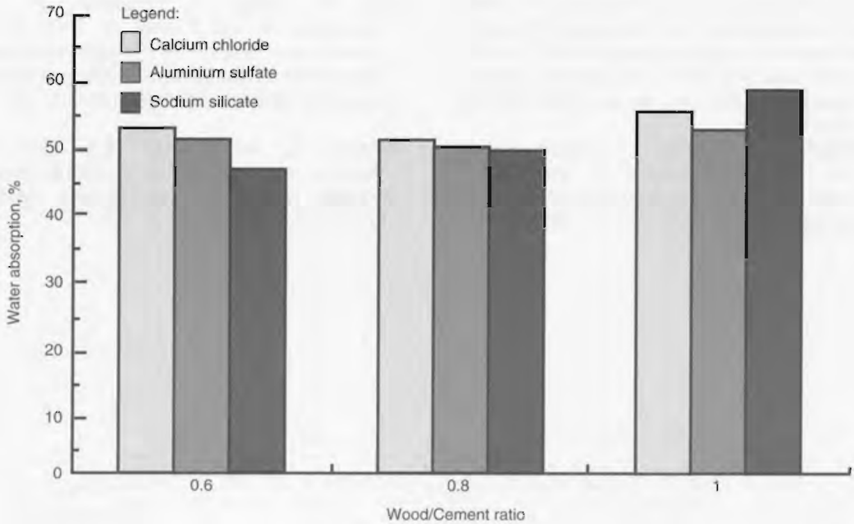

Figure 4. Effect of wood/cement ratio and accelerators on the water absorption of WWCBs manufactured from *A. mangium*.

Conclusions

Acacia mangium has shown potential as a raw material for wood-wool cement board manufacture, provided that: (a) the wood-wool is soaked in water to remove extractives, and (b) suitable cement-setting accelerators are used to improve bonding between wood and cement. Among the cement accelerators examined here, aluminium [$Al_2(SO_4)_3$] was most effective in enhancing the properties of boards with the three wood:cement ratios.

Further experiments are necessary in order to optimise the properties of boards manufactured from *A. mangium*. Such experiments could include examining the effects of different types and amounts of accelerator, wood-wool, geometry, pre-treatment method, board thickness and density, and rice hull ash.

Optimisation of board properties will be undertaken in a pilot-scale plant at FPRDI, and the technology will eventually be transferred to existing commercial wood-wool cement board plants in the Philippines.

Acknowledgment

This paper is a part of the on-going collaborative project of the Forest Products Research and Development Institute (FPRDI), Laguna, Philippines and the Department of Forestry, The Australian National University, Canberra, Australia and CSIRO, Melbourne, Australia. The financial support provided by the Australian Centre for International Agricultural Research (ACIAR) is gratefully acknowledged.

References

Biblis, E.J. and Lo, C.F. 1968. Sugars and other wood extractives: effects on the setting of southern pine-cement mixtures. Forest Products Journal 18 (8), 28–34.

Cabangon, R.J. 1997. Rapid curing of wood-wool cement boards from yemane (*Gmelina arborea* R.Br.) by direct heat application during pressing. MS Thesis. University of the Philippines at Los Baños, College, Laguna.

Eusebio, D.A. and Generalla, N.C. 1984. Effects of various chemicals on the properties of wood-cement boards from some wood species. Unpublished report, FPRDI, College, Laguna, Philippines.

Lee, A.W.C., Hong, Z., Phillips, D.R. and Chung, Y.H. 1987. Effect of cement/wood ratios and wood storage conditions on hydration temperature, hydration time, and compressive strength of wood-cement mixtures. Wood and Fiber Science, 19 (3), 262–268.

Liu, Z. and Moslemi, A.A. 1985. Influence of chemical additives on the hydration characteristics of western larch wood-cement-water mixtures. Forest Products Journal, 35 (7/8), 37–43.

Moslemi, A.A. and Pfister, S.C. 1987. The influence of cement/wood ratio and cement type on bending strength and dimensional stability of wood-cement composite panels. Wood and Fiber Science, 19 (2):165–175.

Rahim, S. and Wan Asma. 1989. Cement-bonded particleboard from *Acacia mangium*. A preliminary study. Journal of Tropical Forest Science, 2 (4), 267–273.

Sandermann, W., Preusser, H.J. and Schweins, W. 1960. The effects of wood extractives on the setting of cement-bonded wood materials. Holzforschung, 18 (12), 53–59.

Semple, K.E. and Evans, P.D. 1997. Compatibility of some Australian acacias with Portland cement. Holz als Roh und Werkstoff (in Press).

Tachi, M., Nagadomi W., Tange, J., Yasuda, S. and Terashima, N. 1988. Manufacture of wood-cement boards. II Cement-bonded particleboards from Malaysian fast-growing trees. Mokuzai Gakkaishi, 34 (9), 761–764.

Tachi, M., Tange, J., Nagadomi, W., Susuki, Y., Terashima, N. and Yasuda, S. 1989. Manufacture of wood-cement boards. IV Cement hardening inhibitory components of the Malaysian fast-growing tree, *Acacia mangium*. Mokuzai Gakkaishi, 35 (8), 731–735.

Zhengtian, L. and Moslemi, A.A. 1985. Influence of chemical additives on the hydration characteristics of western larch wood-cement-water mixtures. Forest Products Journal, 35 (7), 37–43.

Growth and Performance of *Acacia crassicarpa* Seedling Seed Orchards in South Sumatra, Indonesia

Arif Nirsatmanto[1]

Abstract

Seedling seed orchards of *Acacia crassicarpa* were established at South Sumatra and initially laid out as a provenance/progeny test for 134 open-pollinated families from 10 seedlots collected from natural provenances in Papua New Guinea (PNG) and Queensland, Australia (Qld). The families are classified into three groups: groups A and B are from PNG, and group C from Qld. Data on height, dbh and multi-stemming were collected at 4–16 months after planting. Analysis of variance and covariance were made using plot mean, and the value of heritability was estimated as family mean heritability. The survival rates for all seedlots within each group are high (>90%). The average growth rates of PNG seedlots for all periodical measurements were better than those from Qld; however the highest proportion of trees which needed no singling was found in Qld seedlots (mostly >50%). Family variation in height and dbh within each group was highly significant; mean family heritability is 0.44–0.62 for height, and 0.27–0.58 for dbh.

IN nature, *Acacia crassicarpa*, one of the very adaptable fast-growing tropical species, tolerates more adverse conditions than *A. mangium*, *A. auriculiformis* or *A. aulacocarpa* especially on dried and degraded soils (Gunn and Midgley 1991).

In Indonesia, *A. crassicarpa* has become one of the main species to be proposed on the Industrial Forest Plantation Program. This is not only because it is a suitable species for industries, but it also has good potential for other forestry purposes. In 1986–87, the first large plantation and trial of *A. crassicarpa* in Indonesia was established at Riam Kiwa, South Kalimantan as a part of the Indonesia–Finland Merchanised Nursery and Plantation Project (ATA-267). It has been suggested that this species be regarded as one of the promising species for initial reforestation of alang-alang grasslands for industrial and land protection (Nikles 1990).

A. crassicarpa is becoming increasingly important as many forest companies become interested in planting it in their concession areas. Therefore seedling seed orchards have been established in order to improve the genetic quality of such plantations. The growth and performance of seedling seed orchards in South Sumatra are discussed.

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Methods and Materials

Trial sites

Seed used for establishment of the seedling seed orchards here was received from CSIRO Australia in January 1994. The 134 families tested in the trials came from seedlots of two provenances: Papua New Guinea (PNG) and Queensland, Australia (Qld). Those families are classified into three groups: A, B, and C. Group A and B comprise families from PNG seedlots, whereas group C is from Qld seedlots. Each group was established separately at least 1 km apart. Details are shown in Table 1.

Seed sowing was conducted in September 1994, then 1–2 weeks later the germinated seeds were pricked out into a 10 × 15 cm polybag containing sand + soil + fertiliser. After 3 months in the nursery, seedlings were delivered to the field and planted soon after. Every 6 months plants were fertilised with NPK, 100 gram per tree. Although the number of families tested in each group differs, the design of the trials is similar: 12 replications of a randomised complete block of 4 × 2 spacing. The total number of

Table 1. Characteristics of seedlots and families of *Acacia crassicarpa* tested in the seedling seed orchards.

Seedlot	Latitude (°S)	Longitude (°E)	Altitude (m)	Families (# tested)	Height (m)	Dbh (cm)		Singles[1] (%)	Survival (%)
						at 12 months	at 16 months		
PNG (group A)									
13680 Wemenever	8°51′	141°26′	30	17	5.76	3.99	6.06	34	96
15646 Wemenever	8°56′	141°17′	20	15	5.87	4.03	5.99	40	96
16353 NE of Balamuk	8°49′	141°20′	20	4	6.03	4.19	6.08	34	87
17552 Bensbach	8°53′	141°17′	25	20	6.22	4.06	6.00	46	86
Mean of 56 families					**5.97**	**4.07**	**6.00**	**38.5**	**91.25**
PNG (group B)									
16597 Gubam-Bimadebun	8°37′	141°55′	25	23	6.62	5.10	6.95	31	90
16598 Gubam-Bimadebun	8°37′	141°55′	25	18	6.57	5.11	7.08	30	91
Mean of 41 families					**6.59**	**5.11**	**7.02**	**30.5**	**90.50**
Queensland (group C)									
16128 Jardine River	11°02′	142°22′	20	14	4.32	2.91	3.94	54	88
16775 Parish of Annan	15°36′	145°19′	80	3	4.72	2.92	4.10	61	93
18943 Olive River	12°19′	142°50′	60	4	4.50	3.01	4.03	42	92
17944 Claudie River	12°48′	143°18′	20	16	4.39	2.96	4.08	54	86
Mean of 37 families					**4.48**	**2.95**	**4.04**	**52.75**	**89.75**

[1] 'Singles' = trees which needed no singling, i.e. not multi-stemmed

planted seedlings for each family is 48. The trial site at Pendopo, South Sumatra is at latitude 4°S, longitude 104°E and altitude 80 metres. The climate type is 'A' (Schmidt and Ferguson method), mean annual rainfall is 2781 mm, maximum and minimum temperatures are 33°C and 24°C, respectively.

Measurement and analysis

Measurements of height, dbh (diameter at breast height over bark), and multi-stem (assessed according to whether trees must be singled or not) were made at 4, 8, 12 and 16 months after planting. Height was measured at all periodical measurements, dbh at 12 and 16 months with templates graduated in 1-cm increments, and multi-stem at 4 and 8 months; for the purpose of data analysis here, multi-stem at 4 months is excluded, because its performance was represented by the data on the last measurement.

Analysis variances were carried out on a PC computer following Kurinobu et al. (1994). The linear model for analysis variance using plot mean data (Harvey 1979) is as follows:

$$Y_{jk} = \mu + R_j + F_k + E_{jk}$$

where:

Y_{jk} = plot mean of the k-th family in the j-th replication
μ = mean of population
R_j = an effect of the j-th replication
F_k = an effect on the k-th family
E_{jk} = error associate with Y_{jk}.

Estimation of family mean heritability on each trait is calculated using the following formula (Zobel and Talbert 1984):

$$h^2_f = \sigma^2_f/(\sigma^2_f + \sigma^2_e/k_1)$$

where:

h^2_f = family heritability
σ^2_f = family variance component
σ^2_e = error variance component
k_1 = coefficient of family variance component.

Results and Discussion

General growth performance

The average survival rate for all seedlots within groups A, B and C was 90.5%, with two PNG seedlots within group A (13680 and 15646) having the maximum of 96% (Table 1). Average height growth of the three seedling seed orchards was a different pattern for each, for example, growth slightly declined in the second period for group A and group B, and was almost linear for group C; but all of them increased in the third period, as shown in Figure 1.

Generally, growth of the seedlots introduced from PNG was found to be better than those from Qld seedlots (see Table 1). The superiority of PNG seedlots in these results is almost the same as that in the previous report at Melville Island, Australia (Harwood et al. 1993). Among the two groups of PNG seedlots, average growth from two seedlots

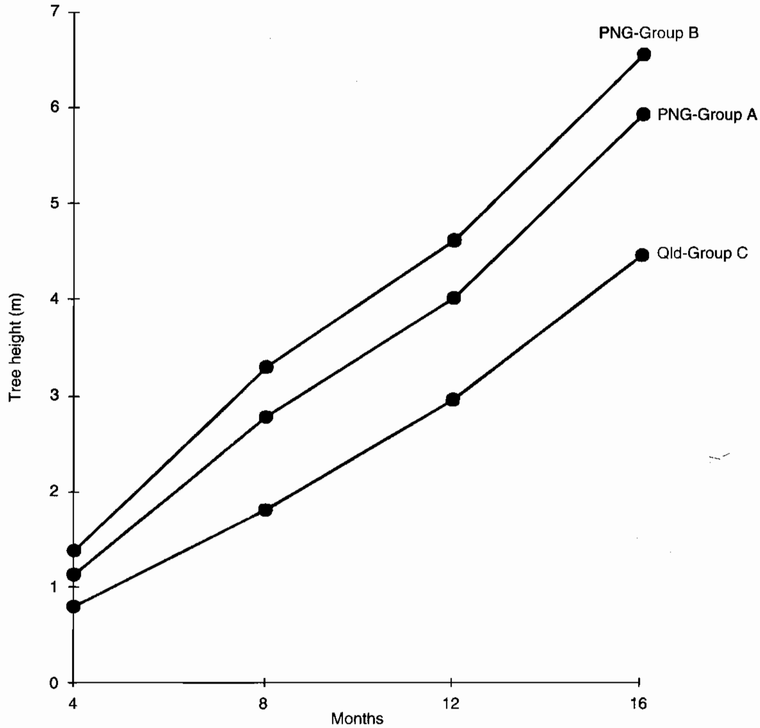

Figure 1. Height growth on four periodical measurements (4, 8, 12 and 16 months) in the three groups of seedling seed orchards (PNG-group A, PNG-group B and Qld-group C).

within group B (Gubam-Bimadebun) was higher than those of four seedlots within group A. Observations based on form trait (multi-stem) showed that the proportion of trees which did not need singling was larger for Qld seedlots than those for PNG. Thus, each group has different advantages, which suggests that the current system of managing the breeding population is appropriate.

Heritability

Family heritability was estimated provisionally on two traits: height and dbh on the last measurement. Family variation on height and dbh within each group was highly significant at the 0.01 level. Estimated family heritability for all groups was 0.44–0.62 on height and 0.27–0.58 on dbh, as shown in Table 2. Even though the growth of families from the Qld seedlots was not as high as those from the PNG seedlots, they had the highest family heritability on both traits; the lowest family heritability was in the PNG group A seedlots. However, these are provisional results because the trees are still young and the pattern may change as they age.

Table 2. Family variance and heritability estimated for height and dbh (measured on the last measurement, 16 months).

Traits	PNG seedlots		Qld seedlots
	Group A	Group B	Group C
Height			
— variance component	0.087**	0.028**	0.066**
— mean heritability	0.44	0.47	0.62
Dbh			
— variance component	0.037**	0.065**	0.111**
— mean heritability	0.27	0.42	0.58

** Significant at 0.01 level

Future Directions

According to the current breeding strategy, the seedling seed orchards will be thinned by removing the two poorest trees within each plot at 24 months. During the first period of thinning, measurements will be made twice more in order to complete the present data set and add some new traits, especially on stem straightness. The second and final stages of selective thinning will be implemented at 40 and 52 months respectively. In the second generation breeding program, plus trees will be selected a few times before final selective thinning and again after final selective thinning.

Acknowledgment

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References

Gunn, B.V. and Midgley, S.J. 1991. Exploring and accessing the genetic resources of four selected tropical acacias. In: Turnbull, J.W. Advances in Tropical Acacia Research. Proceedings of a Workshop held in Bangkok, Thailand, 11–15 February 1991. ACIAR Proceedings No. 35, 57–63.

Harvey, W.A. 1979. Least square analysis of data with unequal subclass number. US Department of Agriculture Research Reports.

Harwood, C.E., Haines, M.W. and Williams, E.R. 1993. Early growth of *Acacia crassicarpa* in a seedling seed orchard at Melville Island, Australia. FAO, Rome, Forest Genetic Resources Information No. 21.

Kurinobu, S., Nirsatmanto, A. and Seido, K. 1994. A Manual of Procedure for Preliminary Analysis of Data Measured in Seedling Seed Orchards. JICA-FORDA, FTIP, 19, 43 p.

Nikles, D.G. 1990. Proposal for tree improvement and other work required to enhance the effectiveness of the Indonesia–Finland Project: Trials and pilot tree plantation for rehabilitation of alang-alang grasslands around Riam Kiwa, and improvement of cut-over rainforest lands near Kintap, both in the South East of South Kalimantan Indonesia. Report prepared for Enso Forest Development Ltd, Finland.

Zobel, B. and Talbert, J. 1984. Applied Forest Tree Improvement. John Wiley & Sons, New York, 505 p.

Molecular Genetics Research on *Acacia* Species in Indonesia

Anto Rimbawanto[1]

Abstract

The tree improvement program of *Acacia* species in Indonesia is beginning to incorporate molecular genetic techniques. These offer the potential to increase genetic gains by way of accurate characterisation of genotypes and genotyping, detection of genetic variation, and early selection using molecular markers. Molecular genetics research of tree species in Indonesia began in 1996, and is being carried out by the Forest Tree Improvement R&D Institute. At the current stage of the program the need for genotyping and examination of genetic variation is a priority. Using RAPD markers we found that genetic diversity of *Acacia mangium* is the lowest of four acacias. We also found an indication that *A. aulacocarpa* of PNG and Queensland may in fact be two different species.

IN the humid tropics, the acacias are important plantation species. There are about 1100 *Acacia* species in the genus (Boland et al. 1984), of which at least four are predominant in plantations in Indonesia: *A. aulacocarpa*, *A. auriculiformis*, *A. crassicarpa*, and *A. mangium*. The widespread planting of the genus is due to its ability to:

- grow rapidly in a wide range of environments with poor soil fertility;
- fix atmospheric nitrogen;
- compete successfully with *Imperata cylindrica*; and
- produce wood for a wide range of uses.

Genetic improvement and breeding of *Acacia* spp. are among the most active programs in Southeast Asian countries compared with other fast growing species. Indonesia is also making big efforts to improve the genetic quality of the species. Apart from the tree improvement work being carried out by private companies, government agencies such as the Forest Tree Improvement R&D Institute have established 20 trial sites of progeny tests of *A. auriculiformis* (2 sites), *A. aulacocarpa* (1 site), *A. crassicarpa* (5 sites), and *A. mangium* (12 sites). The first generation of selected families/individuals of *A. mangium* are to be available in 1998.

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Integration of Molecular Genetics Research

Conventional methods of genetic improvement through selection, testing, and breeding have been practised for some time with dramatic results. There is evidence that plantation productivity has increased significantly through selection and breeding. One of the classic examples is the increase in pulpwood production of *Eucalyptus* in Aracruz Florestal, Brazil. Through intensive selection the mean annual increment (MAI) increased from 28 to 45 m^3/ha/yr (Champinhos 1991).

Orthodox breeding technology has led to the recombination of a wide spectrum of genes rather than specific alterations of only the trait of interest (Walter and Smith 1995). Molecular techniques have been applied to the tree improvement program to further increase genetic gains by way of:

- accurate characterisation of genotypes and genotyping,
- detection of genetic variation, and
- early selection using molecular markers.

Genotyping will be useful in clonal identification of clonal seed orchards where mislabeling errors of 10–15% are common (Wheeler and Jech 1992).

The use of molecular markers for studying genetic diversity has become routine work. RFLP ('random fragment length polymorphism') markers have been used to estimate genetic diversity between and within populations of *A. mangium*, but RAPDs ('random amplified polymorphic DNAs') are less laborious markers and are becoming common for this type of study (Williams et al. 1990).

Molecular genetics is a new research field in the Indonesian forestry research program. The Ministry of Forestry with technical assistance from the Japan International Cooperation Agency (JICA) established an isozymes laboratory at the Forest Tree Improvement R&D Institute in 1992. The facilities of this laboratory were upgraded in 1996 to carry out DNA research. As a research institution in tree improvement, our molecular genetics research is designed to complement the genetic improvement program. Currently, the work is focused on genetic identification and the estimation of genetic variability and relatedness.

The Institute's selective breeding program is expected to have completed its first generation cycle in 1998. After culling, some 150 individuals from 35 families of each subline (i.e. 50% of the total family) will be selected. Since these populations will be used as a breeding population for further breeding it is important that genetic diversity remains high. DNA markers will be used to examine relatedness of the selected individuals. An assessment of the level of genetic diversity and relatedness of the selected individuals and families will be crucial for the next breeding cycle. A research plan is already in place for *A. mangium* progeny testing. The assessment will be carried out using RAPD markers. Such markers have been used successfully in other species such as *Gliricidia* sp. (Chalmers et al. 1992), *Eucalyptus* sp. (Nesbitt et al. 1995) and *Shorea leprosula* (Lee et al. 1996).

The role of molecular genetics in tree improvement is shown in Figure 1. At each point of activity of the breeding cycle, molecular genetics could provide information relevant to the need of the activity. Our research program has been developed to address those questions.

Genetic Diversity and Phylogenetics of *Acacia*

Genetic variation of base populations is a prerequisite for tree breeding and selection programs. Molecular techniques offer a rapid and accurate way of examining genetic variation. The choice of markers ranges from co-dominant markers such as RFLP and SSCP ('single strand conformation polymorphism') to dominant markers such as RAPD.

Our work using RAPD markers concentrated on four species: *A. auriculiformis*, *A. aulacocarpa*, *A. crassicarpa* and *A. mangium*. In this study the level of genetic diversity was expressed as genetic distance according to the F coefficient of Nei and Li (1979). Among the four acacias, genetic distance of *A. mangium* was the lowest with the value of 0.08; the proportion of polymorphic loci in *A. mangium* was also low (Table 1).

Table 1. Genetic diversity of four *Acacia* species, measured by number of polymorphic loci and genetic distance.

Species	Genetic diversity	
	No. of polymorphic loci	Genetic distance
A. aulacocarpa	23/41 <0.56>	0.26
A. auriculiformis	20/46 <0.43>	0.15
A. crassicarpa	24/47 <0.51>	0.19
A. mangium	10/38 <0.26>	0.08

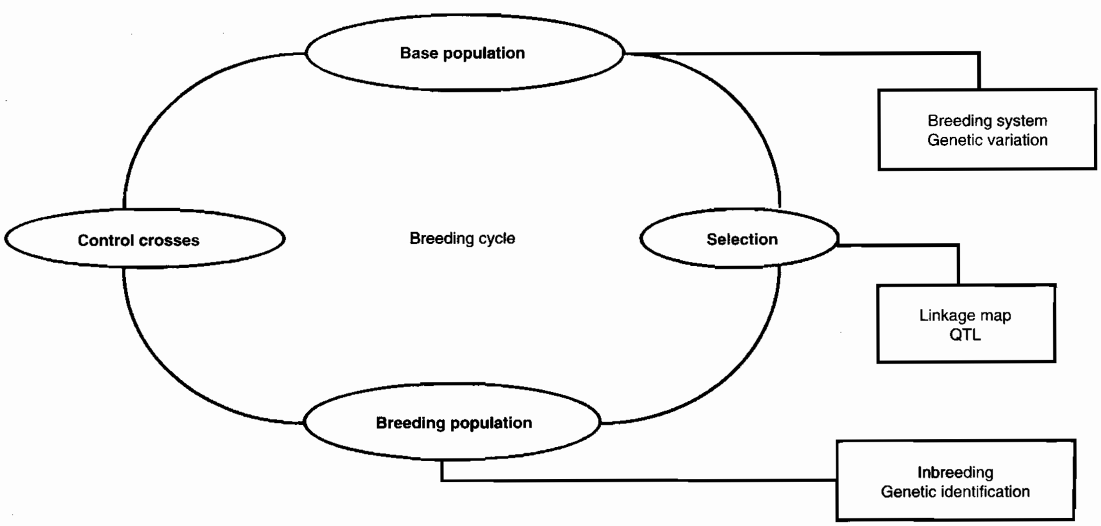

Figure 1. The role of molecular genetics in tree improvement programs.

Cluster analysis grouped the species into two main clusters which correspond to the degree of relatedness between species, with *A. auriculiformis* and *A. mangium* in one group, and *A. aulacocarpa* and *A. crassicarpa* in another (Figure 2). We are particularly interested in *A. aulacocarpa* since the variation among populations (PNG and Queensland) is high. In fact species from the two regions may be different species; our sequencing data show that there is a point mutation at 320 kB (unpublished data) which separates the PNG and Queensland populations. Work is currently in progress to examine a wider geographic sample of 87 seedlots from 18 provenances.

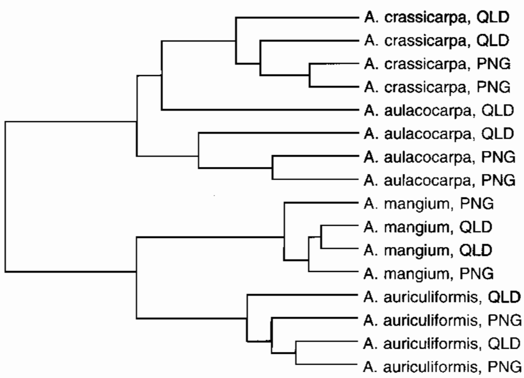

Figure 2. Schematic representation of the grouping of the four *Acacia* spp. based on UPGMA method.

References

Boland, D.J., Brooker, M.I.H., Chippendale, G.M., Hall, N., Hyland, B.P.M., Jonhston, R.D., Kleining, D.A., and Turner, J.D. 1984. Forest Trees of Australia. Canberra, Australia, Nelson/CSIRO, 687 p.

Chalmers, R.J., Waugh, R., Sprent, J.I., and Powell, W. 1992. Detection of genetic variation between and within populations of *Gliricidia sepium* and *G. maculata* using RAPD markers. Heredity, 69, 465–472.

Champinhos Jr., E. 1991. Plantation of fast growing species for tropical areas. In: Davidson, J., ed., Proceedings of the Regional Symposium on Recent Advances in Mass Clonal Multiplication of Forest Trees for Plantation Programmes. UNDP/FAO-FORTIP, Cisarua, Bogor.

Lee, S.L., Wickneswari, R., Mahani, M.C. and Zakri, A.H. 1996. *Shorea leprosula* Miq. (Dipterocarpaceae): A species with high genetic diversity but low population differentiation revealed by RAPD analysis in Peninsular Malaysia. In: Mohamad, O., Mahani, M.C. and Zulkiflie, Z., ed., Proceedings of the Second National Congress on Genetics, Genetics Society of Malaysia, UKM, Selangor, 200–212.

Nei, M. and Li, W.H. 1979. Mathematical model for studying genetic variation in terms of restriction endonucleases. Proceedings of the National Academy of Science, USA, 76, 5269–5273.

Nesbitt, K.A., Potts, B.M., Vaillanourt, R.E., West, A.K. and Reid, J.B. 1995. Partitioning and distribution of RAPD variation in a forest tree species *Eucalyptus globulus* (Myrtaceae). Heredity, 75, 628–637.

Walter, C. and Smith, D.R. 1995. Transformed *Pinus radiata* now growing in greenhouses at the New Zealand Forest Research Institute (NZFRI). Dendrome, Forest Tree Genome Updates, 2 (2), 1–4.

Wheeler, N.C. and Jech, K.S. 1992. The use of electrophoretic markers in seed orchard research. New Forests, 6, 311–328.

Williams, J.G.K., Kubelik, A.R., Livak, K.J., Rafalski, J.A. and Tingey, S.V. 1990. DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. Nucleic Acids Research, 18, 6531–6535.

Short Communications

Effectiveness of Symbiotic Associations Involving Native Rhizobia and Temperate Australian Acacias

J.J. Burdon[1], A.H. Gibson[1,3], S.D. Searle[2], J. Brockwell[1] and M. Woods[1]

Poster abstract

Australian acacias represent a major resource for use in forestry, sustainable agriculture and mine-site rehabilitation through the world. Despite this, very little is known about their interaction with nitrogen-fixing symbionts (rhizobia) particularly with respect to: (i) the degree to which the effectiveness of the interactions formed varies between rhizobial isolates; (ii) the extent to which the performance of individual isolates on different host provenances is correlated; and (iii) the extent of host-based variation in the ability to form effective associations. Our study aimed to answer these questions.

Collections of seed and rhizobia were made from 67 populations of 22 species of *Acacia* across southeastern Australia. Standard isolation techniques were used to produce pure cultures of the 700 rhizobial isolates made. These materials were then used in a series of trials assessing the effectiveness of particular symbiotic associations. All trials assessed aerial dry matter production of young *Acacia* seedlings after 12–16 weeks' growth in a 50:50 sterilised mix of vermiculite and river sand inoculated with the appropriate rhizobial cultures.

For the *Acacia* species tested, marked within-provenance variation in seedling growth occurred as a result of inoculation with different strains of rhizobia isolated from those sites. In several instances, the growth response of the least effective combination was less than 10% of that of the most effective combination. Significant differences in the mean performances of isolates taken from different sites were only detected in *A. dealbata.*

Significant variation was detected in the mean response of provenances of *A. dealbata*, *A. implexa* and *A. mearnsii* to a range of 'elite' rhizobial isolates and in the ability of those isolates to form effective associations across all provenances. However, there was evidence of a differential provenance × isolate interaction only in *A. implexa.* An extensive trial involving reciprocal inoculation of isolates of varying effectiveness (two elite, one moderate and one poorly effective) between three provenances of each of *A. dealbata, A. implexa, A. irrorata, A. mearnsii* and *A. melanoxylon* again detected significant provenance and isolate variation. With the exception of *A. dealbata*, there was no evidence of a provenance × rhizobial origin interaction effect.

Trials involving 10 half-sib families of *A. dealbata, A. mearnsii* and *A. melanoxylon* detected significant host-based variation in growth response. A particularly dramatic effect was seen in *A. dealbata* where the interaction between ineffective isolate 1801 and half-sib family 1292 produced plants with a dry weight more than 10 times greater than the mean of the interaction of the same rhizobial isolate and the nine other half-sib families.

Conclusions

- Significant variation exists in the ability of different rhizobial isolates to establish effective nitrogen-fixing associations with host plants from their site of origin. The average *Acacia* host-rhizobial isolate combination was only about 70% as effective as the best combination.
- The growth performance of *Acacia* seedlings showed marked host provenance and rhizobial isolate effects. However, there was very little evidence of isolate × provenance effects. This suggests that, in most situations, elite rhizobial cultures selected from one provenance will continue to perform well in association with other provenances.
- Significant host-based variability in the ability to form effective symbiotic interactions was detected in half-sib families of *A. dealbata, A. mearnsii* and *A. melanoxylon*. This suggests that, in any *Acacia* breeding program, attention should be given to possible consequences for the effectiveness of symbiotic relationships.

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Australian Acacias for Sustainable Development in China: Rhizobia and Nitrogen Fixation

Kang Lihua[1], Li Sucui[1], Sun Bing[1], J. Brockwell[2], A.H. Gibson[2,4] and S.D. Searle[3]

Poster abstract

An investigation was conducted in the laboratory and nursery at the Research Institute of Tropical Forestry to define characteristics of the symbiotic association between species of *Acacia* and their root-nodule bacteria.

It was found that: (i) inoculation of *Acacia* with rhizobia often leads to high levels of nitrogen fixation; (ii) different *Acacia* species and different provenances within species respond differently to inoculation with the same sets of *Rhizobium* strains; (iii) Chinese *Rhizobium* strain LL026 is highly effective in nitrogen fixation for several *Acacia* provenances, and Australian strain CC1563 is also useful especially for *A. mearnsii*; (iv) it is most improbable that a single *Rhizobium* strain highly effective for all *Acacia* provenances will ever be found; (v) peat is the best carrier for *Acacia* inoculant; (vi) *Acacia* nodulation and nitrogen fixation in the nursery are improved when clay soils are amended with organic matter; (vii) most *Acacia* rhizobia are sensitive to acidity but strongly acid-tolerant strains do exist; (viii) calcium phosphate should not be used to correct acidity in nursery soil; and (ix) soil rhizobia in *Acacia* plantations increase in number as time progresses.

It was concluded that: (i) in preparing inoculants for use in forest nurseries, it will be prudent to use a specific inoculant for each different species of *Acacia*, each inoculant containing several effective *Rhizobium* strains; (ii) inoculant should be peat-based; and (iii) light-textured nursery soils promote nodulation and nitrogen fixation.

This investigation has provided a microbiological background for the preparation of preinoculated, *Rhizobium*-rich nursery soils that will deliver well-nodulated *Acacia* seedlings ready for outplanting.

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Rhizobium Inoculants for Australian *Acacia* Species

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The timber stock in much of the arid/semi-arid tropics (ASALs) is declining through cutting for firewood, fencing and fodder. Australian woody species may grow rapidly in these environments. The success rate for many plantations in Africa ASALs is small. Several factors contribute to successful establishment e.g. genotype × site matching, nursery culture and conditioning, plant nutrition, water availability, freedom from animal grazing. Microbial symbioses, for example between eucalypts and mycorrhizas or between legumes and nodulating, nitrogen-fixing bacteria such as rhizobia, may play an important roles in plant nutrition and hence establishment and growth.

One key issue in establishing successful symbiotic associations is whether the natural soil populations in the different planting locations (perhaps in a different continent) are capable of forming effective associations. If the microbial population is deficient, then can the associations be established through inoculation in the nursery and possibly in the field?

A second key issue is whether the symbiotic associations that compete for carbon with other plant sinks are a drain on the plant's resources and thereby decrease the chances of successful establishment under water and heat stress in the field. Conversely the symbiotic associations may develop more vigorous plants better able to withstand the establishment stresses. Mycorrhizas are believed to benefit plant water relations in water limiting conditions but there are few if any experiments indicating what this may translate to in ASALs.

Several studies have shown that Australian *Acacia* species vary in their relationships with *Rhizobium/Bradyrhizobium*. Some species nodulate readily with a range of strains (i.e. are promiscuous), others are quite specific in their requirements. This note describes the development of inoculants for Australian acacias adapted to ASALs. The first phase of the work was concerned with isolating and testing *Rhizobium* strains for their suitability as inoculants, for the plant species under test, and potentially useful for ASAL plantings. The second phase involved the use of these inoculants in the nursery.

The initial research involved the Australian Tree Seed Centre, which provided seed of *Acacia* species occurring in ASALs in northern Australia along with soil from the seed collection sites. This soil was used to inoculate bait plants grown in otherwise semi-sterile conditions in the glasshouse at University of Queensland, which would 'select out' the *Rhizobium* and mycorrhiza propagules and form symbiotic associations.

Nodulation was assessed from 6 to 16 weeks after the baiting began and rhizobia strains were isolated from several nodules from each bait plant. These strains were then assessed in an authentication trial, also grown in the glasshouse, using the original species as the test host. The best strains were then further tested in a replicated, N-fixation effectiveness trial, growing plants for 3–6 months, depending on their growth rate and the season. An automated watering system to minimise cross contamination was developed for these trials. Plants were grown in washed, sterilised sand and watered for the first three weeks with a nutrient solution containing 2 mM N as ammonium nitrate and thereafter with N-free nutrient solution. Pots were watered until free draining occurred so plants were not nutrient limited except for N.

From these tests the most effective strains were selected as potential inoculant strains and further tested for their survival in culture and in inoculant carrier at room temperature. The latter is important if inoculants are stored before use or shipped around the world.

Soils, roots and nodules were collected from more than 70 sites in northern Australia, mainly Queensland. From these a collection of about 440 authenticated rhizobia strains was compiled, using 28 *Acacia* species as bait plants. These trials showed that some soils contained rhizobia strains differing in their specificity and effectiveness from the bait host. Cross species effectiveness tests showed that some *Acacia* species required specific strains, others were more promiscuous.

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Some soils did not contain rhizobia capable of nodulating the hosts growing in the soil at the point of collection. This could reflect the poor survival of rhizobia in surface soils at that site and there may be rhizobia at depth which nodulate that species, or the soils may lack the specific rhizobia. Generally the bait plant species that did not nodulate with the original collection site soil only nodulated with a restricted range of strains from other soils, suggesting that the original soils may have failed to form nodules because they lacked the specific rhizobia required by that host.

For six species, the original soil contained no homologous rhizobia and strains were selected for testing with these recalcitrant species based on the taxonomic affinities of the hosts. Trials were conducted in sand culture in a glasshouse growing the plants for 2–4 months depending on the species. This worked well. For example, the strain PMA 440 selected for *Acacia gonoclada* was originally isolated from nodules of *A. cowleana*, a closely related species; similarly for *A. thomsonii* (PMA 435 ex *A. neurocarpa*) and *A. melleodora* (PMA 496 ex *A. dictyophleba*). For *A. adsurgens*, *A. tumida* and *A. difficilis*, PMA 502 originally isolated from *A. difficilis* was not effective. Effective strains for *A. victoriae* and *A. acradenia* were derived from soil baiting with a broad-based mixture of soils. *Bradyrhizobium* strains from *A. holosericea* were highly effective on *A. melleodora*, *A. adsurgens*, *A. gonoclada*, *A. thomsonii* and *A. difficilis*. We are yet to find an effective strain for *A. anaticeps*.

When different strains were tested on different *Acacia* hosts, nodulation within a botanical group was generally effective. We wish to explore whether this has taxonomic significance. This knowledge should facilitate selection of strains for new *Acacia* species from the existing collection. We now have inoculant strains for 25 ASAL *Acacia* spp. (Tables 1 and 2). Earlier research had selected inoculant strain PMA 311 for *A. mangium*, *A. auriculiformis*, *A. aulacocarpa* and *A. crassicarpa*, species adapted for planting in humid environments (Dart et al.1991).

Table 1. *Rhizobium* inoculant strains and their original hosts.

PMA Strain	Hosts
482	*A. acradenia*
251	*A. ampliceps*
459	*A. ancistrocarpa*
430	*A. colei, A. neurocarpa, A. thomsonii, A. gonoclada*
478	*A. coriacea*
440	*A. cowleana, A. gonoclada*
479	*A. cuthbertsonii*
494	*A. dictyophleba*
455	*A. eriopoda*
500	*A. hemsleyi*
428	*A. holosericea*
471	*A. lysyphloia*
435	*A. neurocarpa*
311	*A. mangium*
312	*A. melleodora*
451	*A. salicina*
467	*A. stipuligera*
502	*A. tenuissima, A. adsurgens, A. tumida, A. difficilis*
442	*A. torulosa*
489	*A. victoriae*
494	*A. dictyophleba*
496	*A. melleodora*
482	*A. acradenia*

Table 2. Recommended *Rhizobium* strains for dryland *Acacia* species.

Species	PMA strain numbers
A. ampliceps	251
A. ancistrocarpa	459, 457, 462
A. adsurgens	502, 428
A. acradenia	482, 485
A. colei	429, 430
A. coriacea	478, 474, 476
A. cowleana	440
A. cuthbertsonii	479, 474, 311
A. dictyophleba	494
A. difficilis[1]	502, 430
A. eriopoda	455, 456
A. gonoclada	440, 430
A. hemsleyi	500, 501, 311
A. holosericea	431, 428
A. lysiphloia	471, 469
A. melleodora	496, 428
A. neurocarpa	435, 430
A. salicina	451
A. stipuligera	467, 466
A. tenuissima	502
A. tumida	502, 444
A. thomsonii	435, 430
A. torulosa	442, 443
A. victoriae	489, 488

[1]Strains 502 and 430 for *A. difficilis* are fast-growing *Rhizobium* strains. The rest are slower growing *Bradyrhizobium* strains.

The original strain PMA 21/1 selected as an inoculant for *A. holosericea*, *A. neurocarpa* and *A. colei* had not been evaluated for survival over a long period at room temperature in the peat carrier, when it was first used as an inoculant. Tests of rhizobia populations in the carrier in Zimbabwe by Mrs. Mary Rider at the Marondera Research Station, Zimbabwe and Dr. David Odee, Kenya Forestry Research Institute (KEFRI), Muguga, Kenya on material shipped to them from UQ, showed that the original populations of PMA 21/1 in the inoculant had decreased below the level of 10^6 cells g^{-1} carrier, our benchmark for useful inoculant. We prefer to use 10^7 g^{-1} as a cut off point for good quality inoculants. Most of our inoculants leave the UQ laboratory at $>10^9$ cells g^{-1} peat. Subsequent tests at UQ confirmed that strain PMA 21/1 was a poor survivor in carrier at room temperature, and new strains were selected which were more effective in N-fixation than PMA 21/1 and which survived very well at room temperature. Populations of $>10^9$ g^{-1} were measured in peat inoculants of these strains sent to Zimbabwe and returned, so that we appear to have solved the storage and transport problem with inoculants for *A. neurocarpa* (PMA 430), *A. holosericea* (PMA 428), *A. colei* (PMA 429) and *A. tumida* (PMA 445). We plan to conduct further nursery and field experiments to assess whether we can select one strain which is equally effective on *A. neurocarpa*, *A. colei* and *A. holosericea* or use a multi-strain inoculant mixture containing all three strains, thus reducing the number of inoculant packages required (and hence avoiding confusion in the nursery)

An ACIAR/ATSC trial in West Timor with *A. neurocarpa*, *A. colei* and *A. holosericea*, with and without inoculation in the nursery, demonstrated a large response to inoculation in the field (Table 3). Observations in the nursery where inoculants are not used have also indicated large responses to inoculation. Nursery experiments at KEFRI indicate the Australian acacias nodulate poorly without inoculation.

Table 3. Response to inoculation of *Acacia* spp. at Oetium, West Timor 22 months after outplanting.

	Height (m)		Diameter at ground level (cm)		Survival (%)	
	+R	–R	+R	–R	+R	–R
A. colei	3.1	2.2	2.0	1.5	99	76
A. holosericea	4.1	2.8	2.7	1.9	94	6
A. neurocarpa	3.4	2.0	2.3	1.4	91	59
SEM	0.4		0.26		6	

(Data from Harisetijono, Maralop Sinaga, F.H. McKinnell, C.E. Harwood and P.J. Dart, Growth of Australian *Acacia* species and their response to *Rhizobium* inoculation in field trials on two contrasting soil types in Nusa Tenggara Timur, Indonesia. Manuscript in press).

In nursery trials at QFRI, Gympie in 1994 and 1995, inoculation produced excellent nodulation on *A. holosericea*, *A. colei* and *A. neurocarpa* and there was no apparent effect of conditioning by reducing watering frequency, on nodule integrity, or number or weight per plant. We recommend that *Rhizobium* inoculants be applied in the nursery as a routine practice as they are very simple to use.

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Reference

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

Vegetative Propagation of *Acacia* Species at the Forest Tree Seed Enterprise in Nghia Binh, Vietnam

Tran Van Dinh[1]

The Forest Tree Seed Centre of Nghia Binh is a member branch of a forest tree seed company in middle Vietnam, with headquarters located in Quy Nhon town, Binh Dinh province. The elevation of its territory ranges from 0 to 50 m above sea level. Climatic data are listed in Table 1.

The main tasks of the enterprise are: establishing seed orchards and seed stands of forest tree species; and supplying seed and planting material to afforestation programs in the region. The Centre has established a network of seed orchards and seed stands for forest tree species such as *Eucalyptus*, *Casuarina*, *Acacia* and species indigenous to the region such as *Pterocarpus macrocarpus* and *Afzelia macrocarpa*.

In 1995 the Forest Tree Seed Enterprise of Nghia Binh received funding from the Ministry of Forestry to build a centre for vegetative propagation of forest tree species, with a capacity for 120 000 seedlings. Propagation experiments have since been undertaken on species such as *Eucalyptus*, *Casuarina* and *Acacia*.

Results from Experiments on Vegetative Propagation of Acacias

Constraints

Climatic conditions are difficult for nursery work generally and cutting work specifically. Procedures need modifying to suit conditions. Trials have shown that temperature and humidity can be controlled in the mist spray bed by increasing the spraying intensity. Strong winds and high temperatures interfere with the system of steel frames and nylon covers in the propagation beds.

Inexperience in the production of rooted cuttings of forest tree species has made operations more difficult than otherwise.

Results

In the first trials the cutting material was derived from young seedlings of *A. auriculiformis* and older seedlings of *A. crassicarpa*. Trials involved dipping cuttings in indolebutyric acid (IBA) powder at different concentrations, inserting them into river sand. High levels of rooting were achieved with *A. auriculiformis* and moderate levels with *A. crassicarpa* (see Table 2).

Propagation of seedlings in this way was highly successful. The lower rate of rooting in *A. crassicarpa* may be due to use of older material for cuttings.

Cuttings of hybrid acacias (*A. mangium* × *A. auriculiformis*) taken from material obtained from the Research Centre of Forest Tree Improvement (Forest Science Institute of Vietnam) were treated with 500 ppm IBA powder and placed in pots with a mixture of 50% coconut husk and 50% sandy soil. They were kept moist with a 15–20 second spray every 2 minutes during the day and every 15 minutes at night. Rooting percentage was calculated after 1 month. Table 3 shows some differences in rooting percentages between different clones.

Other activities at the Centre include a cooperation program with a forest plantation company. It involves collection of best clones for future propagation, selecting superior trees of hybrid acacias and producing seedlings from cuttings, establishing a 2-ha clone bank for hybrid acacias and establishing a network of clonal trials to determine the best ones for industrial plantations.

Discussion

Producing rooted cuttings can be influenced by numerous factors. The following need to be considered:

Cutting material The best rooting percentages were obtained from juvenile material—80% of cuttings from seedlings under the age of 60 days took root.

[1] Forest Tree Seed Centre of Nghia Binh, Vietnam

Rooting medium Two kinds of rooting medium were used—river sand, and sandy soil/coconut husk mixture—both chosen for the high drainage necessary for cuttings exposed to maximum mist spraying intensity. River sand has the advantage of being suitable for high-density planting of cuttings, thus increasing the capacity of the nursery. It was found that the best time to plant cuttings into pots was when callus tissue appeared just before root formation.

Planting out It may be feasible to transport cuttings in river sand from the propagation house for transfer into pots at a temporary nursery close to the forest planting site. This cost-efficient method needs further research and trial however.

Hormones The preferred hormone is powdered indole butyric acid. There has been no relationship established between hormone concentration and rooting percentage or speed of rooting.

Watering regime In the mid-region of Vietnam, conditions are hot and dry and the winds are strong in the time set aside for propagation of cuttings. In these conditions the only way to control temperature and humidity in cutting beds is to increase the spraying intensity.

Future Activities

The following activities are planned:

- Improve techniques to increase rooting percentages and shorten time to rooting
- Find solutions for transporting the rooted cuttings for long distances
- Undertake research to find how to increase numbers of rooted cuttings without enlarging the existing propagation house.

Conclusions and Suggestions

At the Forest Tree Seed Enterprise of Nghia Binh the existing facilities have enabled the first steps towards acacia improvement but results are still poor. More effort is needed to meet the demand for forest planting in the region. It is hoped the centre will achieve this with the cooperation and support of others in future activities.

Table 1. Mean values of temperature and rainfall in Binh Dinh Province.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual average
Temp. (°C)	23.3	23.8	25.2	27.2	28.7	29.6	29.6	29.7	28.2	26.6	25.2	23.7	26.7
Rainfall (mm)	50	20	10	45	45	55	45	215	440	330	140	1415	234

Table 2. Rooting percentages for *A. auriculiformis* and *A. crassicarpa*.

Date	Species	Age of seedling (days)	No. of cuttings	IBA concentration (ppm)	No. rooted	Percentage rooted
August 14	*A. auriculiformis*	80	210	500	280	99
			105	100	105	100
			85	0	85	100
August 23	*A. crassicarpa*	140	89	500	64	72

Table 3. Rooting percentage of different clones of hybrid acacia.

Date	Clone no.	No. of cuttings	No. rooted	Percentage
August 6	23	202	149	73.3
August 7	33	203	164	80.7
August 8	32	260	209	80.3
August 9	16	155	136	87.7
August 10	27	18	14	77.7
August 13	5	144	76	52.7
August 14	10	229	121	52.8

Preliminary Evaluation of the Suitability of *Acacia auriculiformis* and *A. mangium* in the North of Central Vietnam

Ngo Dinh Que[1]

In Vietnam about 10 million hectares of land have been cleared of forest, and the country is now undertaking the urgent task of establishing 1–2 million hectares of industrial forest plantation by the year 2000. Acacias have been planted in many instances and the species *A. auriculiformis* and *A. mangium* feature in 30–40% of the plantation areas.

Much of the area planted experiences good growth conditions but in some instances the forest grows poorly. Scientists in the north of central Vietnam, one of the eight economic forest regions in the country, have undertaken trials of these two *Acacia* species in order to match their growth requirements to the land available.

Scope of Study

Acacia auriculiformis and *A. mangium* have been introduced into Vietnam over the past 10 years. The Northern Central Region, between 16 and 23°N and 103 to 108°E (approx. 5 million ha), represents 16% of the total land area and encompasses the provinces of Thanh Hoa, Nghe An, Ha Tinh, Quang Binh, Quang Tri and Thua Thien Hue. Forest covers about 30% of the region, and another 30% is bare land and denuded hills.

Climate Mean temperature, 22–24°C, rainfall of 600–2000 mm distributed unevenly throughout the year in the upstream catchment of the Ca River.

Topography Over 45% of the land is steeply sloping (Class 3, 25–35°)

Soils Soil layers are thin (500–1000 mm thickness in 56% of the area and under 500 mm in 30% of the area). Soils are mainly loam and clay with average humus content.

Method of Evaluation

The method used was according to the work devised by Prof. Do Dinh Sam in the State research 'Evaluation of forest land potentiality (1991–1995)'. It is based on comparison of climatic and soil characteristics with requirements of planted species:

S1 most suitable
S2 suitable
S3 rather suitable
N not suitable, or limited for planting trees

Climatic factors assessed were: mean annual temperature; highest average temperature of the hottest month; lowest average temperature of the coldest month; annual rainfall. Other factors were: soil type; soil layer thickness; land slope; altitude. Suitability thresholds were derived from ecological characteristics of tree species in reference documents and results of practical forest planting over many years. Criteria are listed in Tables 1 and 2, suitability of locations is listed in Tables 3 and 4.

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Table 1. Criteria for establishing suitability levels for planting *A. auriculiformis*.

Suitability levels	S1	S2	S3	N
Mean annual temp (°C)	>25	24	21.5	<20
Av. temp. of hottest month	>32	31	29	<28
Av. temp of coldest month	>18	16	13	<12
Av. annual rainfall (mm)	>2000	1750	1250	<1000
Soil type	A*	B	C	D
Elevation (m)	300	300–600	600–800	>800
Degrees of slope	<15	15–25	25–35	>35
Soil layer thickness (mm)	>1000	500–1000	<500	Not measured

*A: grey soil, yellowish brown old alluvium, reddish brown soil on basalt, and schist; B: Acid sulfate effect, reddish brown soil on limestone, yellowish red soil on acidic magma and sandstone, black soil; C: Sea shore sand, red sand eroded soil with exposed stone, reddish yellow humus on semi-arid mountain soil; D: Salty soil, mountain humus, marsh, peat, limestone mountain soil

Table 2. Criteria for establishing suitability levels for planting *A. mangium*.

Suitability levels	S1	S2	S3	N
Mean annual temperature (°C)	>25	24	21.5	<20
Av. temp. of hottest month	>32	31	29	<28
Av. temp. of coldest month	>18	16	13	<12
Av. annual rainfall (mm)	>2000	1750	1250	1000
Soil type or group	A*	B	C	D
Elevation (m)	300	300–600	600–800	>800
Degrees of slope	<15	15–25	25–35	>35
Soil layer thickness (mm)	>1000	500–1000	<500	Not measured

*A: Grey soil, yelowish brown on old alluvium, feralite soil, neutral/basic igneous rocks, alluvial deposit; B: Acid sulfate soil, feralite soil on sandstone, feralite soil on limestone; C: Seashore sand, semi-arid brown soil, eroded soil with exposed stone; D: Salty soil, black soil, humus on mountain reddish yellow humus

Table 3. Suitability of locations for planting of *A. auriculiformis*.

Suitability levels	S1		S2		S3		N	
	Ha	%	Ha	%	Ha	%	Ha	%
Thanh Hoa	—	—	42 000	14	119 000	66	62 000	20
Nghe An	—	—	8 000	2	127 000	32	262 000	66
Ha Tinh	—	—	—		40 000	59	28 000	41
Quang Binh	—	—	—		83 000	62	50 000	38
Quang Tri	—	—	—		20 000	12	155 000	88
Thua Thien–Hue	—	—	—		26 000	21	97 000	79
Whole region	—	—	50 000	4	415 000	41	656 000	55

Table 4. Suitability of locations for planting of *A. mangium*.

Suitability levels	S1		S2		S3		N	
	Ha	%	Ha	%	Ha	%	Ha	%
Thanh Hoa	—	—	113 000	37	127 000	42	64 000	21
Nghe An	—	—	38 000	10	95 000	24	265 000	67
Ha Tinh	—	—	8 000	12	26 000	38	34 000	50
Quang Binh	—	—	2 000	2	62 000	47	68 000	52
Quang Tri	—	—			20 000	12	155 000	89
Thua Thien–Hue	—	—			26 000	21	97 000	79
Whole region	—	—	161 000	13	356 000	30	683 000	57

General Remarks and Recommendations

Acacia auriculiformis is planted in areas concentrating on low hills, in plot and lot boundaries of *Pinus merkusii* plantations, in bands in inland sandy areas. This is an important species planted for revegetation and soil improvement everywhere.

Low hills: *A. auriculiformis* can grow quite well in all site conditions except on stony hills where growth is poor. When conditions are right, trees grow fast with a large thick crown and quick canopy closure. Results of growth measurements in *A. auriculiformis* plantations from Thanh Hoa to Thua Thanh–Hue show that, depending on site conditions, increments are 1.2–2 cm/year for mean diameter and 0.7–1.6 m/year for height.

Inland sandy area: *A. auriculiformis* is planted in belts on raised bunds. It develops fast in the first 3 years but slower later on. It is much more tolerant of acid sulfate conditions than *Casuarina equisetifolia* and *Eucalyptus* spp., but it has met with difficulties and failed to thrive in many areas.

Trieu Hai (Quang Tri) and Phu Loc (Thua Thien–Hue): Six years after planting in inland sandy areas with seasonal flooding the mean diameter of the trees was only 2 cm and the average height was 2.5–3.3 m. Trees had poor, stunted form and foliage was yellowed. Worse results were registered with Phu Da and Phu Vang in Thua Thien–Hue with hundreds of hectares of *A. auriculiformis*, *Casuarina equisetifolia* and *Eucalyptus* spp., where 4 years after planting trees were only 30–40 cm tall.

This is an inland sandy area of thousands of hectares with shallow ground water (40–60 cm below the surface). A black–blackish brown peat or gley layer 30–40 cm thick creates an environment unsuitable for *A. auriculiformis*.

The greatest weakness of *A. auriculiformis* is poor wind resistance. Each year storms bring down many trees and damage the foliage. The coppicing ability of these trees is poor, and thus attention must be paid to devising a suitable layout when planting trees.

Acacia mangium, like *A. auriculiformis*, can grow on many different soil types. Over the past 4–5 years it has been planted on a small scale in parts of the region. Trees showed fast growth in the first 2 years, bearing large phyllodes and producing a large crown. The species has been planted for protection and soil improvement, as well as for fuel and green manure supply. *A. mangium*, however, has a higher requirement in depth of soil and soil moisture.

When planted under favourable conditions the growth increments of *A. mangium* are higher than *A. auriculiformis*. In Huong Tra (Thua Thien–Hue) on sandstone soil with added fertiliser, 2-year-old trees attained 5 m in height and 7 cm diameter, while in Phu Loc 18-month-old trees have a mean diameter of 4.4 cm.

This is a species with great promise for future plantings. However, until more is known about uses for the timber it will be only planted on a limited scale. More research and more extended trials are needed.

Name Changes Impending for CSIRO Seedlots of *Acacia aulacocarpa*

M.W. McDonald[1,3] and B.R. Maslin[2]

This preliminary summary of our taxonomic revision of *Acacia aulacocarpa* Cunn. ex Benth. and its relatives (McDonald and Maslin, in prep.) is to make users of CSIRO seedlots aware of our impending new nomenclature for the group. Our revision substantially alters the present concept of *A. aulacocarpa.*

The '*Acacia aulacocarpa*' group comprises nine closely related taxa. The taxonomy of two of these—*A. crassicarpa* Cunn. ex Benth. (a common , trans-Torresian species) and *A. wetarensis* Pedley (endemic to the Indonesian island of Wetar)—remains unchanged and documented by Pedley (1975 and 1978), Thomson (1994), Maslin and McDonald (1996) and McDonald and Maslin (in prep.).

Our research has revealed that the name *A. aulacocarpa* has been widely misapplied. Typical *A. aulacocarpa* is a small tree, mostly 5–8 m tall, with a scattered but extensive distribution along the coast and adjoining tablelands of Queensland. It is conspecific with *A. aulacocarpa* var. *fruticosa* C.T. White, a variant previously thought to be restricted to the Glasshouse Mountains region of southeastern Queensland. Seed of typical *A. aulacocarpa* has not, to our knowledge, been distributed by CSIRO.

The following new taxa and a species that warrants reinstatement comprise the remainder of the '*A. aulacocarpa*' group (note: the names given below, except *A. lamprocarpa*, are provisional and will become valid only after they have been formally published in McDonald and Maslin, in prep.):

Acacia '*celsa*' Tindale ined. (subsp. C in Thomson 1994) is a rainforest tree which occurs in the wet tropics region of north Queensland and can reach 30 m in height with a straight bole up to 90 cm diameter at breast height. This species has shown excellent growth potential for reforestation in Guyana (David 1980). The area trialed in Guyana has an equatorial rainfall (mean annual rainfall 2225 mm with two months receiving less than 100 mm), remarkably constant temperatures throughout the year (mean ca 27°C) and constant high humidity. Documented as producing one of the strongest bleached kraft pulps from a range of tropical acacias tested (Clark et al. 1991) and has been used as a source of sawn timber (Boland et al. 1984).

Acacia '*disparrima*" M.W. McDonald & Maslin ined. There are two subspecies. Subsp. '*disparrima*' (subsp. E in Thomson 1994) has a coastal and subcoastal distribution in southeastern Queensland and northern New South Wales. It grows to a tree up to 12 m tall. This species may have potential for reforestation use primarily on seasonally dry subtropical sites which receive 700–1200 mm mean annual rainfall. Subsp. '*calidestris*' M.W. McDonald & Maslin ined. (subsp. D in Thomson 1994) occurs in north Queensland primarily in the Einasleigh Uplands region. It usually grows as a small tree less than 8 m tall. This taxon may warrant trial as a source of fuelwood or as an amenity species in the seasonally dry tropics, primarily on sites which receive 800–900 mm mean annual rainfall with a 7–8 month dry season.

Acacia lamprocarpa O. Schwarz. (subsp. A in Thomson 1994). This species was originally described in 1927 and it will be reinstated. It extends from the Kimberley region in Western Australia east to the Gulf of Carpentaria in Queensland. *Acacia lamprocarpa* is a fire tolerant, slow-growing tree usually less than 10 m tall. Because of its slow growth rate and relatively small stature it is likely to have limited potential for wood production but has been used for mine site rehabilitation in tropical Northern Territory, Australia (Langkamp 1987).

Acacia '*midgleyi*' M.W. McDonald & Maslin ined. is restricted to Cape York Peninsula in north Queensland where it occurs along rivers and in rainforests. On rainforest sites it occurs as a straight-boled tree 25–30 m tall with a diameter at breast height of up to 90 cm. This species has considerable potential for plantation wood production in the seasonally dry tropics on sites that receive 1100–2000 mm mean

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annual rainfall with a 6–7 month dry season. The specific epithet commemorates our colleague Mr Stephen J. Midgley for his contributions to the exploration of the genetic resources of Australian acacias.

Acacia 'peregrina' M.W. McDonald & Maslin ined. (subsp. B in Thomson 1994) is endemic to the southern lowlands of New Guinea. This species can attain a height in excess of 40 m (making it the tallest known species of *Acacia*), with a straight bole up to 100 cm in diameter at breast height. Luangviriyasaeng et al. (these Proceedings) have shown *A. 'peregrina'* to have excellent potential as a plantation species in the seasonally dry tropics on sites that receive a mean annual rainfall of 1300 mm with a 6–8 month dry season. Many other favourable trial results are summarised by Thomson (1994).

Our research shows that three new species in the group have excellent potential for wood production in tropical plantation forestry and warrant further research: *A. 'peregrina'* (in the past trialed as Papua New Guinea *A. aulacocarpa*), *A. 'midgleyi'* (rarely trialed to date) and *A. 'celsa'*.

Depleted and extant ATSC seedlots reassigned to their new provisional names are listed in Table 1. Readers interested in obtaining seedlots for further research should contact: CSIRO Forestry and Forest Products, Australian Tree Seed Centre, PO Box E4008, Kingston, ACT, 2604, AUSTRALIA; e-mail: atsc@ffp.csiro.au; fax: (Aus 02) (Internat +612) 62818266; or use our web site: http://www.ffp.csiro.au/tigr/atscmain/index.htm

Table 1: Depleted and extant ATSC seedlots formerly distributed as *Acacia aulacocarpa* reassigned to their new provisional manuscript names.

Seedlot	Species	Provenance	Origin	Lat. (° 'S)	Long. (° 'E)	Alt.
12048	*A. 'celsa'*	Kennedy	Qld	18 00	146 00	10
13380	*A. 'celsa'*	Atherton	Qld	17 18	145 30	750
13865	*A. 'celsa'*	Buckley LA	Qld	17 09	145 37	720
13877	*A. 'celsa'*	Julatten	Qld	16 35	145 25	410
13959	*A. 'celsa'*	Yungaburra	Qld	17 16	145 35	750
18285	*A. 'celsa'*	Kuranda	Qld	16 40	145 31	460
13866	*A. 'disparrima'* ssp. *'calidestris'*	Garioch	Qld	16 40	145 18	400
14969	*A. 'disparrima'* ssp. *'calidestris'*	Cooktown	Qld	15 41	145 12	125
17905	*A. 'disparrima'* ssp. *'calidestris'*	Mt Molloy	Qld	16 40	145 15	420
18082	*A. 'disparrima'* ssp. *'calidestris'*	Mt Molloy	Qld	16 40	145 17	420
14591	*A. 'disparrima'* ssp. *'disparrima'*	Yeppoon	Qld	23 06	150 45	6
16667	*A. 'disparrima'* ssp. *'disparrima'*	Mt Morgan	Qld	23 50	150 15	480
16919	*A. 'disparrima'* ssp. *'disparrima'*	Biloela	Qld	24 00	150 00	200
17151	*A. 'disparrima'* ssp. *'disparrima'*	Noosa	Qld	26 16	152 48	200
17154	*A. 'disparrima'* ssp. *'disparrima'*	18 Mile Creek	Qld	25 33	152 28	50
17739	*A. 'disparrima'* ssp. *'disparrima'*	Mt Larcom	Qld	23 50	151 00	70
17891	*A. 'disparrima'* ssp. *'disparrima'*	Samford	Qld	27 17	152 51	50
18983	*A. 'disparrima'* ssp. *'disparrima'*	Mylestom	NSW	30 28	153 02	0
18984	*A. 'disparrima'* ssp. *'disparrima'*	Maclean	NSW	29 27	153 13	0
11869	*A. lamprocarpa*	Melville Island	NT	11 40	131 00	140
15715	*A. lamprocarpa*	Borroloola	NT	15 38	136 25	3
16168	*A. lamprocarpa*	Gove Airport	NT	12 19	136 49	60
16180	*A. lamprocarpa*	Maningrida	NT	12 11	134 18	40
18227	*A. lamprocarpa*	West Salt Creek	NT	15 01	133 11	100
18228	*A. lamprocarpa*	Kununurra	WA	15 38	128 40	37
18576	*A. lamprocarpa*	Blackmore River	NT	12 41	130 56	40
18834	*A. lamprocarpa*	Arthur Creek	WA	16 02	128 20	0
18877	*A. lamprocarpa*	Doongan	WA	15 23	126 17	200
16136	*A. 'midgleyi'*	Piccaninny Creek	Qld	13 09	142 48	40
18001	*A. 'midgleyi'*	McIlwraith Range	Qld	13 44	143 20	500
18358	*A. 'midgleyi'*	Old Lockhart	Qld	12 50	143 18	15
13687	*A. 'peregrina'*	Iokwa	PNG	08 41	141 29	35
13688	*A. 'peregrina'*	Keru	PNG	08 32	141 45	40
13689	*A. 'peregrina'*	Oriomo River	PNG	08 48	143 09	20
15649	*A. 'peregrina'*	Keru	PNG	08 33	141 45	30
15650	*A. 'peregrina'*	Bensbach	PNG	08 51	141 15	20
15651	*A. 'peregrina'*	Oriomo	PNG	08 50	143 08	15
16112	*A. 'peregrina'*	Morehead	PNG	08 42	141 34	30
16113	*A. 'peregrina'*	Keru to Mata	PNG	08 35	141 45	30

Table 1. (continued)

Seedlot	Species	Provenance	Origin	Lat. (° 'S)	Long. (° 'E)	Alt.
16612	*A. 'peregrina'*	Mai Kussa River	PNG	09 29	142 25	15
16946	*A. 'peregrina'*	Balimo	PNG	08 05	142 58	12
16947	*A. 'peregrina'*	Makapa	PNG	07 56	142 35	15
16948	*A. 'peregrina'*	Isago Arimia River	PNG	08 01	142 41	10
16949	*A. 'peregrina'*	Duaba	PNG	08 13	142 58	25
16950	*A. 'peregrina'*	Wasua Pedeya	PNG	08 17	142 52	10
16976	*A. 'peregrina'*	Wipim	PNG	08 47	142 52	45
16979	*A. 'peregrina'*	Wipim	PNG	08 40	142 43	40
16981	*A. 'peregrina'*	Kapal	PNG	08 37	142 47	40
16982	*A. 'peregrina'*	Kuru	PNG	08 52	143 05	30
16985	*A. 'peregrina'*	West Oriomo DPI	PNG	08 52	143 08	20
16988	*A. 'peregrina'*	Pongaki	PNG	08 40	141 51	30
16989	*A. 'peregrina'*	Derideri	PNG	08 40	141 50	30
16995	*A. 'peregrina'*	Arufi	PNG	08 43	141 55	25
16996	*A. 'peregrina'*	Bimadebun	PNG	08 38	142 03	40
16998	*A. 'peregrina'*	Oriomo	PNG	08 49	143 06	10
17549	*A. 'peregrina'*	Old Zim Oriomo	PNG	08 48	143 06	20
17551	*A. 'peregrina'*	Bensbach-Balamuk	PNG	08 53	141 17	25
17560	*A. 'peregrina'*	Dimisisi	PNG	0831	142 13	50
17585	*A. 'peregrina'*	Wemenevre	PNG	08 42	141 27	20
17600	*A. 'peregrina'*	Tokwa	PNG	08 42	141 32	30
17601	*A. 'peregrina'*	Serki	PNG	08 25	141 49	60
17602	*A. 'peregrina'*	Gubam	PNG	08 37	141 54	25
17627	*A. 'peregrina'*	Morehead	PNG	08 40	141 30	20
17628	*A. 'peregrina'*	Keru	PNG	08 33	141 45	30
17629	*A. 'peregrina'*	Gamaeve	PNG	08 58	142 53	20
17850	*A. 'peregrina'*	Erambu-Bupul	Ind	08 02	141 00	40
17867	*A. 'peregrina'*	Lake Murray	PNG	06 51	141 29	55
17873	*A. 'peregrina'*	Wipim-Oriomo	PNG	08 49	142 54	45
19149	*A. 'peregrina'*	Balimo	PNG	08 03	142 38	15
19270	*A. 'peregrina'*	Balimo	PNG	08 03	142 38	15
19272	*A. 'peregrina'*	Kapal	PNG	08 45	14 35	10
19301	*A. 'peregrina'*	SSO Fiji PNG	Fiji	18 00	178 00	0
19687	*A. 'peregrina'*	SSO Thailand PNG	Tha	14 13 N	101 55 E	420
19746	*A. 'peregrina'*	Upper Aramia	PNG	07 56	142 35	15
19747	*A. 'peregrina'*	Balimo	PNG	07 57	142 52	15
19758	*A. 'peregrina'*	SSO Kuranda PNG	Qld	16 49	145 38	0
19785	*A. 'peregrina'*	SSO Kuranda PNG	Qld	16 49	145 38	0

References

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. Nelson-CSIRO: Melbourne.

David, C.A. 1980. *Albizia* and *Acacia* species trials on white sands: three years after planting. Unpublished report. Guyana Forestry Commission, Georgetown, Guyana.

Clark, N.B., Balodis, V., Guigan, F. and Jingxia, W. 1991. Pulping properties of tropical acacias. In: Turnbull, J.W., ed., Advances in Tropical Acacia Research. ACIAR Proceedings No. 35. Australian Centre for International Agricultural Research, Canberra, 138–44.

Langkamp, P.J. 1987. Germination of Australian Native Plant Seed. Inkata Press: Melbourne.

Maslin, B.R. and McDonald, M.W. 1996. A Key to Useful Australian Acacias for the Seasonally Dry Tropics. CSIRO: Melbourne.

McDonald, M.W. and Maslin, B.R. (in prep.). A Revision of the Salwoods: *Acacia aulacocarpa* Cunn. ex Benth. and its Relatives (Leguminosae: Mimosoideae: Section Juliflorae). To be submitted to Australian Systematic Botany.

Pedley, L. 1975. A revision of the extra-Australian species of *Acacia* subgenus *heterophyllum*. Contributions from the Queensland Herbarium, No. 18.

Pedley, L. 1978. A revision of *Acacia* Mill. in Queensland. Austrobaileya, 1, 75–234.

Thomson, L.A.J. 1994. *Acacia aulacocarpa*, *A. cincinnata*, *A. crassicarpa* and *A. wetarensis*: an Annotated Bibliography. CSIRO: Melbourne.

A Taxonomic Database on Acacias of South Asia

Sudershan Kumar and J.K. Maheshwari[1]

Abstract

A taxonomic database on legumes of eight South Asian countries (India, Pakistan, Nepal, Bhutan, Bangladesh, Myanmar, Sri Lanka and the Maldives) has been developed under the aegis of the International Legume Database and Information Service (ILDIS), UK. The database contains information on the following parameters:

1. accepted name and synonyms;
2. vernacular names, language, region and source reference;
3. life form details, including life span and habit, etc.;
4. conservation status;
5. geography and status (native or introduced);
6. uses;
7. pointers for description, illustrations and distribution map;
8. detailed taxonomic information; and
9. bibliography and source of reference for each dataset.

In South Asia, *Acacia* is the third largest legume with 113 species, numbers one and two being *Astragalus* (179) and *Crotalaria* (131) species. The maximum number of taxa (native and introduced) occur in India (109) followed by Pakistan (26), Sri Lanka (20), Myanmar (15), Nepal (13), Bangladesh (11), Bhutan (6), and Maldives (1). The state and district-wise distribution of these taxa has also been analysed for the Indian region. The detailed analysis shows following state-wise occurrence of the taxa: Tamilnadu (53), Karnataka (38), West Bengal (25), Maharashtra (20), Madhya Pradesh (19), Uttar Pradesh (19), and Rajasthan (18), etc. The district-wise analysis shows the occurrence of *Acacia pennata* in as many as 82 districts, followed by *A. leucophloea* (81), *A. catechu* (80) and *A. tortilis* (71).

The database has been developed by using an international format that is globally comparable and can be utilised for developing research programs in the fields of biosystematics, biodiversity, conservation, plant genetic resources, phytochemistry and agroforestry of acacias. The Phase I database is being interlinked with Phase II modules on applied botanical data like taxonomic tool kit, uses, ecology, nodulation, phytochemistry and images, etc. A detailed analysis of acacias of South Asia, based on data gathered during the last 5 years under the ILDIS South Asia Programme, is available from the authors.

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